The potential of cineplasty in the contemporary society

Investigating a historical technique for prosthetic hand control

Nynke Heeringa

Master thesis



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Preface

Dear reader,

It is with great excitement that I present to you my graduation thesis. This document marks the end of a very special chapter: my years as an Industrial Design Engineering student in Delft, where my interest for medical design started. Throughout my studies, my fascination for the human body, biomechanics, and prosthetic design has only grown stronger. So when the opportunity arose to dedicate my graduation project to cineplasty: na historical, almost forgotten technique with surprising modern potential, it felt like the perfect fit. Working at the intersection of human-centred design, medicine and engineering, and has been incredibly inspiring, and I am grateful for every conversation, sketch, prototype, and insight that shaped this journey. Finishing this project makes me realise how much I have grown as a researcher, designer, and collaborator and marks an important step in my development as a professional within the field of multidisciplinary research and design.

I would like to express my sincere thanks to the Reinier Haga Orthopaedic Centre for welcoming me into their clinical world. Thanks to Nina Mathijssen for her advice and openness throughout the project. A special thanks Gerald Kraan for his guidance, enthusiasm, and clinical view throughout the project. I am equally grateful to my whole supervisory team: Richard Goossens, Gerald Kraan, and Gerwin Smit. Thank you for your expertise, your encouragement, and the many moments where your passion for medical innovation pushed me to think deeper and design better. I could not have wished for a more capable and supportive team.

My appreciation also goes to all the surgeons, rehabilitation physicians, prosthetists, therapists, and prosthesis users who shared their time, experiences, and honest perspectives with me. Your insights brought this project to life and grounded it in the reality of clinical practice and daily living.

Finally, to my family and friends: thank you for your endless support, your patience, and the many coffees, dinners, study breaks, and pep talks that carried me through this process. You made the challenging moments lighter and the good moments even better.

With this work, I hope to contribute a small step toward improving prosthetic care and to spark renewed curiosity for a technique that once held great promise.
Enjoy reading!

Colophon

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Summary

This graduation project investigates the potential relevance of cineplasty—a historical surgical technique for prosthetic hand control—in contemporary prosthetic care. Cineplasty, developed in the early 20th century, directly couples a muscle (typically the biceps) to a prosthetic device through a surgically created tunnel, enabling intuitive mechanical control and preserving natural proprioceptive feedback. Although cineplasty fell into obscurity after the rise of myoelectric prostheses in the 1960s, its unique sensory advantages raise the question of whether a modernised version could offer value today, especially given the increasing global need for durable, intuitive, and affordable prosthetic solutions.

The project begins by outlining the historical development of prosthetic technology, from ancient mechanical devices to modern multi-articulating hands. Despite major technological advances, **current prostheses still struggle to replicate natural proprioception**, often forcing users to rely heavily on vision. Cineplasty stands out because it maintains the body's original feedback loop through activation of muscle spindles and Golgi tendon organs. This foundational insight motivates the exploration of whether cineplasty could be re-evaluated using modern surgical techniques, materials, and design principles.

To understand the contemporary relevance of cineplasty, a scoping review was conducted. The scoping review revealed a limited and historically dated evidence base: most publications originate from 1900–1960, involve small and homogeneous populations, and provide low levels of evidence. Access to older sources was restricted, further narrowing the available knowledge. This confirms a substantial gap in modern scientific literature on cineplasty.

Interviews with prosthesis users, rehabilitation physicians, surgeons, prosthetists, and therapists provided essential insights into clinical feasibility, user priorities, and practical constraints. A rare long-term user case—an individual who has used a cineplastic prosthesis for over 60 years—demonstrated that **cineplasty can remain functional, intuitive, and low-maintenance in daily life**. However, experts emphasised that cineplasty's relevance today is highly situational. While proprioceptive feedback is consistently recognised as a unique benefit, **concerns remain regarding aesthetics, surgical invasiveness, infection risk, and the gap between functional performance and user expectations**.

The Discover phase further explored amputation types, surgical considerations, rehabilitation protocols, and the biomechanical foundations of proprioception. Upper-limb amputation significantly reduces range of motion and functional capacity, and rehabilitation is lengthy and complex. Experts

highlighted that prosthesis acceptance depends not only on function but also on comfort, cosmesis, and the prevention of compensatory movement patterns that can lead to long-term injuries.

In the Define and Develop phases, the project used a range of design methods and expert consultation to generate and refine potential improvements to cineplasty. This resulted in two improvements: **the surgery technique is changed in such a way that the cosmetic outcome is improved** accordig to experts, and **a Cover is added to as well conceal as protect the connection** between the rod and the stump. The prototype was developed iteratively and assessed by experts, who concluded that a modernised version of cineplasty could offer added value for a specific user group, particularly those prioritising intuitive control and durability over aesthetics.

Although cineplasty offers an unparalleled proprioceptive advantage by preserving the body's natural sensory loop, this benefit comes with a significant trade-off: the surgical modification of the limb inevitably affects cosmetic appearance. The presence of a visible muscle tunnel, scarring, and changes in muscle contour conflict with contemporary user expectations, where aesthetics and social acceptance play an increasingly important role in prosthesis choice. At the same time, modern alternatives such as myoelectric control, targeted muscle reinnervation (TMR), and pattern-recognition EMG systems provide intuitive control without requiring invasive surgery, making them more appealing to users who prioritise appearance, reversibility, and minimal medical risk. These non-surgical systems, while lacking the intrinsic proprioception of cineplasty, compensate through technological sophistication, improved cosmetic design, and the absence of permanent anatomical alterations. As a result, t**he decision between cineplasty and contemporary prosthetic control methods ultimately hinges on a balance between sensory performance and cosmetic acceptability**, highlighting both the unique value of cineplasty and the practical barriers that limit its widespread adoption today.

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1. Introduction

This chapter introduces the project by first outlining the historical development of prosthetic technology, providing the context in which current solutions have emerged. It then defines the assignment, clarifies the scope, and identifies the key stakeholders involved. Finally, the chapter presents the structure of the report, guiding the reader through the organisation of this Graduation Report.

1.1 The first prostheses
1.2 The assignment
1.3 Scope & stakeholders
1.4 Report structure
Conclusion

1.1 The first prostheses

Prostheses are being created as a solution for missing body parts as long as we can think of. They have undergone immense developments. Evidence of a foot prosthesis from 600 B.C. is found on an Egyption mummy (Mingren, 2026). Since then, prostheses have undergone immense developments.

One of the first prosthetic hands was made for the Roman general Marcus Sergius, who had lost a hand during the Second Punic War (218–201 BC). This iron prosthetic hand allowed him to resume combat (Zuo & Olson, 2014). Another notable prosthetic device from the medieval times (shown in Figure 1) was the iron hand of German knight Götz von Berlichingen, created after he lost his hand during the Siege of Landshut around 1505. The prosthesis featured articulated fingers and thumb that could be passively positioned, enabling him to grasp reins and wield weapons in battle (Zuo & Olson, 2014).

This first development in prosthetic control is developed further into impressive multiarticulary hands nowadays. However, the experience of **feedback** of these actions, providing precise and comfortable control, remains challenging (Diaz-Hernandez, 2025).

Around 1900, a prosthetic techique that could preserve the human feedback loop was introduced: **cineplasty**. By directly connecting the muscle to the prosthesis. More than 100 years later, this technique still shows unique properties concerning feedback compared to current alternatives (Kumar, 2025).

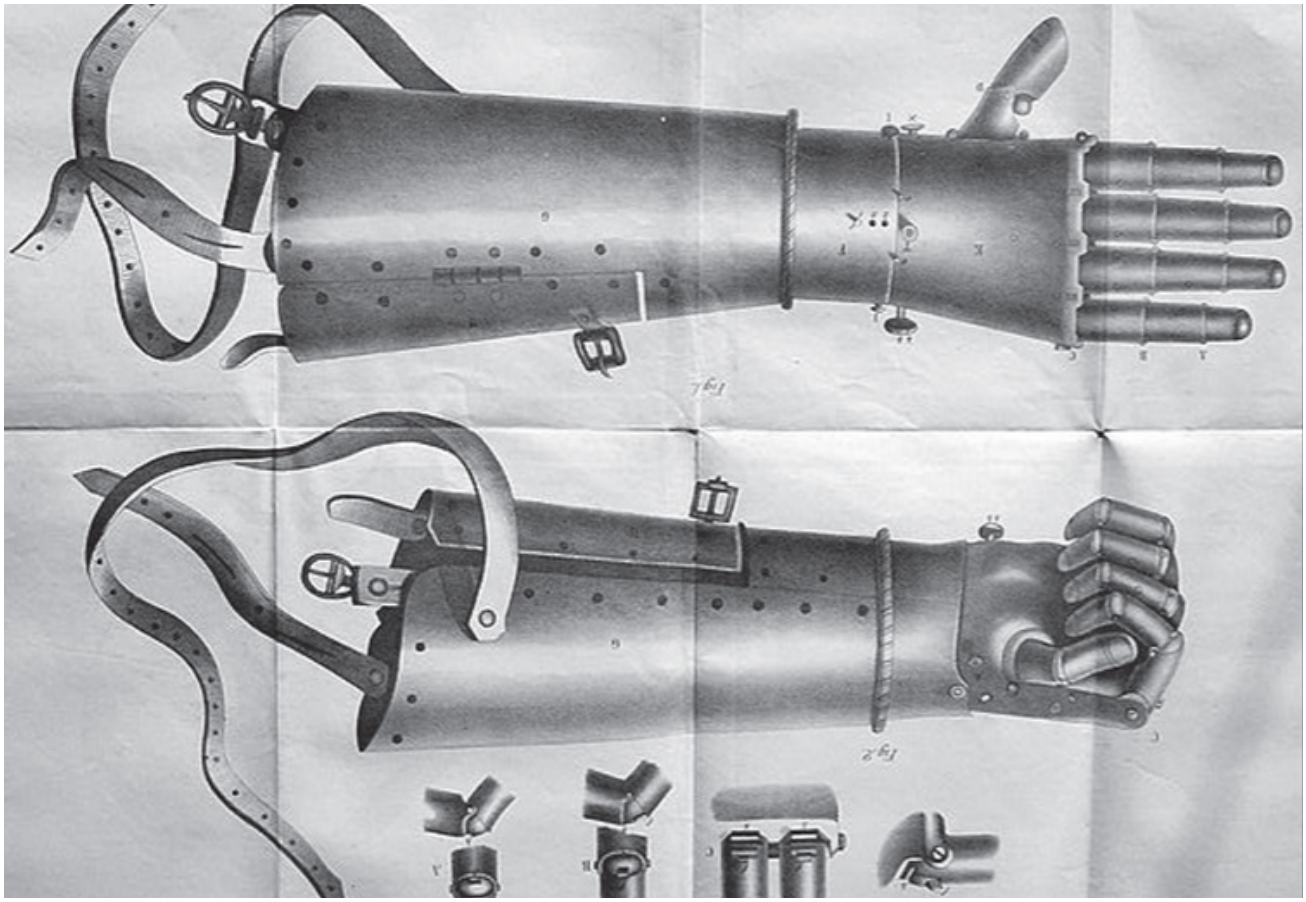


Figure 1. Drawing of the iron hand of German knight Götz von Berlichingen (1505) (Zuo & Olsen, 2014)

1.2 The assignment

Cineplasty is a technique for prosthetic control (mostly prosthetic arms) since the beginning of the 20th century (Tropea et al., 2017). By creating a **tunnel through a muscle in the arm**, most often the biceps, a prosthetic hand could be opened and closed by the contraction of the muscle. This tunnel is surgically created, by piercing the muscle and covering the inside of this tunnel with skin (see *Chapter 2.5.1* for the surgery steps). This way, the rod through the tunnel could compared with a large piercing. Besides, the biceps insertion is cut which eliminates the flexion function and increases the muscle excursion, causing optimal hand opening and closing (Brückner, 1992). However, since the '60, this technique has fallen into obscurity, most likely due to the rise of the myoelectric alternative that does not require surgery (Weir, 1995).

prosthetic hand mechanically to the muscle preserves the natural feedback, enabling **exact and intuitive control**, which is extremely unique property in current prosthesis offer. Building on this motivation, the project examines how the concept of cineplasty can be optimised for modern prosthetics. The goal of the project is to validate these optimisations with help of proposing a redesigned prototype to experts in the field of medicine, prostheses and to prosthetic users themselves. See *Appendix A.I* for the approved Project Brief.

To ensure medical quality and maintain direct access to clinical expertise, the Reinier Haga Orthopaedic Centre was involved in the project, with Nina Mathijssen serving as the primary point of contact. In addition, Prof. dr. Gerald Kraan

Design goal: *"Design a prototype based on the principle of cineplasty to investigate whether cineplasty is desireable for lower arm amputees in the contemporary society."*

This project aims to identify whether the cineplastic technique could be of **value in the current prosthetics offer**. Especially now, with the rising number of amputations due to the wars around us, it is important to research the value of this technique. For example Ukrain, where over 60.000 soldiers have lost a limb as a result of their fight for freedom (Vennink, 2025). The question for functional, durable and affordable prosthetics grows (Vennink, 2025; G. Kraan, personal communication, 20 June 2025). The scope of the project reaches **beyond the military population**; civilian users may also benefit of this technique, since connecting the

supervised both the medical and design aspects of the project. Prof. dr. ir. Richard Goossens contributed his extensive experience in medical design, while Prof. dr. ir. Gerwin Smit provided expertise on cineplasty and the underlying mechanical principles. Together, they formed a well-balanced and an exceptionally competent supervisory team.

1.3 Scope & stakeholders

The scope of a project defines the project's boundaries and specifies the objectives, deliverables, and constraints that structure the planning and execution of the work (see *Appendix A.II* for a full planning overview). At the beginning of the project, the scope was broadened in order to identify the main painpoints of the method, and thus which aspect(s) need(s) to be improved. In this analysis, the prosthesis, the surgery technique as well as the connection of prosthesis to muscle were included, see Figure 2.

The most important stakeholders in the scope of this project are:

- Prosthesis users
- Clinical experts: rehabilitation physicians, plastic and orthopaedic surgeons
- Prosthetists
- Physiotherapists and ergotherapists

Experts are closely involved in the project. See Figure 3 for the stakeholder overview.

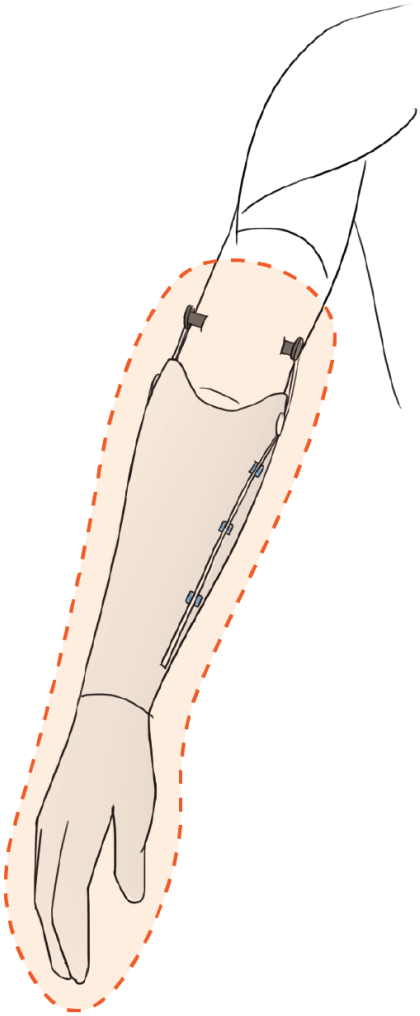


Figure 2. Scope of the project: the cineplastic prosthesis

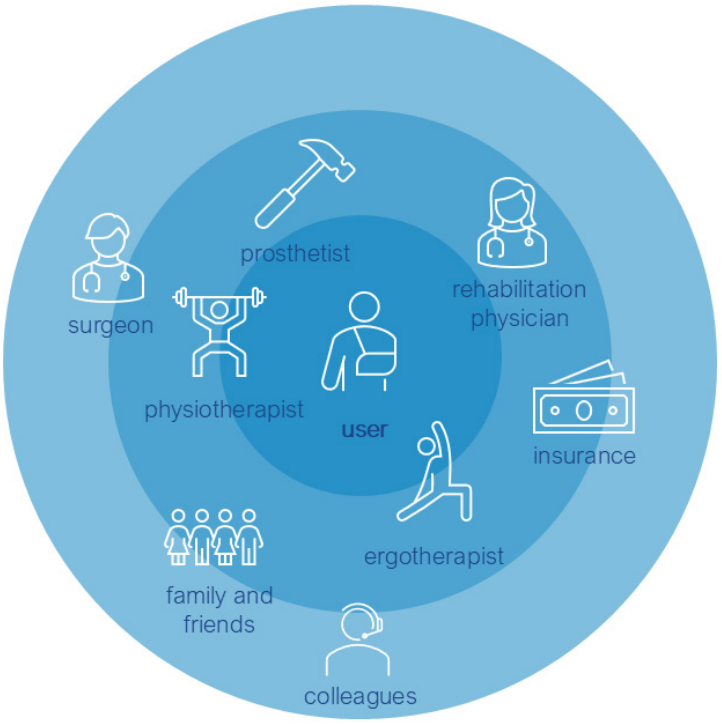


Figure 3. Stakeholder overview in the context of cineplasty

1.4 Report structure

The project follows the **Double Diamond framework**, in which each diamond comprises a phase of divergence and convergence, see Figure 4 (Design Council, 2026).

The first diamond focuses on research: **exploring the scope** of the project and defining its direction. During this phase, the historical development of cineplasty and the context of prosthetics were analysed. Based on insights gathered from literature, shadowing sessions, and interviews with experts, the key advantages and limitations of the technique were identified, the position of cineplasty relative to other prosthetic options, as well as the user group most likely to benefit from its application. This phase led to an overview of requirements and criteria for the renewed version of cineplasty.

The second diamond centres on **concept development** and prototyping. In this phase, a broad range of ideas for prosthetic solutions based on the principles of cineplasty was generated and explored. Following further expert consultation and evaluation of the design criteria, one concept was selected and developed into a functional prototype. This prototype was subsequently assessed by experts, who concluded that an improved form of cineplastic prosthesis could indeed offer added value for the intended user group. The project concludes with recommendations for future development.

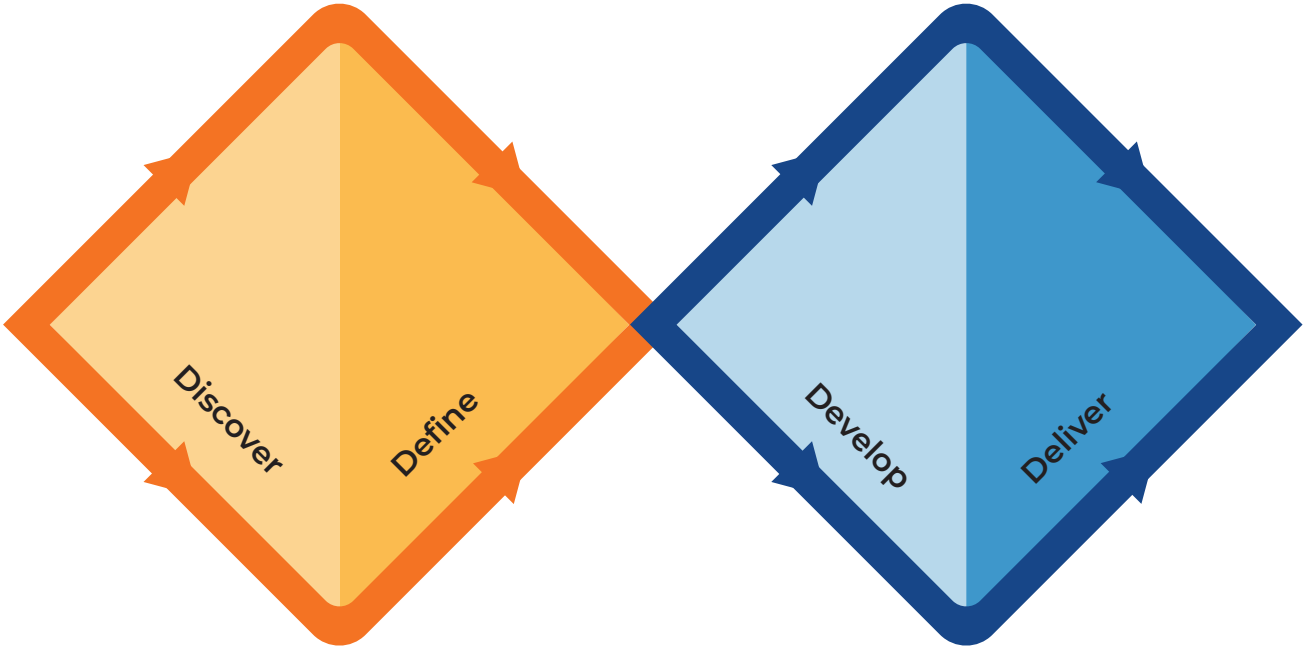


Figure 4. The report structure is based on the Double Diamond method (adapted from Design Council (2026)

Conclusion

The developments outlined in this chapter show that the current rise in amputations, driven in part by recent conflicts, has created a need for prosthetic solutions that are robust, intuitive, and accessible. When this contemporary demand is viewed through the long arc of prosthetic history, cineplasty emerges as a technique worth revisiting. Across centuries of innovation, prosthetic technology has steadily improved mechanical function and control, yet it still struggles to recreate the natural **proprioceptive feedback** that biological limbs provide. Cineplasty is exceptional in this regard: rather than simulating feedback through electronics or sensors, it preserves the body's original feedback loop by directly linking muscle contraction to prosthetic movement.

This unique property positions cineplasty as a potentially valuable alternative in today's prosthetic landscape, especially for users who prioritise reliability, durability, and intuitive control. The emergence of new technologies around 1960 and changing aesthetic expectations have probably caused its decline. With modern surgical techniques, improved materials, and a clearer understanding of user needs, the technique may be re-evaluated in a new light.

To explore this potential responsibly, the project adopts a **human-centred approach**, recognising that the value of cineplasty cannot be assessed through literature and technical analysis alone.

The perspectives of those who work with, design, prescribe, and use prostheses are essential to understanding whether cineplasty could meaningfully contribute to contemporary care. Throughout the project, **interviews and consultations** with key stakeholders—surgeons, rehabilitation physicians, prosthetists, therapists, and prosthetic users—serve as a guiding thread, providing insight into clinical feasibility, user priorities, surgical considerations, and practical constraints. By involving key stakeholders throughout the process, the project therefore sets out to **explore whether cineplasty can be modernised** to meet contemporary standards and user expectations.

The Double Diamond structure provides the framework for this investigation, guiding the transition from historical context and problem definition toward concept development, prototyping, and expert validation.

In this way, the chapter concludes not only by framing the motivation for the project, but by establishing cineplasty as a historically grounded yet forward-looking opportunity—one that may address some of the most persistent challenges in modern prosthetic design.

2. Discover

This chapter defines the project's scope using the three core pillars of industrial design: people (desirability), technology (feasibility), and business (viability) (van Boeijen et al., 2013). Desirability is explored by clarifying what cineplasty is and how it works, illustrated through a representative use case, and by outlining the effects of amputation and the rehabilitation process. The underlying principle of cineplasty is also introduced: proprioception. Viability is assessed by examining current prosthetic solutions and competing alternatives on the market. Feasibility is analysed through a comprehensive review of existing literature. Together, these perspectives allow the scope of the project to be uncovered.

2.1 What is cineplasty?
2.2 Use case
2.3 Approach on discovering the scope of cineplasty
2.4 Amputation
2.5 Proprioception
2.6 Prostheses
2.7 A Deep dive into cineplasty
Conclusion

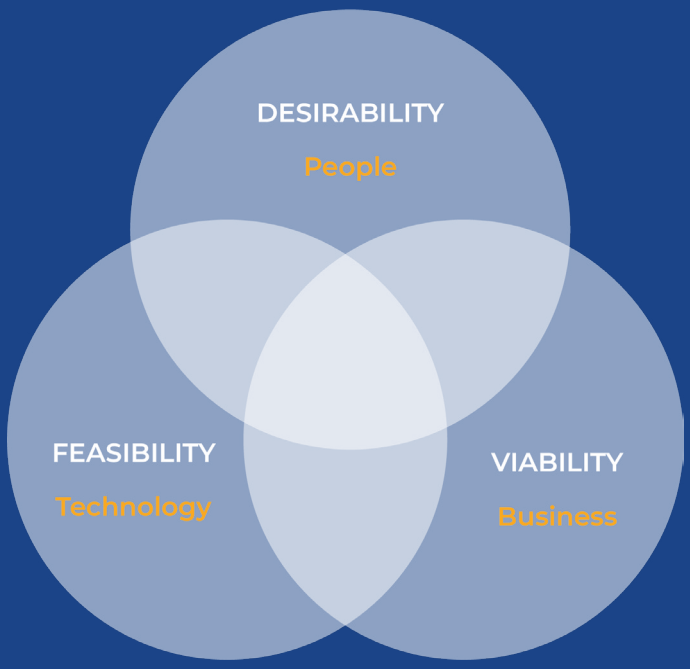


Figure 5. Three main pillars in industrial design: people, technology and business (van Boeijen et al., 2013)

People

2.1 What is cineplasty?

In this project cineplasty is referred to as the direct connection to a muscle or tendon to mechanically control a prosthesis. Contracting the muscle shortens a cable, which transfers this movement from a muscle to the terminal device as shown in Figure 6 This way the biceps control the opening and closing movement of the prosthetic hand or hook (Weir, 1995). Cineplasty is performed on several thousand patients from 1900 onward, often post war, but is fallen in obscurity around 1960 (Spittler & Woodard, 1953). This report will analyse if a return of cineplasty is desired in the current prosthesiology, and which improvements are required to make this happen.

The unique property of cineplasty is the preservation of proprioception by directly connecting the prosthetic to the human muscle and its own natural sensors. Thus, the muscle can as well create movement as 'feel' the feedback of the movement. By preserving this natural feedback loop, Golgi tendons and muscle spindles are activated and are able to provide feedback of the performed movements (Leskovar et al., 2026). This complex functioning of the human body remains challenging to imitate with the help of technology (Diaz-Hernandez, 2025). More about this topic can be found in *Chapter 2.4*.

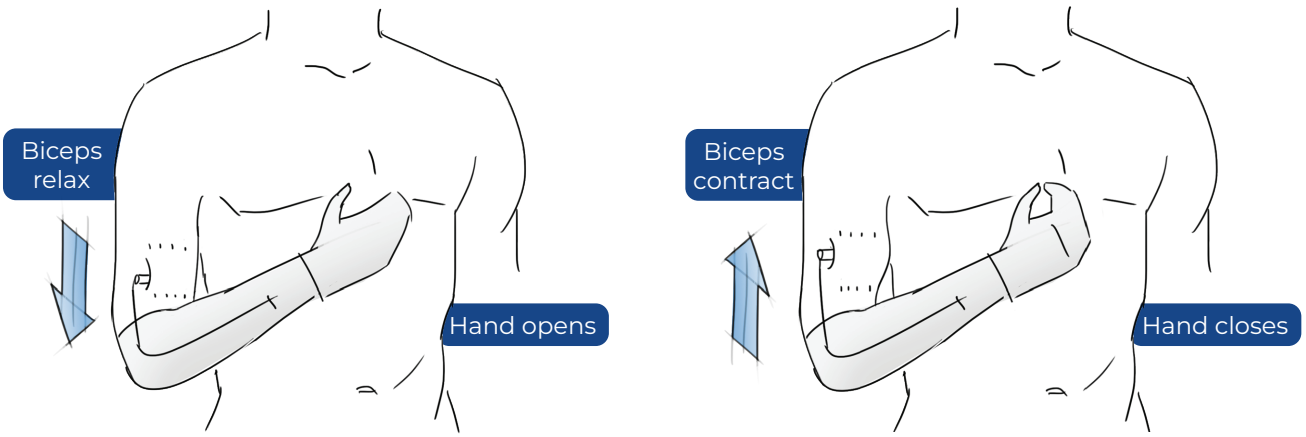


Figure 6. Workikng principle of biceps cineplasty

2.3 Use case

Since the cineplastic procedure has not been performed for a long period of time, it was challenging to find experts of experience. Via prosthetic experts, contact was established with a woman who lost her arm above the elbow at the age of 22 has been using a cineplastic prosthesis for **more than 60 years**. The results of this visit (see *Appendix B.I* for the full interview) illustrate that cineplasty can remain functional and valuable in contemporary daily life. She uses the cineplasty primarily to lock her prosthetic elbow in a chosen position, while elbow flexion is achieved through a shoulder strap. Although the system does not provide a grasping function, she reports not missing it, as she relies on her intact hand for most activities and uses the prosthetic for fixation and support.



Figure 7. Cineplastic tunnel in the biceps, after above elbow amputation. (a) and (b) with the rond inserted, (c) and (d) the tunnel without the rod is shown

She describes herself as **satisfied with the prosthesis** and has been using her current device for nearly five years. Maintenance needs have been minimal—only two cable replacements over this period. She wears the prosthesis throughout the day, removing it only for showering, sleeping, or during very warm weather when the socket becomes uncomfortable.

Despite her long-term use, she prefers not to go outside with the prosthesis visible. She emphasises that this reluctance is unrelated to the cineplastic mechanism itself or the presence of the muscle tunnel. She mentioned that no one notices the tunnel while swimming, when she does not wear her prosthesis. Her overall assessment is pragmatic: "It is functional, and I do not know any better." She acknowledges that the prosthesis is **not cosmetically appealing**, but she is satisfied with what is available to her.

Functionally, the locking mechanism does not always operate perfectly, yet she finds its control intuitive and reports that she adapted to it quickly. She experiences **no pain or discomfort** in or around the tunnel. For hygiene, she occasionally cleans the tunnel with a damp cotton swab and has never encountered issues with infection or irritation.

It should be taken into account that this success story contains only one subject. Yet, her long-term, positive experience demonstrates that cineplasty can remain a functional, intuitive, and low-maintenance control method, and that it can still offer meaningful value in modern prosthetic use.

2.2 Approach on discovering the scope of cineplasty

During the Discover phase, several resources were consulted, with **literature** and **experts** proving to be the most valuable. Interviews with prosthesis users, clinical experts and prosthetist were conducted to identify and extract important information about cineplasty, see Figure 8 for an overview of the involved experts. Find *Appendix B.II* for a more complete overview of the methods used during this project.



Figure 8. Cineplastic tunnel in the biceps, after above elbow amputation. (a) and (b) with the rond inserted, (c) and (d) the tunnel without the rod is shown

2.3 Amputation

The need for a prosthesis may arise from two primary causes: a **congenital limb deficiency** resulting in a shortened or absent limb, or the surgical removal of a limb. Sometimes it is the only option to survive when eliminating a part of the human body (Kumar et al., 2025). Specifically **upper limb amputations** have always been a relatively common consequence of accidents, wars, and illness (Tropea et al., 2017). The frequence of this procedure, however, is on average very low: the World Health Organization estimates that 0.03% of the world population has undergone an upper extremity amputation, which is 30% of all amputations (Segura et al., 2024). Unfortunately, this percentage rises in times of war. For example, the war in Ukrain has cost **over 60.000 soldiers** a limb so far (Vennink, 2025). When focusing on the upper extremity, in general, transradial (below the elbow) amputations are more common (Segura et al., 2024). In times of war however, transhumeral (amputation above the elbow) is seen more frequently because of the high tournequets placement in combat (C2, C9). See Figure 9 for the different levels of amputations.

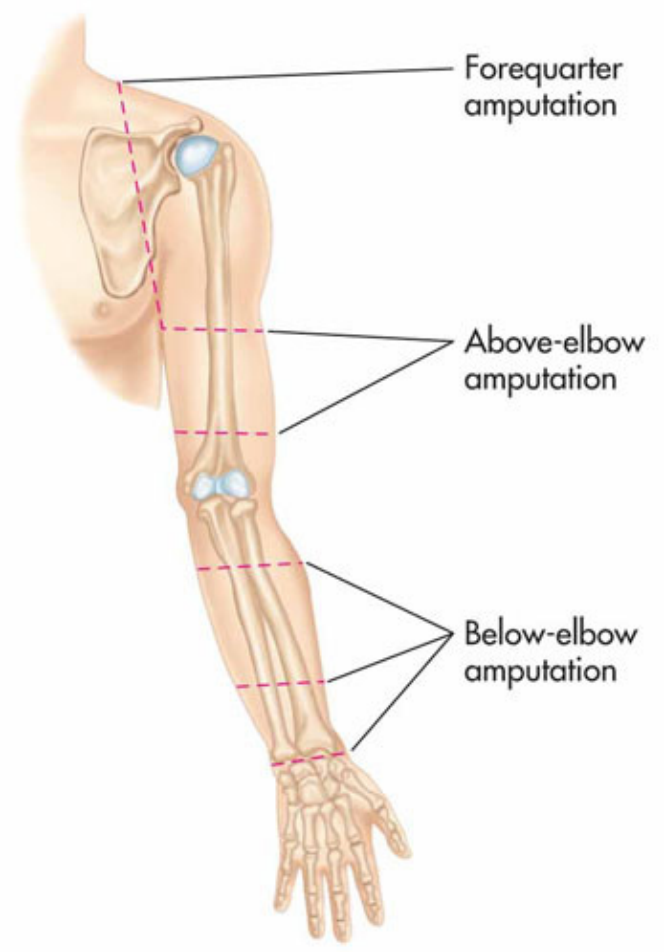


Figure 9. Different levels of amputation (*Upper limb prosthesis,* n.d.)

2.3.1 Surgery

Sometimes, the surgeon has a choice of amputation level. Most of the time, the surgeon chooses for the most conservation of the arm, keeping the elbow intact when possible. **Preservation of the elbow joint** is important for the prosthesis options after amputation, since amputation 8 to 10 cm proximal to the ulnar styloid provides the greatest variety of prosthesis options for functional restoration of the extremity, while 5 cm is also sufficient for successful prosthetic fitting (Diaz-Garcia & Cederna, 2013). The presence of the epicondyles could be used to fit the prosthesis. When amputating through the elbow this remains a possibility, but this technique has no preference since the greater length of the residual upper arm creates limb length discrepancy (Diaz-Garcia & Cederna, 2013).

The procedure steps of a lower arm amputation are shown in the drawings of Figure 10 below (Diaz-Garcia & Cederna, 2013).

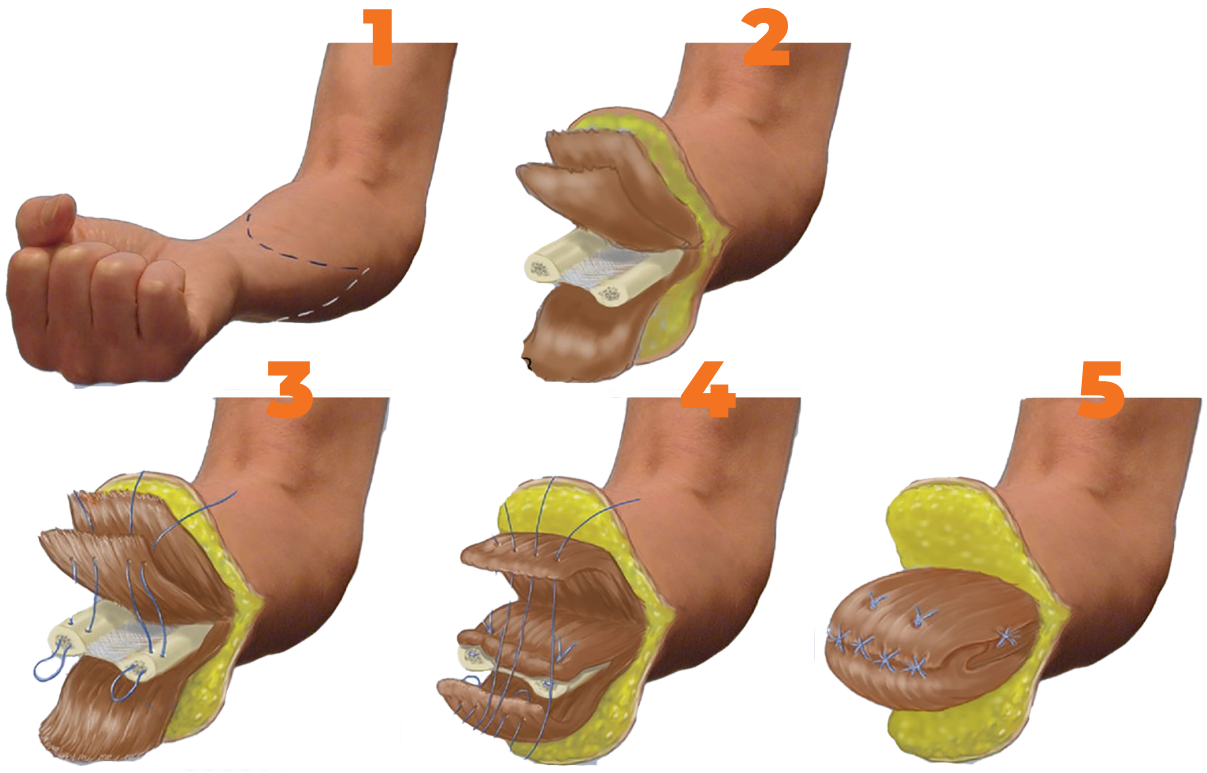


Figure 10. Surgical procedure steps of a lower arm amputation (Diaz-Garcia & Cederna, 2013)

2.3.2 Range of motion

The human hand has over 30 joints, which could all perform at least one motion, resulting in a wide range of motions (ROMs) (Standring, 2016). In the scope of this project, amputation leads to eliminating the wrist and hand, which has a huge impact on the ROM of the upper extremity and results in **drastically lower functionality** of the arm. Transradial amputation leads to the loss of function as shown in Figure 11.

The Southampton Hand Assessment Procedure (SHAP) evaluates hand function using tasks based on activities of daily living. These tasks are grouped into six prehensile patterns: tip, lateral, tripod, spherical, power, and extension grip, as shown in Figure 12 (Kyberd et al., 2009). Out of these grips, the **tip grip and power grip** are estimated to be most valuable grip by multiple experts (Van de Kamp, 2025; C1, C2, C10).

Multiple ergotherapists also pressed that besides the function of opening and closing the hand -leading to a specific grip- it is important to provide the option of supination and pronation of the wrist, to prevent prosthesis users to compensate for these movements with different parts of the body (eg. the shoulder or back), leading to ergonomic discomfort which could lead to injuries (C9, C10).

In presence of the complete and healthy arm, finger flexion and extension is performed by the flexor digitorum and the extensor digitorum and supination and pronation by supinator teres and pronator teres. See Figure 13 for the basic overview of the anatomy of the arm that is needed for opening and closing the hand (finger flexion extension) and rotating the wrist (supination and pronation) (Marieb & Hoehn, 2017).

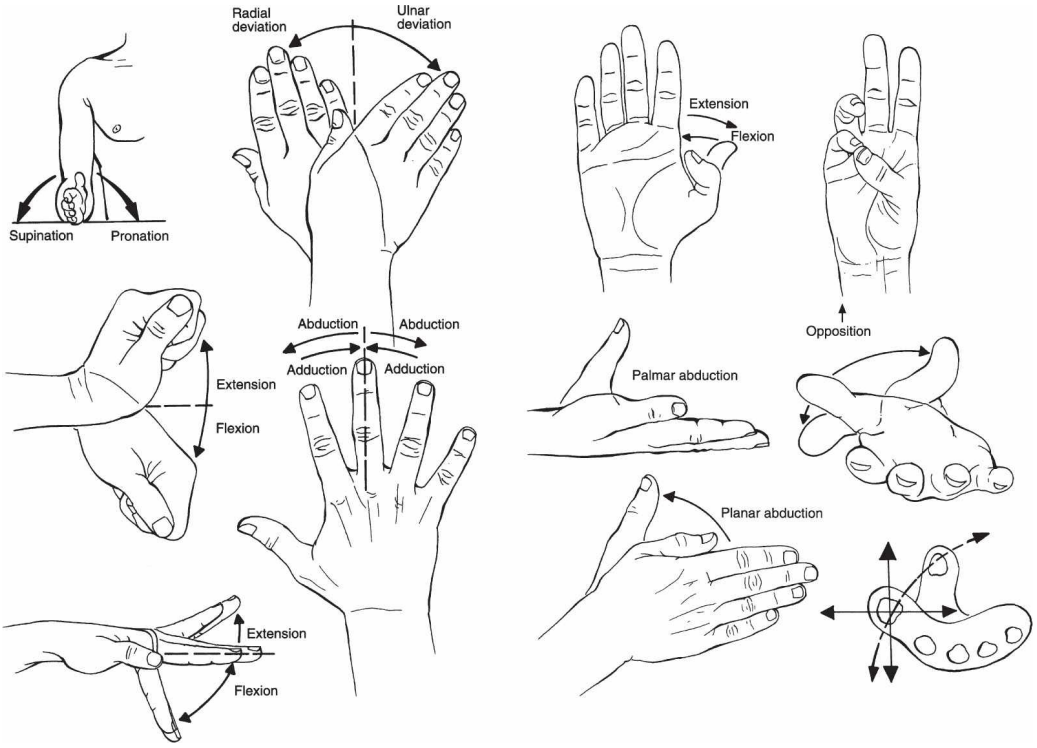


Figure 11. Loss of range of motion as a result of transradial amputation (*Acute wrist and hand injuries*, 2016)

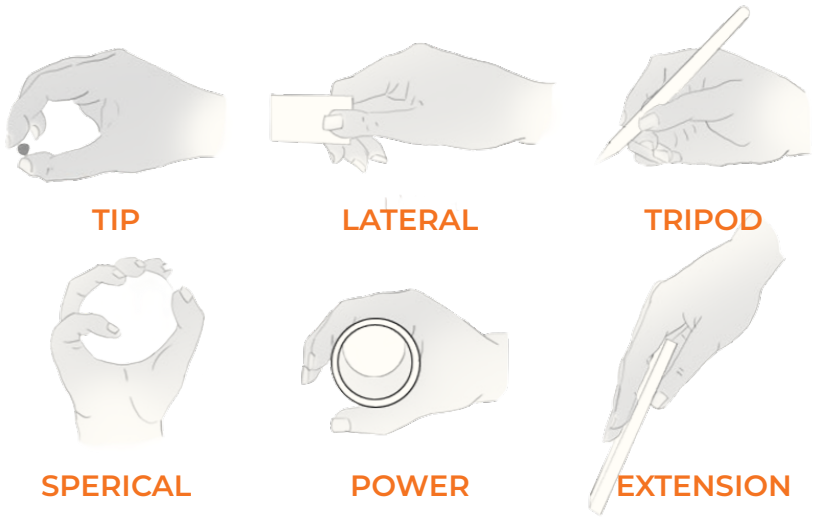


Figure 12. Six grip classifications by Kilberd et al. (2009) (Van de Kamp, 2025)

Besides the loss of these functions due to amputation, the cineplastic surgery also causes **loss of strength in the flexion function**. Since the biceps insertion will be cut (tendonesis) to optimise excursion, the biceps does not take part anymore in flexion (Brückner et al., 1992). See *Appendix B.III* for more information about this topic.

A prosthesis could provide a solution for regaining the most important functions of the lower arm: point and power grip and supination and pronation. However, since the hand is a very complex part to substitute, the prosthesis will never compensate the original natural arm with that much complexity (Gillis, 1948; C1, C2, C10). This strengthens the fact that providing an arm prosthesis that meets the **patient's expectations** remains challenging (C1, C10, P1).

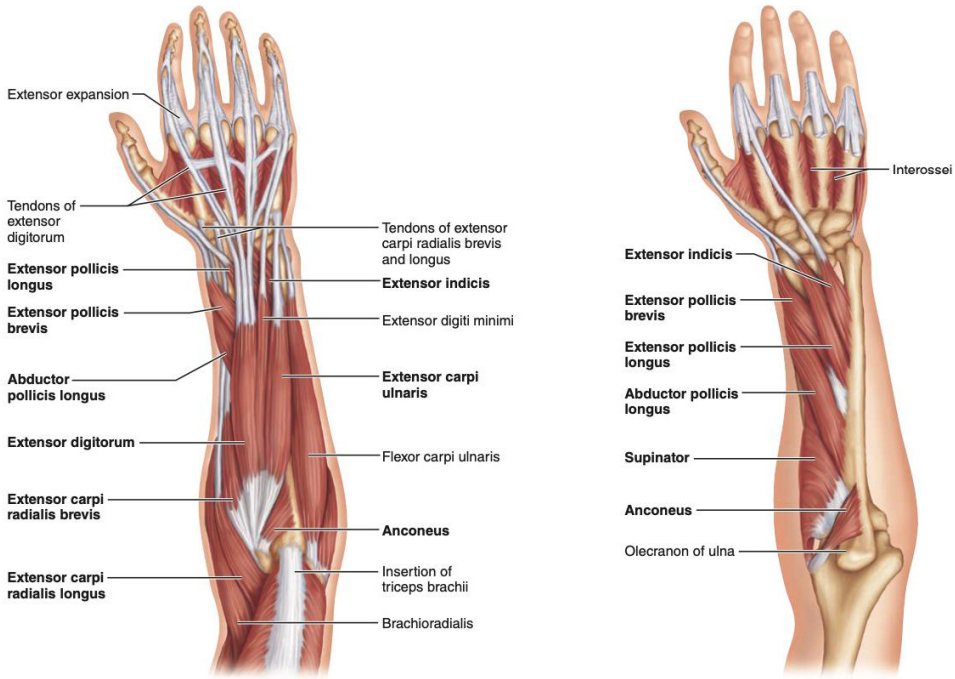


Figure 13. Muscles in the forearm (posterior view of the right arm) responsible for flexion and extension of the hand, and supination and pronation of the lower arm (adapted from Marieb & Hoehn (2017))

2.3.4 Rehabilitation

After surgery, a period of rehabilitation starts. Upper limb amputation rehabilitation protocols consist of multiple steps, which are shown in Figure 14.

According to Kumar et al. (2025), individuals with upper limb amputations encounter **significant difficulties** in preserving everyday functional autonomy. Approximately one third of individuals with upper limb amputations must alter their employment, while nearly two thirds discontinue recreational and professional activities they engaged in before surgery (Diaz-Garcia & Cederna, 2013). Moreover, the social aspect of the hand should not be forgotten. Hands are -similar to the face- part of someone's identity. The loss of a hand could therefore have much more impact than only the functional aspects (C10). Both these drastic impact on someone's life could be mitigated by providing them with the right prosthesis.

Rehabilitation after cineplasty follows a staged protocol that differs from standard post-amputation care. In the first ten days, the operated limb is immobilised with crepe bandaging and a plaster slab, and no movement is permitted to protect the graft and prevent edema; the arm is elevated and gently massaged if swelling occurs (Gale & Hueston, 1957). Once the dressings are removed around day ten and the wound is stable, gentle elbow flexion, pronation, and supination can begin, provided the biceps does not participate (Gale & Hueston, 1957). Independent muscle control is re-established by encouraging static contractions of the contralateral biceps, after which the cineplastically modified biceps may begin controlled activation from the third week onward (Hueston, 1959). This gradual progression supports safe healing while restoring functional muscle use for later prosthetic control.

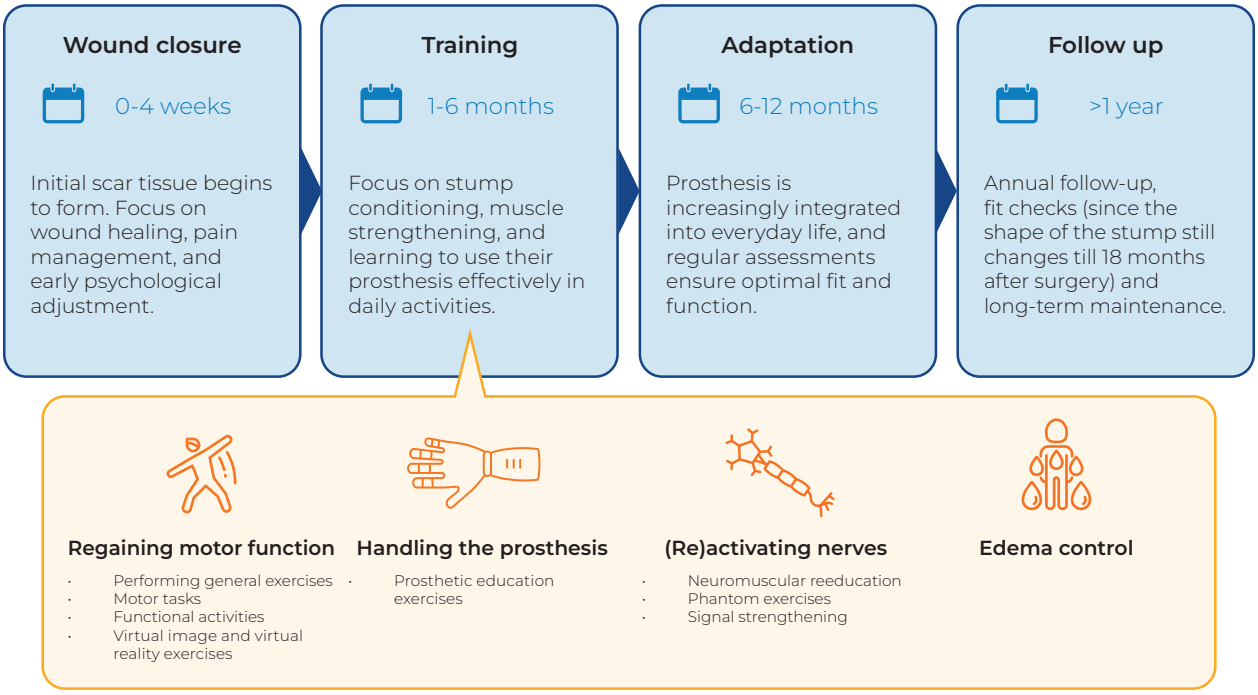


Figure 14. Rehabilitation steps after amputation (Soyer et al., 2016; Teanby, 2022; Amputee Care Centre, 2024).

2.4 Proprioception

Proprioception is **the body's internal sense of position**, movement, and muscle activity, enabling humans to coordinate motion without relying solely on vision. It is described as a "sixth sense" supported by specialised receptors in muscles, tendons, and joints, including muscle spindles, Golgi tendon organs, and joint receptors, which continuously transmit information to the central nervous system (Abraira & Ginty, 2013; Diaz-Hernandez, 2025). Muscle spindles are particularly important: they detect changes in muscle length and contribute to kinaesthesia, the perception of movement (Leskovar et al., 2026). Vega and Cobo (2021) emphasise that muscle spindles act as length-change detectors, providing rapid feedback about stretch velocity and amplitude, while Golgi tendon organs function as tension sensors, monitoring the force generated by muscle contraction and preventing excessive load. Together, these receptors form a tightly regulated system that allows the brain to monitor limb position, adjust movements in real time, and maintain fine motor control (Abraira & Ginty, 2013; Diaz-Hernandez, 2025).

Proprioception in prosthetic use

After amputation, proprioceptive pathways are disrupted, which significantly affects motor control and daily functioning (Diaz-Hernandez, 2025). Users of externally powered prostheses often rely heavily on vision because the device does not naturally provide position or force feedback (Leskovar et al., 2026). This **lack of intrinsic sensory information** is a major contributor to prosthesis rejection (Leskovar et al., 2026).

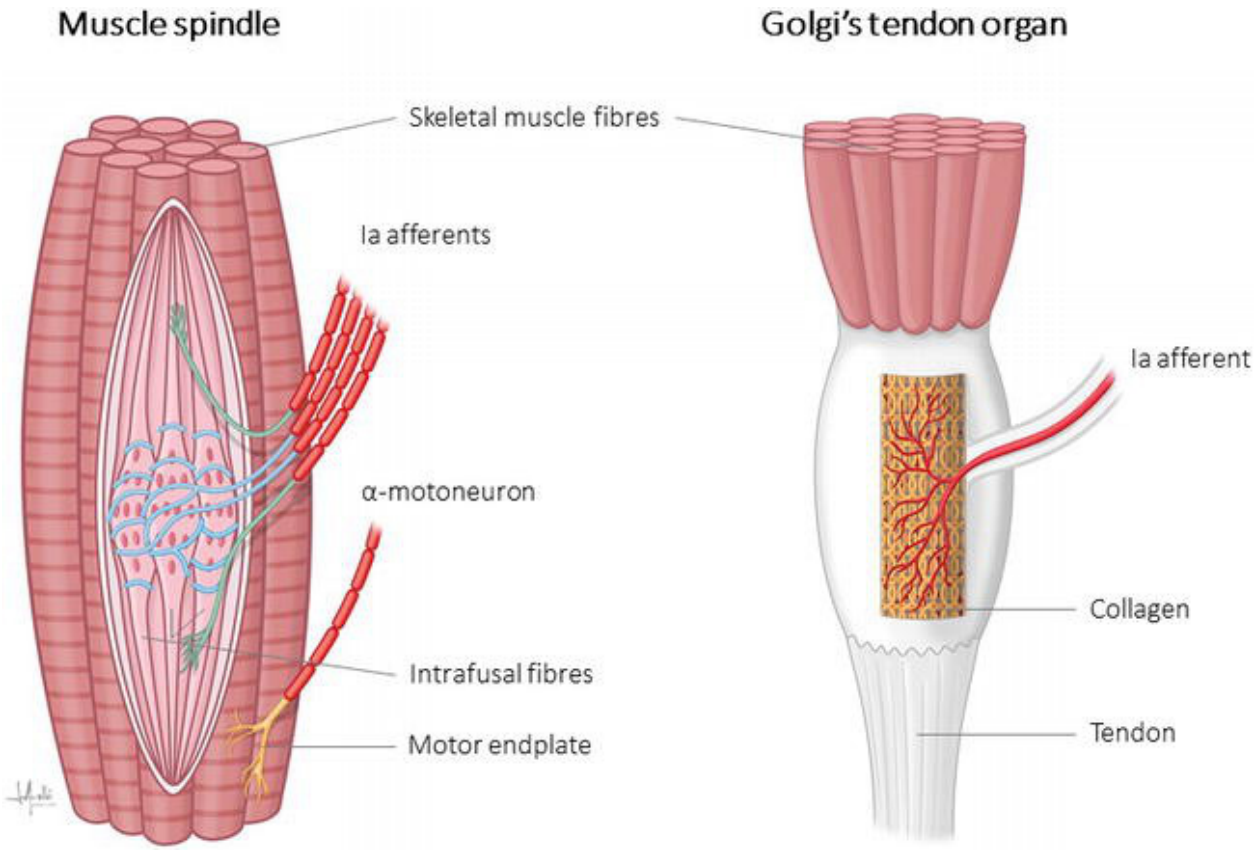


Figure 15. Muscle spindles and Golgi tendon contribute to proprioception (Vega & Cobo, 2021)

Body-powered prostheses inherently provide some proprioceptive cues because cable tension is mechanically linked to the user's body movements. In contrast, externally powered devices separate actuation from user input, removing this natural feedback channel (Leskovar et al., 2026).

The importance of proprioception for prosthesis acceptance and embodiment has been recognised for decades. Sensory feedback—whether natural or artificial—can improve control, reduce cognitive load, and enhance the sense of ownership over the prosthetic limb (Leskovar et al., 2026; Diaz-Hernandez, 2025). When muscle spindles are stimulated, they can even generate illusory sensations of limb motion (Leskovar et al., 2026).
Current approaches aiming to restore or simulate proprioception in prosthetics make use of this interesting property. Proprioceptive research spans invasive and non-invasive strategies, including **neural interfaces** that evoke tactile and position sensations through implanted electrodes (Diaz-Hernandez, 2025), **transcutaneous electrical stimulation** and vibration-based **proprioception illusions** that can non-invasively trigger proprioceptive-like or illusory movement sensations (Leskovar et al., 2026). **Surgical approaches** such as TMR, RPNI, osseointegration-based neural conduits, and AMI aim to recreate physiological muscle–nerve relationships, while Artificial Proprioception systems use electrotactile, vibrotactile, or hybrid encoding to simulate real-time position and force feedback (Diaz-Hernandez, 2025; Leskovar et al., 2026).

See *Appendix B.IV* to learn more about these techniques.

Cineplasty and proprioception
When these approaches are compared to cineplasty, a clear distinction emerges. Neural interfaces and AP systems attempt to simulate proprioception through artificial electrical or mechanical cues, while cineplasty inherently **preserves a natural proprioceptive pathway** by maintaining a direct mechanical link between muscle contraction and prosthetic movement. Body-powered systems already provide intrinsic proprioceptive cues, and cineplasty amplifies this principle by coupling the muscle's mechanical action directly to the prosthesis (Leskovar et al., 2026). This means proprioceptive feedback arises from the user's own muscle activation and the resistance encountered during grasping, without the need for external electronics, encoding strategies, or sensory substitution.

The proprioception literature highlights how **difficult it is to recreate natural proprioception artificially**: neural implants are precise but invasive, while non-invasive methods provide useful but indirect cues. In this landscape, cineplasty is unique because it does not require the nervous system to reinterpret artificial signals - it uses the body's existing proprioceptive mechanisms exactly as intended. This positions cineplasty as a **rare technique that could offer true proprioceptive feedback** in a simple, robust, and intuitive way. Its potential lies in combining this natural feedback with modern improvements, analysing whether it could be a distinctive and promising option within contemporary prostheses offer.

2.5 Prostheses

Prosthetic technology has advanced substantially over the past decades, moving from simple mechanical devices to highly sophisticated systems that support a wide range of functions. This chapter outlines the major developments in prosthetic design from early historical concepts to contemporary solutions, and then introduces the primary options currently available to users for daily life. The range of prosthetic choices is extensive nowadays, and selecting an appropriate device requires careful alignment with the user's functional needs, preferences, and lifestyle. Finally, the chapter highlights several emerging technologies from research, illustrating how ongoing innovation continues to expand what prosthetic systems may offer in the near future.

2.5.1 History of prosthesis development

The prostheses presented in the Introduction of this report were solely passive prostheses, and thus were not seen as functional for daily life. One of the first mechanically controlled upper limb prostheses was designed in 1818 by a German dentist, Peter Bailiff. The concept of control existed out of leather straps using tension in the residual muscles and shoulder was created later in 1868 (Zuo & Olson, 2014; Tropea et al., 2017). From then, mechanical prostheses evolved into the cineplastic technique, first performed in 1900 (Tropea et al., 2017). Somewhat later, a common prosthesis for cineplasty was introduced: the **Sauerbruch prosthesis**, shown in Figure 16.



Figure 16. Cineplastic lower arm prosthesis with two rods located in lower arm for opening and closing the hand (Brückner, 2019)

Analysis of the cineplastic prosthesis

The most used cineplastic prosthesis is the Sauerbruch prosthesis. This prosthesis often made use of a Hüfner hand (Weir, 1995). The prosthesis displayed in Figure 20 is an authentic model produced in 1962. On loan from Dr.ir G. Smit, this impressive prosthesis could be analysed and fotographed and. The (Hüfner) hand was made out of wood, and the socket was made from leather. The prosthesis is strengthed by a metal structure to the lateral and medial side of the prosthesis. The nylon cables were easily (de)connected to a plastic rod with help of press studs, which patients mentioned to experience as functional and easy in use (U3, P2, P5). More versions of cineplastic prostheses can be found in *Appendix B.V*.

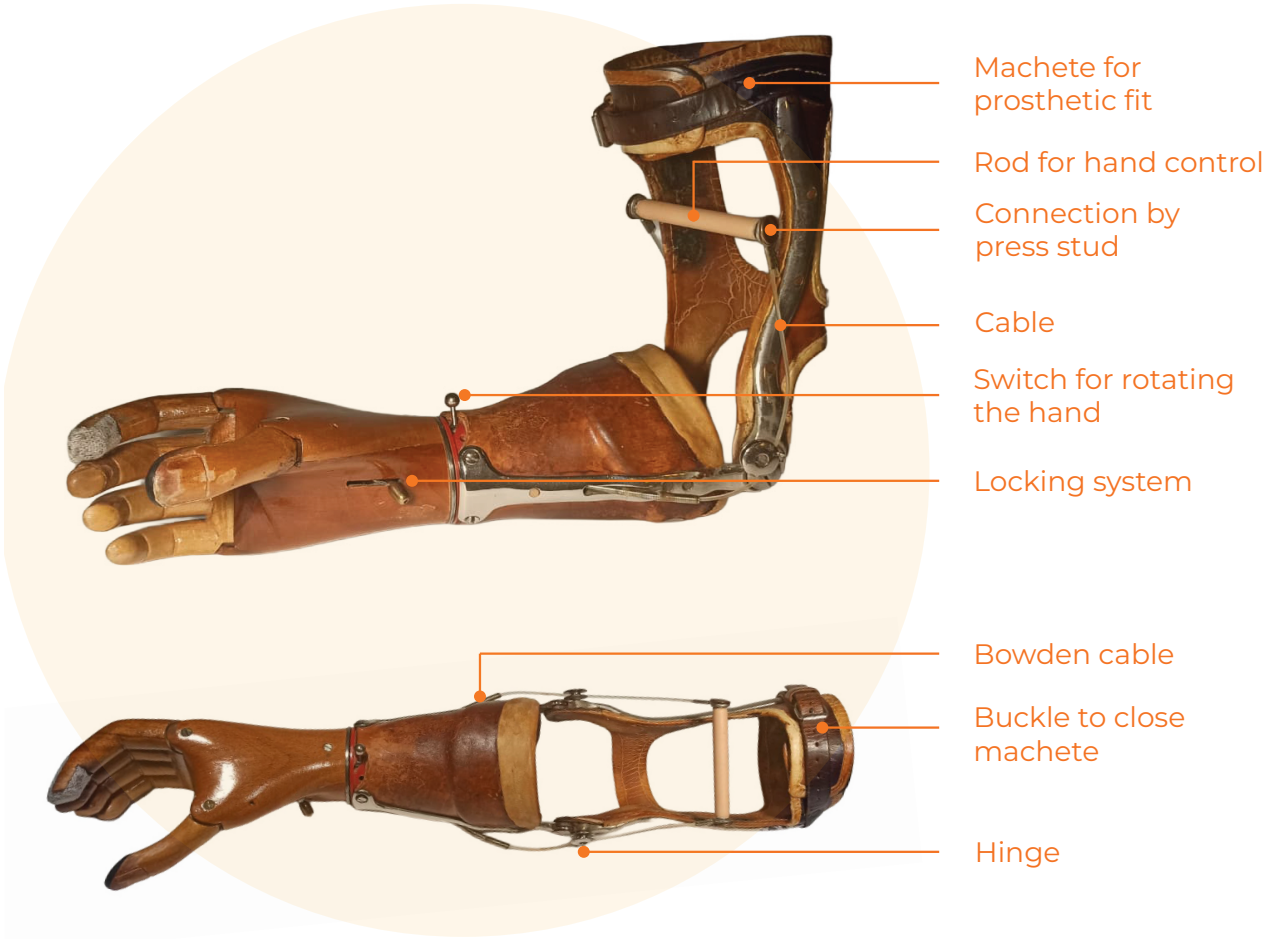


Figure 17. Cineplastic lower arm prosthesis with one rod located in the upper arm (biceps) to close the hand (voluntary closing) (Greifpunkte., n.d.)

Myoelectric developments

The concept of a myoelectric prosthesis was first introduced in 1948 by Reinhold Reiter, who developed a device powered by **amplified surface EMG signals** (Marsh, 2023; Zuo & Olson, 2014). Despite its novelty, his work did not achieve clinical or commercial uptake. A more practical design emerged in 1960 with Alexander Kobrinski's "Russian Hand," which incorporated transistor technology and a cosmetic glove, but its weight, limited functionality, and reliability issues hindered widespread success. Based on this concept, an improved prosthesis was developed by a collaboration of MIT, Harvard Medical School, Massachusetts General Hospital, and Liberty Mutual called the Boston Arm (Marsh, 2023). By the 1980s, myoelectric prostheses had become established in rehabilitation practice worldwide and remain a **standard option** for upper limb amputees today (Zuo & Olson, 2014; P1, P2, P3). Modern developments since then could be found in *Chapter 2.5.4*.

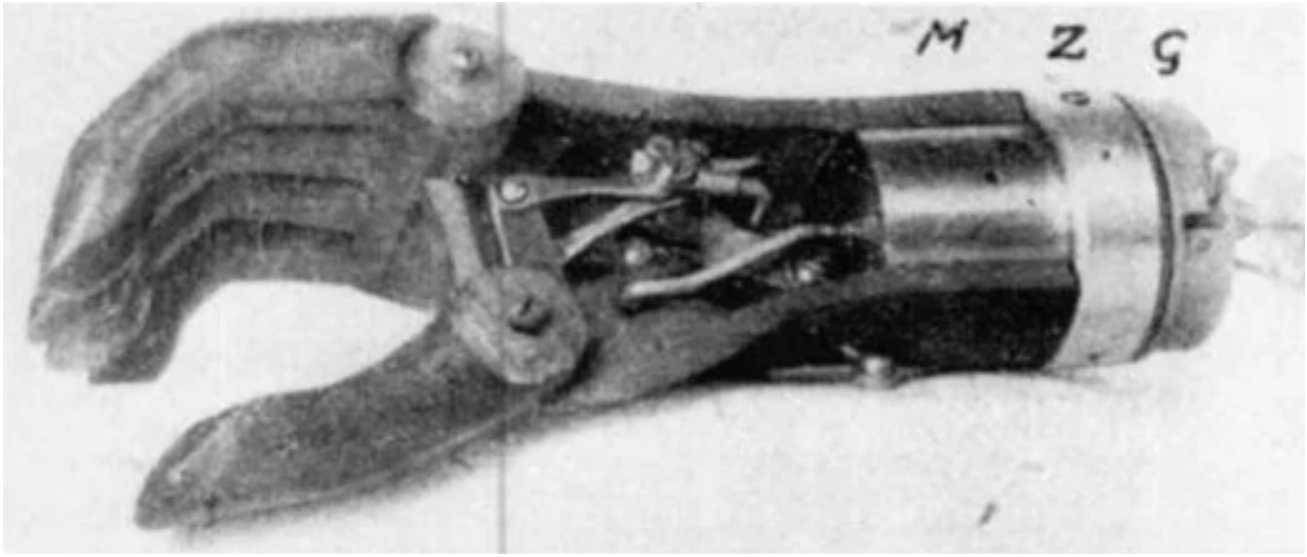


Figure 18. First myoelectric prosthetic hand by Reinhold Reiter (1948) (Ng et al., 2021)

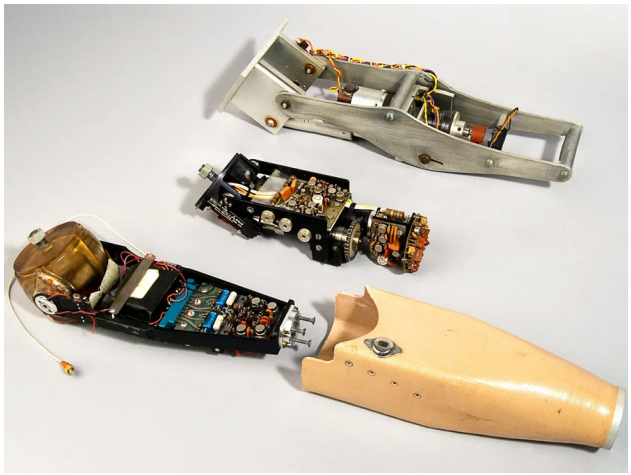


Figure 19. The Boston Arm (1968) (Marsh, 2023)

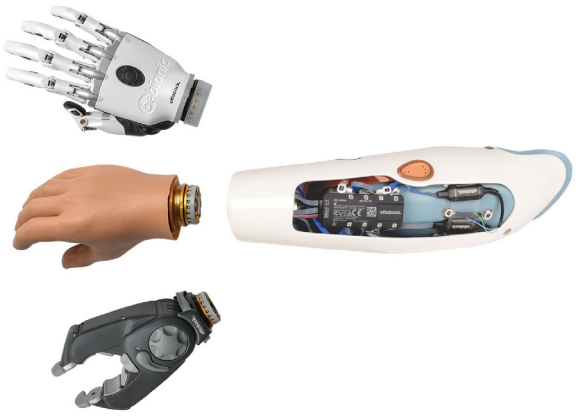


Figure 20. The Bebionic van Ottobock is part of the current myoelectric prostheses offer (*Active and creative with an arm prosthesis*, n.d.)

2.5.3 Current prostheses options

A prosthesis consist of multiple parts: the inside socket that is in contact with the stump, an outside socket and a terminal device (P1, P2, P3). In this project is chosen to focus on a lower arm prosthesis, see *Appendix B.VI* for a clear motivation.
When in need of an upper limb prosthetic, a patient has a choice between a cosmetic (no moving function) or a functional prosthesis. Functional prostheses are divided into mechanical prosthesis, and myoelectrical prosthesis (bron, P1,P3). All sorts of prostheses will be discussed briefly.

Different types of prostheses
Passive/cosmetic prosthesis primarily restore the visual appearance of the limb, though they can also support simple functional tasks such as pushing at the same effective arm length as the intact side (P4; Hoogstraat). Modern devices range from standard PVC arms to highly personalised prostheses created through 3D scanning -mirroring the other hand- and fabrication via carbon laminating, 3D printing or silicone molding by prosthetists or sometimes even specialised artists. Achieving realistic skin tones involves detailed color analysis to reproduce subtle variations (P3; Rijndam, Hoogstraat).

Body-powered/mechanical prostheses offer active movement through mechanical coupling to body motions, typically via harnesses or straps. Cineplastic prostheses fall within this category, using direct attachment to a muscle or tendon for control, with input commonly taken from the contralateral shoulder or through elbow flexion (C2, P1, P3, P4). These devices are generally lighter, more precise, and more reliable than myoelectric systems, as also demonstrated during the Cybathlon 2016 where the TRS Grip Prehensor outperformed advanced myoelectric hands (Smit, 2020; C1, C3).
Acceptance rates remain low (≈20%), partly due to high actuation forces and limited pinch force, whereas earlier efficient designs such as the Hüfner hand showed higher acceptance (70% in 1966), highlighting the importance of low-effort control (Smit, 2020). A known drawback is increased physical load on the contralateral limb, which may lead to overuse (C2, C9, P1).

Around half of Dutch upper-limb prosthesis users rely on **myoelectric prosthesis** (P1, P2, P3). These systems detect muscle activity via electrodes, ranging from simple two-electrode control for opening and closing the hand to multi-electrode setups (up to eight sensors) enabling more complex movements. Pattern-recognition control can further enhance intuitiveness by mapping combinations of muscle signals to user-defined motions (P1, P2, P3, P4). However, myoelectric prostheses are relatively heavy due to integrated electronics, which can strain joints, and they require frequent maintenance, often needing frequent repairs (C1, C2, P1, P3). They are generally unsuitable for heavy or repetitive physical work (P1, P3).

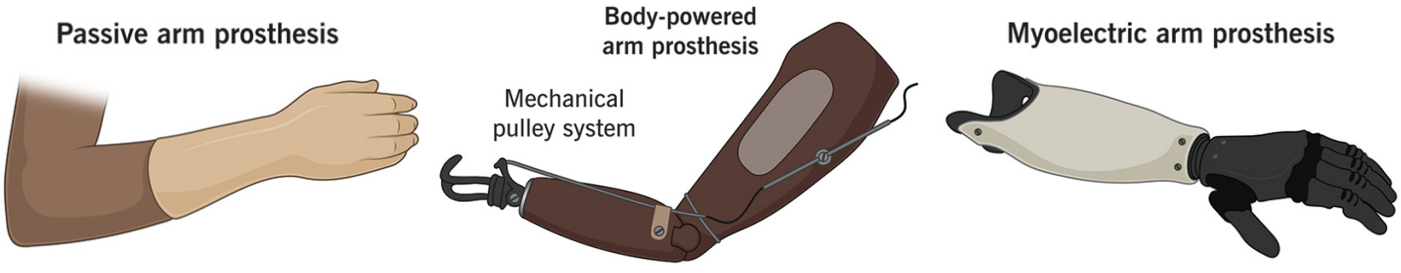


Figure 21. Different types of prosthetics

Connection to the stump

There are multiple options to connect the prosthesis to the stump. One possiblity is a liner with a pin (creating a vacuum and thus connecting to the stump) where a prosthesis could be connected to, fitting the prosthesis to the shape of the stump (mostly using the condyles) or making use of harnessing to connect the prosthesis to the body (mostly the case for upper arm prosthesis users). Another method often used in leg prostheses but less frequently in arm prostheses is osseointegration, where a pin is inserted directly into the users bone, where the prosthesis could be connected to. The biggest drawback of this method is the presence of a stoma - a permanent opening in the skin - which is prone for infection. The operation is currently not covered by insurance, since there is little information/proof/research done, but preliminary findings seem promising (C2).

Production

When visiting Rijndam and the Hoogstraat, several production steps were shown. In most cases, a mould will be created with help of plastering of the stump. Sometimes, the stump is scanned to gain in impresssion of the stump. Adaptations are made to the impression for optimal comfort. After that, a socket will be made from a combination of serin and carbon, for strength optimisation. The socket will be tested and if necessary improved. Finally, the inner socket will be connected to an outer socket and cables or sensors will be included. Finally the selected terminal device will be connected.

Costs & insurance

A rough estimate of costs of different prosthesis choices are listed below (Anders, 2026):

- Cosmetic: 1.500 - 4.500
- Body-powered: 2.500 - 8.5000
- Myoelectric: 15.000 - > 80.000
- Cineplastic: 3.5000-10.000

The estimation of the costs for a cineplastic prosthesis are based on the finding by Smith (2022) that orthopedic surgery costs approximately 2.000 euros per hour.

Systemic challenges remain, particularly in terms of costs and insurance coverage. See *Appendix B.VII* for more information about these challenges.

Comparison

Prosthetic options differ widely in functionality, user experience, and acceptance, and these differences strongly influence whether a device is ultimately used or abandoned. Body-powered terminal devices, for example, continue to perform competitively despite their relative simplicity; they can “compete well with more complex systems, in terms of speed and functionality” (Smit, 2013). Patterns of prosthetic use also vary demographically. Certain devices, such as thumb joint prostheses, have been common in several European countries for decades, whereas their adoption in the Netherlands has only emerged in the past ten years (C4). Similarly, the US tends to choose for body-powered prostheses, where Europe focuses on myoelectric systems (G. Smit, personal communication, 28 November 2026).

Across prosthetic types, user acceptance remains a critical issue. Although many terminal devices are available, approximately 27% of upper-limb amputees do not actively use their prosthesis, and 20% discontinue wearing

it altogether (Smit, 2013; Biddiss & Chau, 2007). A frequently cited reason for rejection is the lack of appropriate sensory feedback (Biddiss & Chau, 2007). Other factors contributing to abandonment include discomfort during wear (e.g., excessive weight or heat), limited added functionality, high physical effort required for operation, and insufficient control. User studies consistently highlight several design priorities, with mass reduction identified as the most important improvement need (Biddiss & Chau, 2007; Smit, 2013).

Despite these challenges, prostheses hold significant value when they **align with the user's lifestyle and expectations**. As one professional noted, "Every prosthesis has value, but it needs to suit the patient's life" (P3). This is echoed by user experiences. One myoelectric prosthesis user stated: "I really miss it when my prosthetic is broken or when I'm not wearing it. When I do not have my prosthetic arm, I have to ask for help and feel handicapped."

Across all device categories, user demands can be broadly summarised by the "three C's": **Cosmesis, Comfort, and Control**. A prosthesis should be aesthetically acceptable, comfortable to wear, and intuitive to operate (Smit, 2013). These principles form an essential lens through which different prosthetic types can be compared, and they underscore the importance of striving toward prosthetic solutions that approach "near-perfect" alignment with user needs. Figure 22 shows an overview of how different types of prosthetics score on criteria derived from literature research and interviews with experts, and are ordered on importance, filled in cooperation with a prosthesis expert.

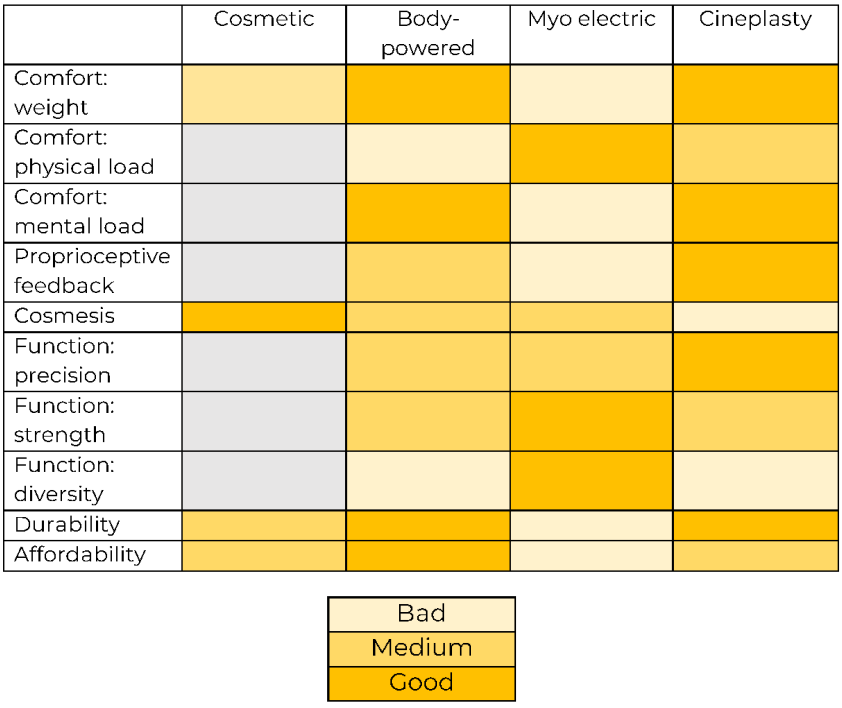


Figure 22. Overview of prosthetic types on criteria

2.5.4 State of the art prosthetic techniques

The development of prosthetics is impressive. Things that were never expected to be possible, are now reality. Prosthetics nowadays are quite far developed in the area of motion and precision, but even the most advanced solutions lack the essential sensory feedback and functional prehension (Kumar et al., 2025). For deeper understanding of this feedback loop please find *Chapter 2.4*.

Most commercial prostheses today provide little or no direct sensory feedback (Sensinger & Dosen, 2020; C1, C3, C4). This lack of sensory feedback leads to the fact that patients sustaining an upper extremity amputation must expend greater energy -both physical and cognitive- to perform the activities of daily living (Diaz-Garcia & Cederna, 2013). Experts stress that even the most advanced prosthetics that can provide valuable feedback and proprioception, cannot surpass the natural system (C1, C2, C7, P2, P3).

Surgically relocating nerves

Regenerative **Peripheral Nerve Interfaces** (RPNIs) are created during amputation surgery to reduce postoperative phantom pain and neuroma formation. The technique works by giving each major peripheral nerve a new, biologically active target. After the nerve is transected at the level of the bone, a small piece of healthy muscle is harvested and prepared. The end of the nerve is then secured inside this muscle graft, which is wrapped around the nerve to create a stable, innervated unit, see Figure 23. Once implanted deeper within the soft tissues, the muscle graft provides the regenerating nerve fibers with an appropriate physiological environment. In doing so, the RPNI prevents painful neuroma formation and establishes a biological interface that can later be used for prosthetic control (Diaz-Garcia & Cederna, 2013).

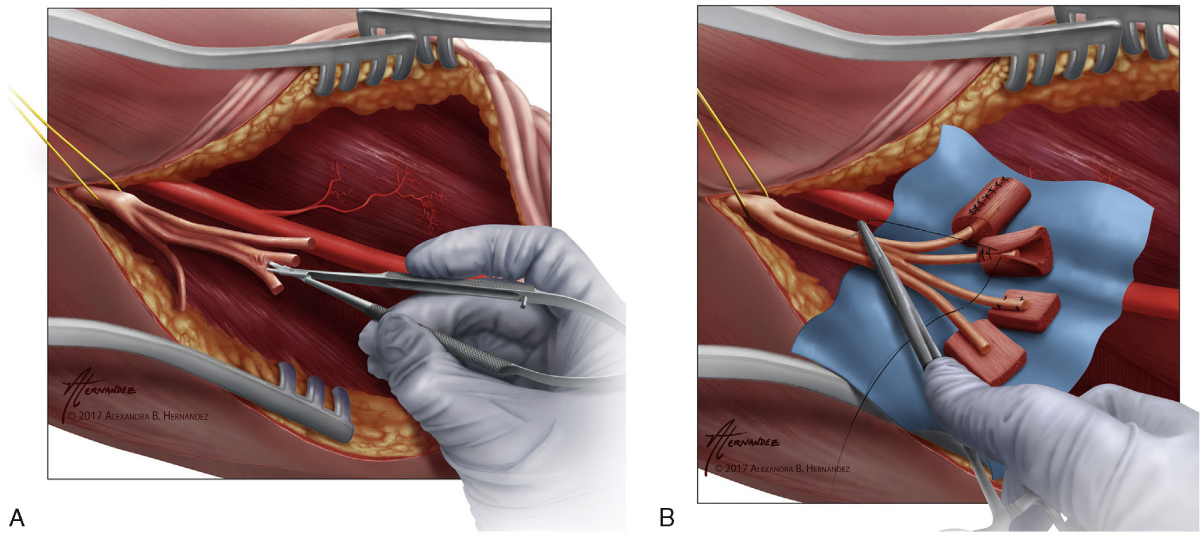


Figure 23. Regenerative Peripheral Nerve Interfaces surgery (Diaz-Garcia & Cederna, 2013).

Targeted Muscle Reinnervation (TMR), first described in 2004, is another surgical technique in which severed nerves that originally supplied the arm or hand are redirected to small motor branches of residual muscles. The procedure serves two main purposes: it prevents the formation of painful neuromas by giving the nerves a new functional target, and it enhances prosthetic control by allowing signals from nerves to be detected by myoelectric sensors, see Figure 24 (Diaz-Garcia & Cederna, 2013; Zuo & Olson, 2014;). During surgery, the surgeon identifies suitable motor branches with a stimulator and connects the major nerves to them. This way, the nerves are provided with a new "home" within existing muscles, enabling more intuitive prosthetic use (Diaz-Garcia & Cederna, 2013). TMR leads to improved intuitive control and enables patients to simultaneously move multiple joints, such as opening and closing the prosthesis while flexing and extending the elbow, drastically increasing the speed of task performance (Zuo & Olson, 2014).

Early applications of Targeted Muscle Reinnervation (TMR) not only improved motor control for amputees but also led to unexpected sensory recovery in the skin over reinnervated muscles. When these areas were stimulated, patients perceived touch as originating from the missing limb. Building on this insight, researchers expanded the technique to include reattachment of sensory nerves to peripheral nerve trunks (Zuo & Olson, 2014).

Targeted Sensory Reinnervation (TSR) isolates and redirects specific sensory nerve fascicles from the median and ulnar nerves to defined cutaneous regions away from the prosthetic interface. The result is a stable, spatially organised "hand map" on the skin.
When combined with sensory feedback devices, TSR enables amputees to perceive and modulate the force applied by a myoelectric prosthesis. Early clinical outcomes demonstrate promising functional recovery, including accurate discrimination of pressure levels, object size, and density without reliance on visual or auditory cues. These huge advantages come at a financial cost of approximately 200.000 euros (Zuo & Olson, 2014).

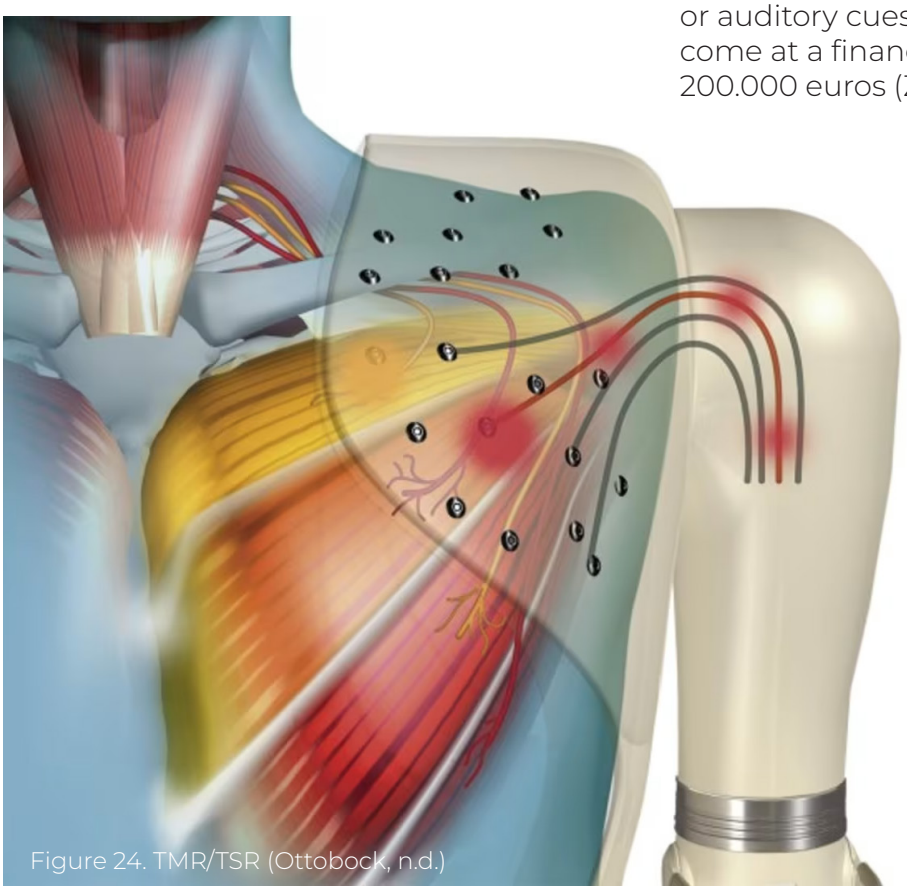


Figure 24. TMR/TSR (Ottobock, n.d.)

Hand transplantation

The earliest attempt at hand transplantation was carried out in Ecuador in 1964, but the hand was amputated within weeks due to acute rejection. A landmark achievement followed in 1998 in Lyon, France, where Dr. Jean Michel Dubernard's team performed the first clinically successful procedure, though the transplanted hand was lost after 29 months because of poor adherence to immunosuppressive therapy. In 1999, a second case in Louisville, USA, achieved long term success, with patient Matthew Scott remaining the world's longest surviving hand transplant recipient. The first bilateral transplantation was subsequently performed in Lyon in 2000 (Zuo & Olson, 2014). More than 100 hand transplations have been performed since then. In the Netherlands, Maartje Bijl received a double hand transplantation in Radboudumc in 2019 (see Figure 25) and se is very satisfied with the functions of her new hands: "My hands are a part of me; I find it very natural. I'm very happy that they really fit my body, and I think the functionality is fantastic. So I'm really happy with them." (NOS Nieuws, 2021).



Figure 25. Maartje Bijl, first patient to undergo a bilateral hand transplantation in the Netherlands (NOS Nieuws, 2021)

Integrating electrodes

A key development in prosthetic development is the use of a **percutaneous osseointegrated interface** by Ortiz-Catalan et al. (2014), which creates a stable, bone-anchored pathway for direct communication between the body and an artificial limb. Unlike traditional surface-based neuromuscular interfaces, this system uses implanted electrodes in peripheral nerves and muscles to provide continuous, high-fidelity control signals and to deliver sensory feedback through neurostimulation, see Figure 26.

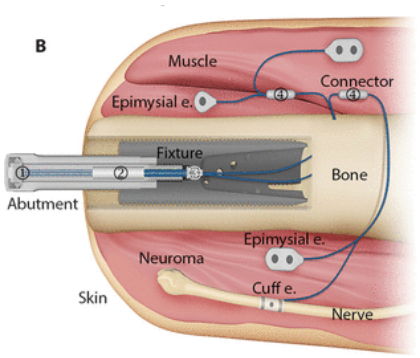


Figure 26. Implanted electrodes in peripheral nerves and muscles to deliver sensory feedback through neurostimulation via osseointegration (Ortiz-Catalan, 2014)

Its uniqueness lies in the long-term stability of this bidirectional link: it enables precise, intuitive prosthetic control that remains reliable across different limb positions and daily environments, while also supporting naturally perceived sensations. This permanent interface represents a major step toward prosthetic limbs that function as seamless extensions of the user's body.

Already in 2011, researchers from Case Western Reserve University (Ohio) achieved t restore the perception of touch by **placing electrodes directly on the nerve** as shown in Figure 27 (IEEE Spectrum, 2016).

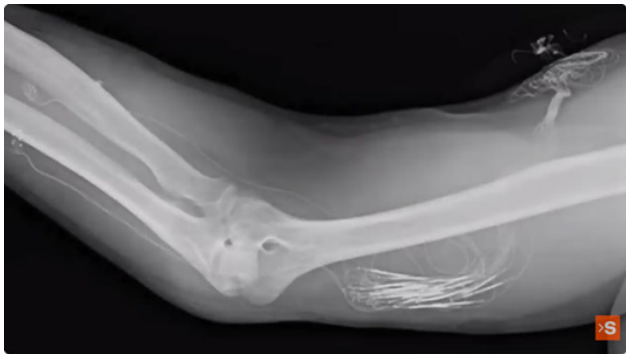


Figure 27. Electrodes placed directly on the nerve (IEEE Spectrum, 2016)

A more recent development in artificial proprioception is demonstrated by Rostamian et al. (2022). In this study, the researchers designed a **biomimetic fingertip containing tactile sensors** that emulate the behaviour of human mechanoreceptors. These sensors capture fine-grained information about surface micro-vibrations and pressure patterns as the fingertip moves across a texture. This tactile input is combined with proprioceptive information derived from the motion of the prosthetic finger itself, allowing the system to interpret how contact forces change with movement. Both sensory streams are encoded into feature sets that represent vibration frequency, amplitude, and spatial pressure distribution. A machine-learning classifier is then trained on these combined features to distinguish between different textures, even when scanning speed varies. By integrating tactile and proprioceptive cues in this way, the system achieves a more robust and human-like form of texture recognition, illustrating how multi-sensory encoding can significantly enhance the perceptual capabilities of prosthetic hands (Rostamian et al., 2022).

Agonist-antagonist Myoneural Interface

The agonist–antagonist myoneural interface (AMI) represents a major state-of-the-art advancement in prosthetic integration, designed to restore the natural muscle dynamics and proprioceptive signaling that are lost in traditional amputation. Unlike earlier approaches such as cineplasty, AMI surgically rebuilds opposing muscle pairs so that when one contracts, the other is mechanically stretched, recreating the physiological signals that underlie proprioception. These muscle-tendon interactions are then monitored with artificial sensors and communicated to a prosthetic limb, enabling the device to interpret the user's intended movements with far greater precision. At the same time, the natural stretch and tension sensed by the reconstructed muscles provide the user with proprioceptive feedback that feels more biologically intuitive than traditional methods, see Figure 28. By restoring both sides of the agonist–antagonist relationship and linking them to modern sensing and control systems, AMI offers a uniquely biomimetic interface that enhances motor control, preserves central proprioceptive pathways, and supports more natural, coordinated use of advanced prosthetic limbs (Herr & Carty, 2021).

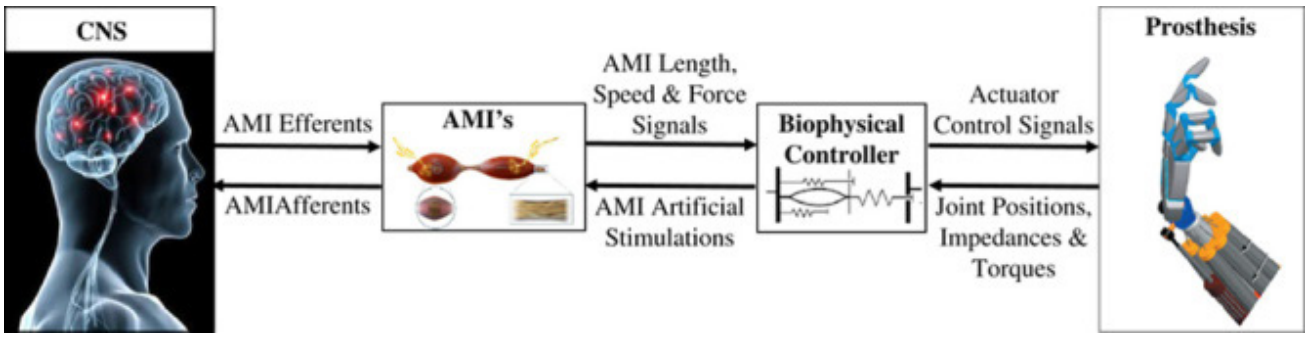


Figure 28. . Agonist-antagonist Myoneural Interface (Herr & Carty, 2021)

Conclusion

A lot of research is done into the developments of (upper limb) prostheses, which results are impressive. State-of-the-art research in arm prostheses is pushing toward invasive neural interfaces and advanced sensory feedback systems. However, lots of these concepts are not ready for the market yet (Segura et al., 2024; Sensinger & Dosen, 2020). Average patients today mostly use simple, non-invasive solutions like vibration, pressure, or visual feedback. The gap between cutting-edge prototypes and what is commercially available remains large (Sensinger & Dosen, 2020).

Sensinger & Dosen (2020) state that some studies show clear performance improvements with feedback (e.g., delicate tasks requiring grip modulation), while others find little or no difference, or benefits only in specific subjects/conditions. This inconsistency is partly due to delays in sensory feedback (50–300 ms) and the ability of internal models to compensate.

The only way to create the complexity of the feedback systems of the human body, is to maintain or expand those systems. Cineplasty is one of the few techniques that makes use of this principle (Diaz-Garcia & Cederna, 2013; Kumar et al., 2025; C1, C3, C4).

Technology

2.6 A Deep dive into cineplasty

More than 100 years ago, in the late nineteenth century, the concept of cineplasty first emerged (Tropea et al., 2017). The strict definition of cineplasty by Spittler and Fletcher (1953) is “any type of surgical procedure which produces some function out of an amputated extremity other than the movement of the extremity itself.” At that time, options for generating active motion in prosthetic devices were limited, making this technique particularly **innovative within its historical context**. Since its introduction, cineplasty has undergone considerable evolution (Weir, 1995). This chapter highlights the major developments of this extraordinary technique over the past century, see *Appendix B.VII* for a full historical analysis.

Figure 29. Patient with prostheses connected to club motor (Magowska & Owecki, 2021)



2.6.1 The evolution of cineplasty

Following its emergence at the end of the nineteenth century, cineplasty evolved through a series of surgical, mechanical, and technological innovations that shaped its clinical relevance throughout the twentieth century. Early foundations were laid by Giuliano Vanghetti, who expanded on earlier body-powered concepts by proposing direct mechanical coupling between residual muscles and prosthetic components (Tropea et al., 2017). The first cineplastic operation was performed in 1900 (see Figure 31 for the surgery procedure), and the technique gained momentum during the World War I, when Vanghetti and others applied it on a larger scale to restore functional control for upper-limb amputees (Tropea et al., 2017; Weir, 1995).

The Krukenberg procedure

Parallel developments explored alternative approaches to restoring proprioception. The Krukenberg procedure, introduced in 1917, converted the radius and ulna into **functional prongs**, preserving tactile sensation and enabling independent grasp without a prosthesis (Gillis, 1948; Kumar et al., 2025). Although highly effective in resource-limited settings, its appearance limited broader acceptance, and cineplasty remained the preferred option when prosthetic devices were available and cosmetic outcomes were important (Kumar et al., 2025). Other early variations, such as loop-based muscle motors, demonstrated the potential of muscle-driven control but were hindered by inefficient force transfer, instability, and hygiene challenges (Mazet, 1958; Weir, 1995).

Sauerbruch's muscle tunnels

A major turning point occurred with Ferdinand Sauerbruch's introduction of muscle tunnels in 1915. His extensive clinical work during WWI -supported by the Prussian War Department- established the foundation for modern cineplasty, see Figure 30 for some prosthesis users with a cineplastic prosthesis and tunnel (Tropea et al., 2017; Weir, 1995). Sauerbruch emphasised coordinated agonist-antagonist muscle use, careful tunnel

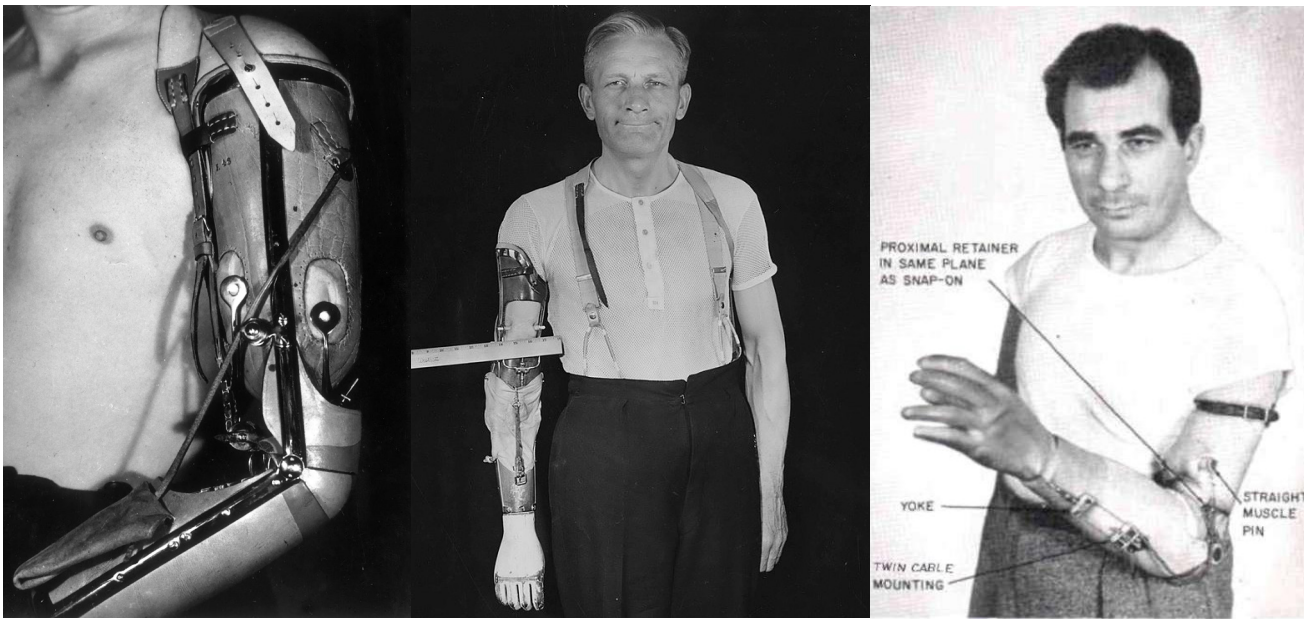
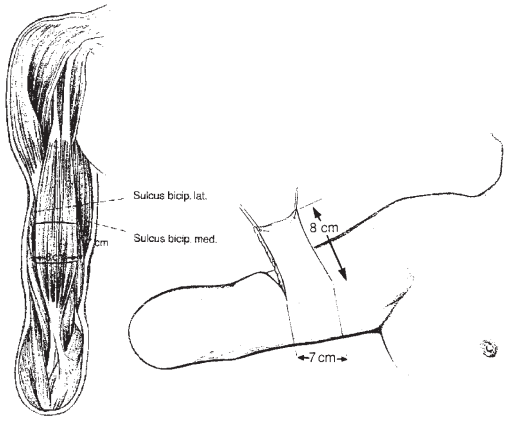
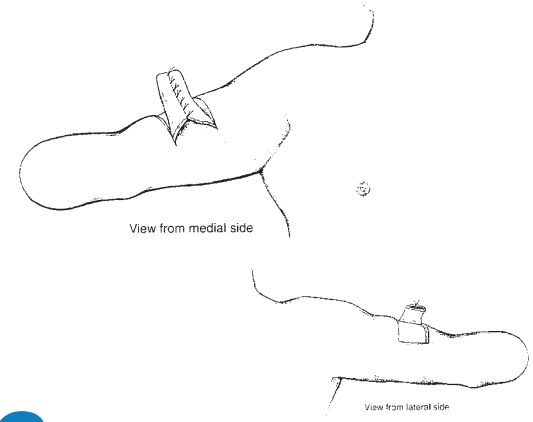


Figure 30. From left to right: cineplastic prosthesis user, biceps and triceps tunnel (Gerste, 2016), cineplastic prosthesis user, biceps tunnel (*Die Geschichte der Prothese,* 2024), Cineplastic prosthesis user, biceps tunnel Pursley, 1955)

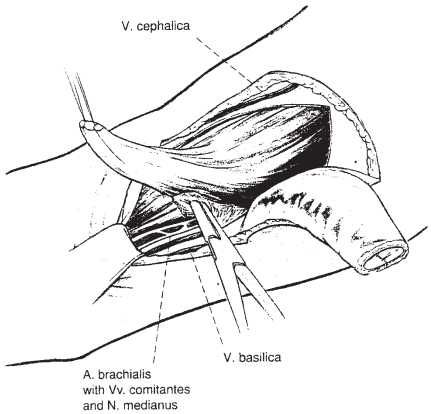
The cineplastic surgery steps for a muscle tunnel



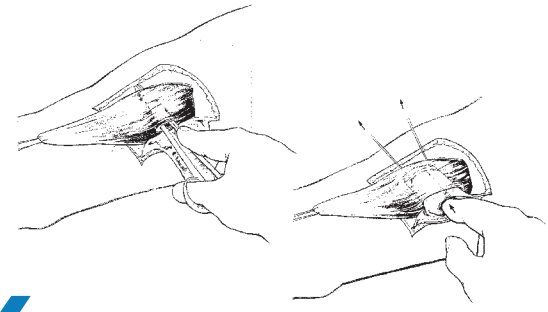
1 Incision overlying the musculus biceps from sulcus bicipitis medialis to the sulcus bicipitis lateralis. The center of the **skin flap** lies over the most prominent point of the muscle belly.



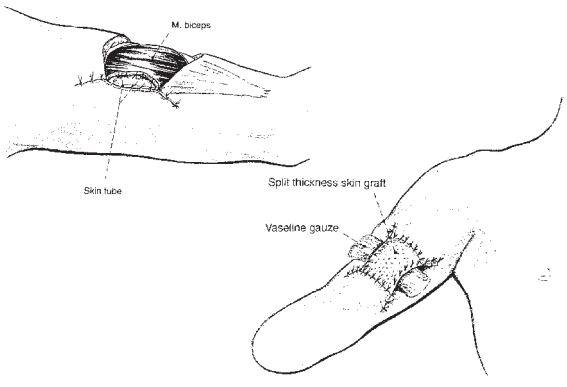
2 Formation of the **skin tube**, ends of the skin flap sutured with resorbable material.



3 **Detachment of the musculus biceps** near its insertion. The muscle is raised distally and freed of any connective tissue adhesions. Sutures are placed in the distal end of the muscle to prevent its splitting in a distal



4 The muscle is positioned loosely into the wound and the skin tube placed across it to determine the location of the muscle tunnel. **Muscle tunnel** and skin tube must be parallel. The muscle fascia is incised over a length of 5 cm between the upper anterior and middle part of the muscle. The muscle is carefully pierced with a blunt forceps, after which the tunnel is enlarged to about 4 cm by using either two fingers or an appropriate dilator. The skin tube is pulled through the muscle tunnel.



5 Care must be taken to preserve a good blood supply to the skin tube. **Suturing** of the free end of the skin tube results in a smaller wound. The remaining skin defect over the musculus biceps is covered with a **split thickness skin graft** taken from the patient's thigh. A neomycin-vaseline gauze is inserted into the tunnel, the same type of dressing is used over the split thickness skin graft. This prevents adhesions to the outer dressing.

Figure 31. Procedure of the cineplastic surgery of a muscle tunnel by Brückner (1992)

sizing, and structured rehabilitation. His circle introduced several refinements, including the first biceps tunnel in a short below-elbow amputee (Spitzy, 1917), improved skin-incision techniques (Erlacher, 1918), and methods to increase muscle excursion (Anschutz, 1919). Over time, the **biceps brachii** emerged as the most reliable motor site for below-elbow amputees, offering superior strength, excursion, and long-term usability compared to forearm or pectoral tunnels (Brav et al., 1957; Brückner, 1992; Spittler & Woodard, 1953). By the mid-twentieth century, biceps cineplasty had become the most widely adopted and clinically successful form of the procedure (Brav et al., 1957; Brückner, 1992; Spittler & Woodard, 1953).

International expansion and interwar developments

International expansion followed WWI, with surgeons in Europe, South America, and the United States adopting and modifying the technique (Weir, 1995). However, **outcomes varied**, and many patients discontinued use due to infection, pain, tunnel insufficiency, or inadequate prosthetic integration (Jottkowitz (1931) and Purckhauer (1925) from Weir, 1995). These reports illustrate the variability in long-term success and the dependence of outcomes on both surgical and prosthetic factors, as described in multiple mid-century follow-up studies (Weir, 1995).

Technological developments during and after WWII significantly influenced cineplasty's trajectory. The introduction of the **Bowden cable** -originating from aircraft control systems and bicycle engineering- modernised prosthetic control and enabled efficient force transmission over curved paths (Weir, 1995). This made body-powered prostheses more reliable and allowed cineplasty to interface effectively with voluntary-opening terminal devices. Engineering studies quantified the force and excursion requirements for functional grasp (Blaschke & Taylor, 1953), informing the design of hooks and hands compatible with muscle-driven control. Material innovations, such as the transition from leather and metal to plastic laminates and plexiglass components, further improved durability (Brückner, 1992; Weir, 1995).

Despite these advances, cineplasty faced increasing competition from conventional body-powered and later myoelectric prostheses. Although motivated users achieved excellent functional outcomes, particularly with biceps tunnels, overall acceptance remained lower than for non-surgical alternatives (Brav et al., 1957). Many clinicians recommended trialing a conventional prosthesis before considering cineplasty (Weir, 1995). Still, users who continued to wear their cineplastic prostheses often reported **highly positive experiences**, valuing the finely graded grip, reduced need for harnessing, and enhanced perception of finger position and applied pressure (Brav et al., 1964; Spittler & Woodard, 1953). Importantly, several long-term users stated that they would recommend the technique to other prosthesis users, demonstrating strong satisfaction among successful wearers (Brav et al., 1964).

Late 20th century: revival and decline

By the late twentieth century, cineplasty declined due to the rise of myoelectric prostheses, the invasiveness of the surgery, loss of surgical expertise, persistent complications, and the lack of modern prostheses designed specifically for cineplasty (Brückner, 1992; Weir, 1995; Weir et al., 2001). Nevertheless, cineplasty retained unique advantagesnatural sensory feedback, force amplification,

independence from external power, and freedom from harnessing. Contemporary reviews note that **cineplasty remains a viable option** for bilateral amputees or individuals in resource-limited settings, where its simplicity and proprioceptive benefits may still offer meaningful advantages (Kumar et al., 2025).

See Figure 32 for an overview of the key development in the evolution of cineplasty.

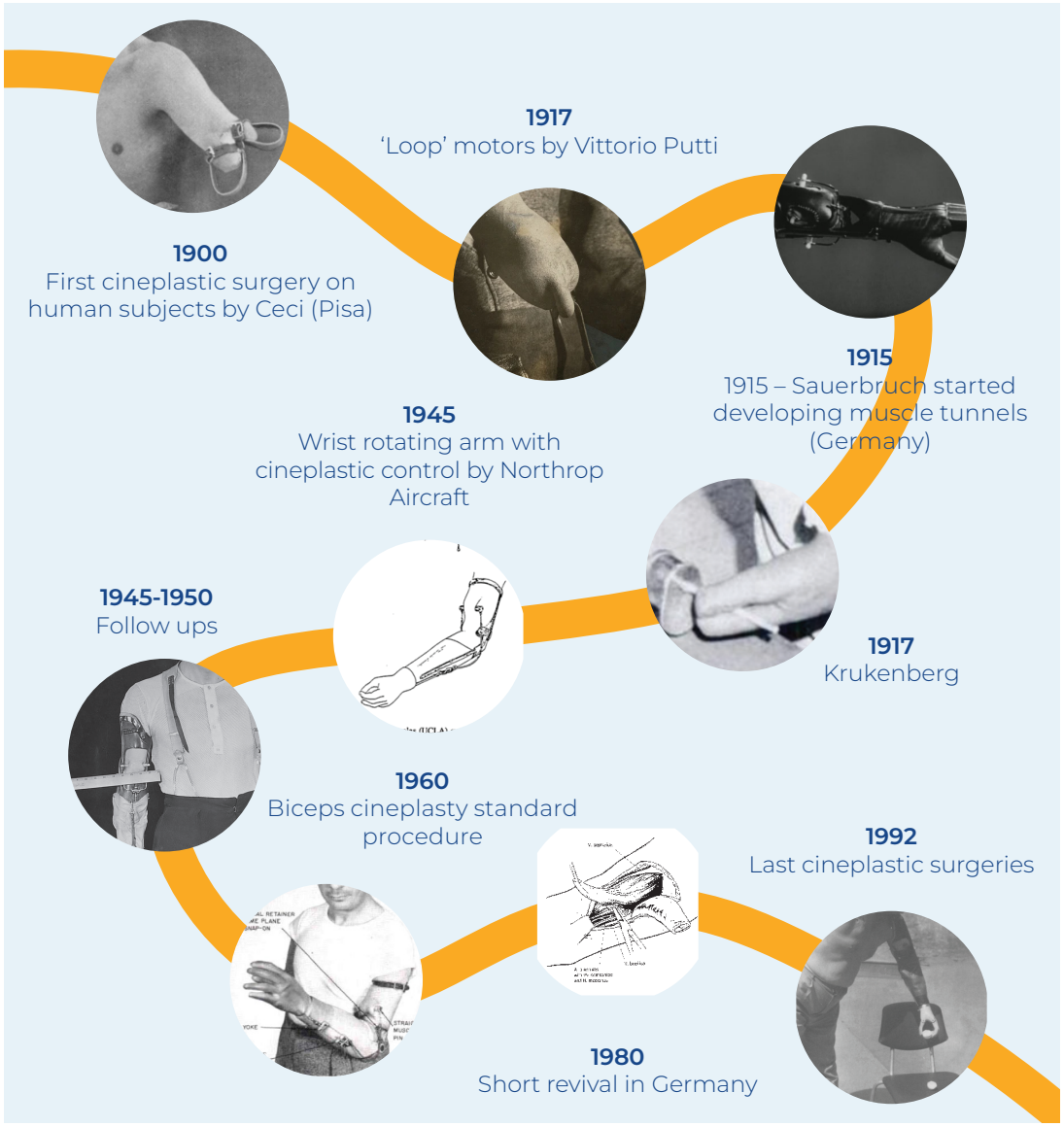


Figure 32. Timeline of cineplastic developments

2.6.2 Future directions of cineplasty

Cineplasty in its original form is not perforemed anymore nowadays. However, some researchers used the principle of cineplasty in the contemporary context. Some of the main developments concerning modern cineplasty are presented.

A recent study by Nambu et al. (2014) tested a simplified form of cineplasty by creating a pseudo cineplasty: the palmaris longus tendon of a nondisabled participant was pierced with a small metal ring and mechanically linked to a prosthetic hand. Combined with **extended physiological proprioception** (EPP), this setup (see Figure 33) allowed the user to feel tension changes from the prosthesis through their own tendon and skin receptors. In controlled experiments without visual feedback, the participant could distinguish between large and small objects with 100% accuracy, and between three object sizes with 80% accuracy, demonstrating that even this minimally invasive approach can provide meaningful, naturalistic sensory feedback.

Another advanced modern interpretation of cineplasty has been proposed in the form of **Biomechatronic EPP**, developed by Mablekos-Alexiou et al. (2015), Kontogiannopoulos et al. (2018, 2020) and Koukoulas et al. (2018). Instead of external tunnels or Bowden cables, this concept uses implanted leadscrew driven servomotors and force sensors connected to the remnant agonist–antagonist muscle pairs and anchored to the forearm bones. This setup enables bidirectional force feedback between the prosthesis and the user while relying on wireless communication and charging, thereby avoiding the dermatological complications of traditional cineplasty. Although still at the conceptual stage, it demonstrates how cineplasty principles can be integrated into a fully implanted, feedback rich control system—provided challenges such as safely coupling muscles to mechanical components can be solved (Grushko et al., 2019).

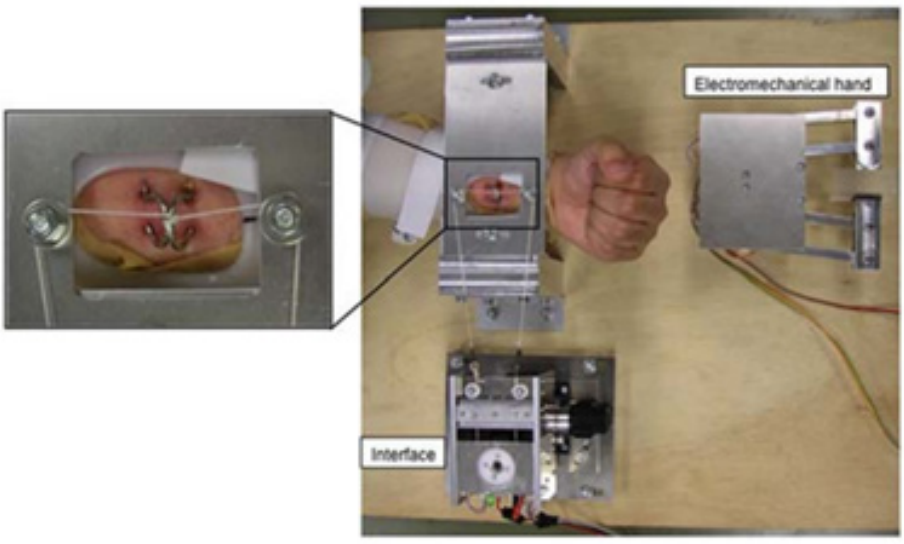


Figure 33. Pseudo cineplasty created by Nambu et al. (2014)

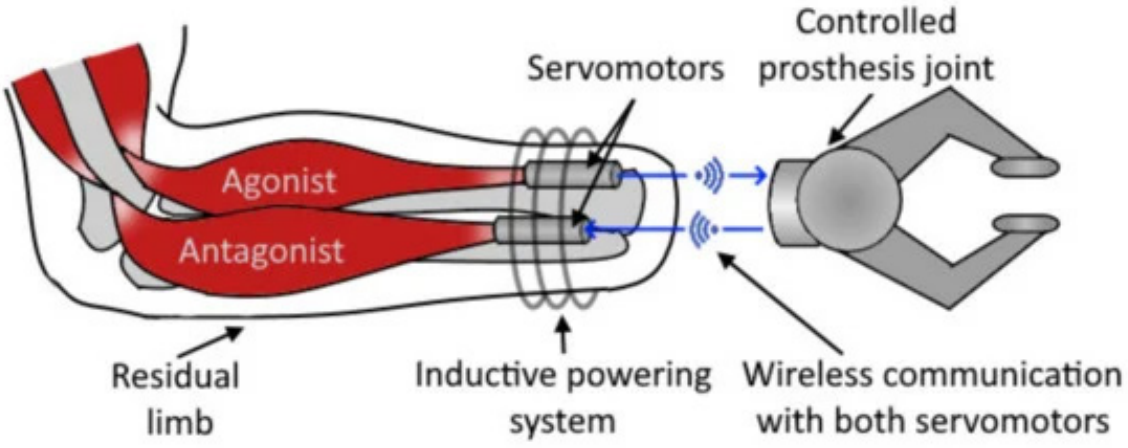


Figure 34. Biomechatronic EPP (Grushko et al., 2019)

The **myokinetic control interface** (MYKI) approach, a concept proposed by Tarantino et al. (2017) uses small implanted magnetic markers whose position shifts with muscle deformation. By tracking these markers with external three axis magnetic sensors in the prosthetic socket, the system can infer both muscle force and joint position. Axial and radial changes in the muscle provide information about isotonic and isometric contractions, enabling proportional control of a prosthetic hand. Because this magnetic coupling allows force and position signals to be transmitted back through the user's own proprioceptors, MYKI represents a contact less, cineplasty inspired interface. Ongoing work focuses on improving marker localisation, reducing magnetic interference, and ensuring the safety and biocompatibility of implanted magnets (Grushko et al., 2019).

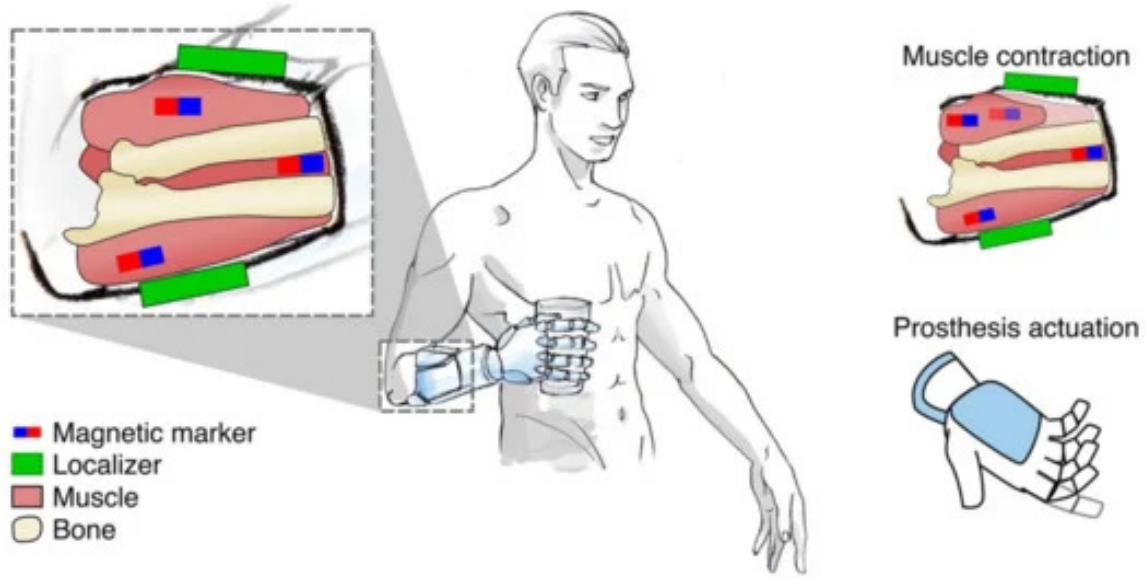


Figure 35. The myokinetic control interface (MYKI) approach (Grushko et al., 2019)

2.6.2 Lacune in literature

When searching for literature, the structure of a **scoping review** was used (Pollock et al., 2024). In the information provided above, multiple references outside of this search (n=20) were used, since the number of results were limiting and acquiring information was the main purpose of this literature review. This in combination with the scope of the project, is why instead of a full scoping review, an abstract was written. See *Appendix B.IX* for the literature included and analysed in this research.

Background Cineplasty is a technique where a rod through the biceps controls a prosthetic hand mechanically. In order to identify whether this procedure has potential in the contemporary prosthesiology, research was conducted.
Objective This scoping review aims to provide an overview of types of evidence regarding the evolution of cineplasty in upper limb prosthetic care, identifying its opportunities and limitations.
Design PubMed, Scopus and Web of Science online databases were searched for articles that report on cineplastic prosthetics in the upper extremity, of which 13 were included, see Figure 36 for the flow diagram of the article selection. Regarding the scope of this half year project, the search was focused on the mentioning of cineplasty, upper limb and prosthetics in the title abstract and keywords, see *Appendix B.IX* for the exact search terms.
Results The articles selected for the paper varied from 1948 till 2025, with a mean of 1964. Geological origin covered Europe (n=5), America (n=5), Oceania (n=1) and Asia (n=2), with most articles from the United States of America and Germany. Level of evidence varied from 5 to 3, with a mean of 5. 62% of the studies concerned patients, with a total of 322 patients, of which 156 tunnel cineplasties were performed. Most studies were analytic studies (62%), of which 2 experimental and 5 observational. The rest (38%) were descriptive studies, of which 2 were survey and 3 qualitative, based on the study designs overview from University of Oxford (2026).
Conclusion These findings demonstrates **a clear gap in the contemporary literature** on cineplasty. Because the technique was primarily developed and studied between 1900 and 1960, most available publications are historically dated, and limited recent work exists. Access to several older sources was restricted, further narrowing the evidence base. The studies that were available were predominantly conducted in the United States and Germany, involved small and often homogeneous populations -frequently healthy male subjects- and generally provided low levels of evidence. Although the included studies span a wide range of study designs, the small number of available studies raises concerns about whether the findings can be considered representative. Taken together, these factors indicate that cineplasty remains underexplored in modern research, confirming a substantial gap in the current scientific literature.

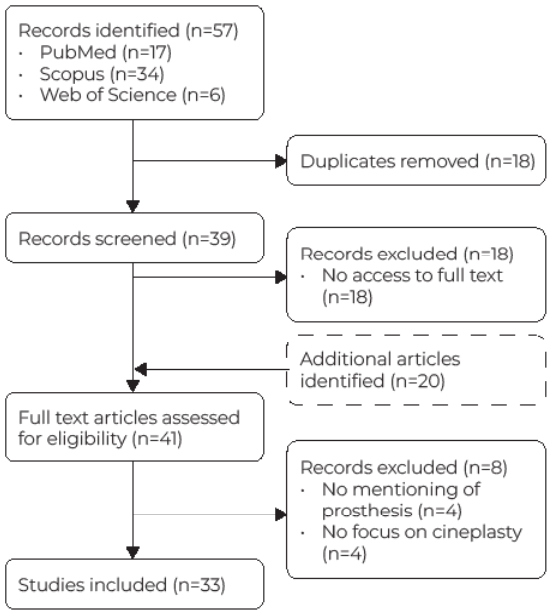


Figure 36. Flow diagram of article selection

2.6.3 Findings from experts



Users

To provide a comprehensive view on this dated concept, experts from different fields were interviewed on the concept of cineplasty with help of a semi-structured interview technique (DeJonckheere & Vaughn, 2019). Experts were approached via supervisors' network, personal network and the community of 'KorterMaarKrachtig'. Experts from the medical field (orthopedic surgeons, plastic surgeons, rehabilitation physicians and ergotherapists), the field of prostheses (prosthetists), and prosthetic users were included. Questions about their experiences in their field of expertise were asked, in combination with questions about cineplasty (see *Appendix B.X and B.XI*). Their educated assumptions were based on their expertise, which helped to gain better insights on the challenges and opportunities within the field of cineplasty in the contemporary society. Next to interviews, research has been conducted by joining orthopedic consultation hours at RHOC, and Hand and Pols Centre in The Hague, analysing values of patients with hand complaints. Besides, knowledge about the practical side of prostheses is gained by by observing the elements of identifying the patients request for help, prosthetics fitting, and finally the production of a prostheses at de Hoogstraat (Utrecht) and Rijndam Orthopedietechniek (Rotterdam), see *Appendix B.XII*.

Prosthesis users

Although patients are in need of medical assistance, every patient remains a person with individual needs and limits. It is important to listen to them, to give them the feeling that they are being heard, and to take their concerns seriously (P2, P3). Above all, patients express a **strong desire to remain independent** (visiting HPC, visiting RHOIC, P1, C10). As one prosthetic user explained: "When I do not have my prosthetic arm (myoelectric), I have to ask for help and feel handicapped" (U1). Independence is closely tied to everyday activities such as driving or cycling, and both users emphasised how essential their devices are for daily life. A prosthesis user described missing the prosthesis whenever it was broken or not worn, noting that even small tasks like tying shoelaces became impossible without it (U1). Another prosthesis user echoed this sense of dependency, explaining that without a prosthesis cycling was no longer possible (C2). In both cases, the prosthesis is not just a medical aid but a **crucial enabler of autonomy in everyday life**.

Comfort and appearance emerged as shared concerns, though expressed differently. All users (female) expressed **appearance** of their prosthesis to be the **most important factor** (U1, U2, U3). The realistic aspect of their prostheses was valued because it blended in naturally, reducing unwanted attention. They both graded diversity in movements as least important aspect, which left durability and control in second place. Together, these perspectives underline that prosthesis design must balance physical comfort with social acceptability.

Functionality was another common theme. Both users identified grasping as the most important movement, yet they also acknowledged limitations. One often relied on her natural hand for tasks requiring strong grip (U1), since myoelectric control was less effective. U2 (in use of a cosmetical prosthesis) recognised the practical importance of grip but resisted solutions that would visibly alter the arm, **preferring discretion over functionality**. This contrast shows how users weigh functional performance against aesthetic and personal identity considerations.


Clinical experts

When asked about cineplasty, both users offered nuanced views. U1 found the idea of a rod through the arm 'gruesome', yet admitted that the control might feel more intuitive and expected it to provide better feedback than myoelectric systems, especially for double amputees. U2 was more open to the concept of cineplasty, reasoning that living with a prosthesis already involves accepting a "foreign element" in the body, and therefore cineplasty could be a practical option - if not painful. She even suggested that, if younger (currently 80 years old), she **would maybe have chosen for cineplasy**, and believed it could fit within the current prosthetic landscape. Taken together, these perspectives reveal a tension: cineplasty's appearance may be off putting, but its promise of intuitive control and direct feedback resonates with users who value practicality and independence.

Clinical experts

Questions were developed in cooperation with a medical expert in training (W. Heeringa) and an experienced clinical expert working in practice (G.Kraan).
When talking to medical experts (rehabilitation physicians (n=3), orthopedic surgeons (n=2) and plastic surgeons (n=3), it was found that comfort is seen as an important factor for prosthesis acceptance, since patients will not use a device that feels uncomfortable (C1, Biddiss & Chau, 2007). While cosmetic concerns are acknowledged, experts emphasise that functionality outweighs appearance, with a clinical expert stating that "a well functioning prosthesis is more important than the cosmetic aspect" (C1, C2, C5). Feedback is consistently highlighted as a critical advantage of cineplasty, as it allows patients to experience a more natural sense of control compared to conventional systems (C1, C2, C3, C4, C5). Current prosthesis practice struggles to provide sufficient feedback, making cineplasty's potential contribution especially relevant (C1, C3, C4). With its main function of grasping - rehabilitation physicians confirmed that the grasping function is the most important function in daily activities – the cineplastic prosthesis could be of great value to prosthetic users (C1, C2, P1, P2, P3). When asking about intuitively of control via the biceps, doctors note that the brain's plasticity enables patients to adapt impressively when muscles are regularly engaged (C1, C4). Cineplasty could therefore offer extended physiological proprioception, restoring sensibility in ways that are particularly valuable for patients with limited vision or blindness (C2).

However, there are some drawbacks of this technique. The condition of the residual limb is considered a major limiting factor, as cineplasty requires stumps of sufficient length and quality tissue to succeed (C1, C2, Weir, 1995). Besides, maintaining the elbow function is considered essential, as it directly benefits grasping ability and overall prosthetic performance (C6). When these indications are met, the surgery is expected to still impose some risks, including:

- The possiblity of infection (C1, C2, C3, C4, C5, C6, C7, C8).
- Tunnel contraction (C1, C6, C8)
- Muscle atrophy due to damage to the muscle (C2, C5, C6).
- Shortening of the biceps muscle, which can complicate wound healing.
- Moreover, the surgeon should be alert for possible nerve damage (C3, C5, C6).
- Skin transplantation donor sites often take longer to heal and can be more painful than the surgery itself (C2, C8).
- Finally, pressure ulcers in the tunnel with frequent prosthesis use is an additional concern of the cineplastic method (C6).



Prosthetists

Another important aspect of the surgery is of course **cosmetics**. Cosmetic outcomes are generally regarded as modest, with divergent views. One clinical expert (plastic surgeon) argued that the surgery would create such an unattractive wound that it would not be accepted in modern practice (C8). Another clinical expert (also plastic surgeon) grading the result as "medium" and noting that amputation itself already reduces the arm's cosmetics (C6). Suggestions to improve appearance include:

- Locating the tunnel deeper in the arm, though transformation of the biceps shape remains difficult to manage (C5).
- Making use of implants (C6, C7).
- Permanently integrate the rod in the muscle biceps, preventing the need of the arm to be opened up (C2).

Despite these drawbacks, cineplasty is **valued for its simplicity** compared to more complex procedures such as TMR or TSR, with shorter surgery times and lower costs (C1). The surgery itself is described as 'simple to average' by 100% of the clinical experts, expecting it to take about 45-60 minutes (C1, C2, C4, C5, C6, C7), which could be confirmed by Gillis (1948) and Spittler & Woodard (1953). Several doctors see potential for cineplasty as a l**ow budget option** in developing countries, where access to advanced prosthetic technology is limited (C2, C5, C6).
In conclusion, the findings show that cineplasty is appreciated for its ability to provide feedback and proprioception, its relative simplicity, and its potential as a low budget solution. At the same time, condition of the residual limb remains a decisive factor for success. Risks such as tunnel contraction, nerve damage, and cosmetic limitations temper enthusiasm. Finally, the aspect of cosmetics is a big point of discussion. There evidently is a trade-off between function and appearance, and it is the goal achieve highest results for both factors.

Prothetists

The prosthetists interviewed share a common recognition that cineplasty is a technique with **limited but specific potential,** yet they approach its value from different angles. At Rijndam, prosthetists emphasised that cineplasty historically offered more freedom than suspension systems, but today patients expect advanced functionality and cosmetic acceptability, which myoelectric and osseointegration techniques are better able to provide (P2, P3). This concern about **patient expectations** is echoed by another prosthetist, who noted that grasping and arm length compensation are the most important priorities for users, and that cineplasty, as a concept, does not seem 'pleasant' compared to modern alternatives (P4).
Both perspectives highlight the gap between cineplasty's simplicity and patients' desire for sophistication. While P1 and P2 pointed out that cineplasty only enables basic hand opening and closing, P4 stressed that younger patients, particularly military users, quickly adapt to myoelectric prostheses and would find cineplasty insufficient. In this sense, both agree that cineplasty **struggles to meet contemporary expectations** for multi-articulated, cosmetically acceptable devices.

At the same time, both groups acknowledged unique advantages of cineplasty. Cineplastic prostheses' **mechanical robustness** (P2, P3, P4) and direct feedback in the biceps is valued, since current prostheses provide limited feedback (P2, P3, P4, P5). They expect cineplasty's direct sensation of movement could fill this gap. They also converge on the idea that cineplasty could reduce

reliance on harnessing, which is often uncomfortable and physically demanding, especially in warm climates (P1, P2, P4).

Where they differ is in their outlook on feasibility. P1 and P2 described cineplasty as technically possible but **constrained by muscle strength and cosmetic drawbacks**, whereas P4 emphasised the practical barriers of involving surgery, longer rehabilitation, and risks such as biceps atrophy. Yet both perspectives converge in seeing developing countries as a potential niche: P1 and P2 suggested cineplasty could be a simple, durable solution, and P4 reinforced this by noting its robustness, low maintenance, and lack of electronics.

Together, the prosthetists portray cineplasty as a technique caught between simplicity and durability on one hand, and modern expectations of functionality and aesthetics on the other. They agree that cineplasty's direct feedback, robustness and elimination of harnessing are meaningful advantages, but also that its cosmetic limitations, surgical demands, and restricted functionality make it unlikely to replace current technologies in mainstream practice. Instead, they see its potential in specific niches — particularly in **resource-limited contexts** where robustness and low maintenance outweigh the demand for advanced, multi-articulated prostheses.

All in all, the findings of these interviews show that cineplasty occupies a complex position within contemporary prosthetic care: valued for its intuitive control and proprioceptive feedback, yet constrained by cosmetic concerns, surgical risks, and strict anatomical requirements. Across medical experts, prosthetists, and users, feedback consistently emerged as cineplasty's most compelling advantage, particularly in comparison to current systems that still struggle to provide meaningful sensory input. At the same time, expectations regarding cosmetics, comfort and multifunctionality have evolved to a point where cineplasty no longer aligns with mainstream prosthetic priorities. The perspectives gathered also highlight that its potential may lie in highly specific contexts—such as low resource settings*—rather than broad clinical application. It is important to remain critical on this assumption, since in order to succeed, surgical experts have to be available, and the materials should be provided. It should be noted that this process takes quite some time, which rises a new challenge in this context.

Taken together, cineplasty's relevance in modern practice remains limited and highly situational, where the major advantage of the feedback offers a unique functional benefit. The question is whether this advantage is able to overcome the gap between functionality and patient expectations, mainly regarding cosmetics.

Conclusion

Cineplasty has undergone more than a century of development, shaped by surgical innovation, engineering advances, and shifting prosthetic technologies. From Vanghetti's early vision of linking residual muscles directly to prosthetic mechanisms to Sauerbruch's refinement of muscle tunnels and the later standardisation of biceps cineplasty, the technique demonstrated both remarkable potential and persistent limitations.

Throughout the 20th century, cineplasty offered unique advantages -particularly natural proprioceptive feedback, freedom from harnessing, and precise control- yet its clinical success remained highly dependent on surgical expertise, prosthetic design, and patient motivation. Despite periods of renewed interest, especially in Germany and the United States, complications, inconsistent outcomes, and the lack of well developed prosthetic interfaces hindered widespread adoption. The **rise of myoelectric prostheses**, with their superior aesthetics and non invasive control, ultimately accelerated cineplasty's decline and contributed to the loss of institutional knowledge as experienced surgeons retired.

Nevertheless, the core principles of cineplasty: **direct muscle coupling, intuitive control, and sensory feedback,** continue to inspire modern research. Contemporary approaches such as pseudo cineplasty, tendon linked sensors, biomechatronic EPP systems, and myokinetic interfaces demonstrate that Vanghetti's foundational idea remains relevant. Although traditional cineplasty is no longer practiced, its remarkable **advantage of maintained proprioception** will be remembered.

A scoping review revealed that only a small and historically dated body of literature on cineplasty exists, with most studies originating from the mid-20th century and offering low levels of evidence. The limited number of accessible publications, combined with restricted access to older sources and predominantly homogeneous study populations, further narrows the reliability and representativeness of current findings. Overall, cineplasty remains **significantly underexplored** in contemporary research, confirming a substantial gap in the modern scientific literature.

Interviews conducted with experts lead to the conclusion that **cineplasty's relevance in modern practice remains limited** and highly situational. Feedback is identified as a unique and functional benefit. The gap between functionality and patient expectations, mainly regarding cosmetics, remains the biggest challenge.

Cineplasty's long history shows both its unique strengths (intuitive control and preserved proprioception) and the practical limitations that prevented widespread adoption. Although modern expert insights confirm that its relevance today is highly situational and challenged by cosmetic expectations, the technique's core principles continue to highlight an important gap and opportunity in contemporary prosthetic research.

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Conclusion

The Discover phase reveals that cineplasty occupies a unique position within the landscape of upper-limb prosthetics. By examining the technique through the lenses of desirability, feasibility, and viability, the chapter uncovers both its potential and its limitations, and clarifies the direction for the remainder of the project.

From a desirability perspective, the exploration shows that cineplasty offers something rare in prosthetic control: a direct mechanical link between muscle contraction and prosthetic movement that **preserves natural proprioceptive feedback**. This stands in contrast to modern prosthetic systems, which often struggle to replicate intuitive sensation and require users to rely heavily on vision. The use case of the long-term cineplasty user illustrates that, despite its age, the technique can remain functional, intuitive, and low-maintenance in daily life. Although this example represents a single case, it demonstrates that cineplasty can deliver durable value when aligned with user needs and expectations.

Understanding desirability also required a deeper look at the impact of amputation, the loss of range of motion, and the challenges of rehabilitation. These insights highlight the complexity of restoring hand function and the importance of intuitive control strategies. The analysis of proprioception further strengthens the relevance of cineplasty: while modern research explores neural interfaces, sensory substitution, and artificial proprioception, these methods remain technically demanding and often indirect. Cineplasty, by contrast, leverages the body's existing sensory pathways without requiring electronics or neural implants.

The viability analysis shows that cineplasty must be positioned within a competitive prosthetic market that includes cosmetic, body-powered, and myoelectric devices. Each category has strengths and limitations: body-powered systems are robust but physically demanding; myoelectric prostheses offer advanced functionality but are heavy, maintenance-intensive, and costly. Cineplasty's mechanical **simplicity** and intrinsic feedback could fill a gap for users who prioritise **reliability** and intuitive control, provided that its **cosmetic and surgical drawbacks** can be addressed.

The feasibility assessment, supported by extensive literature and expert consultation, reveals both opportunities and constraints. Historically, cineplasty fell out of use due to aesthetic concerns, and the need for surgical experience, compared to the rising availability of myoelectric alternatives. However, modern surgical techniques, improved materials, and a clearer understanding of user needs may allow for a renewed interpretation of the method. At the same time, the Discover phase identifies important risks: cosmetic disadvantages, loss of biceps flexion strength, limited movement options due to a single muscle tunnel,

and the need for careful postoperative rehabilitation. The somewhat inconsistent outcomes in historical sources and the scarcity of recent clinical studies further underline a **significant lacune in the literature**, which makes contemporary investigation both necessary and valuable. These factors must be considered in any redesign.

A central outcome of this chapter is the recognition that stakeholder involvement is essential. Through interviews with prosthesis users, rehabilitation physicians, surgeons, prosthetists, and therapists, the project gains a nuanced understanding of **clinical feasibility, user priorities, and practical constraints**. Their insights form the backbone of the project's human-centred approach, ensuring that the exploration of cineplasty is grounded in real-world experience rather than theoretical assumptions. These perspectives will guide the formulation of requirements and shape the direction of the design phase.

In conclusion, the Discover phase establishes cineplasty as a historically grounded yet forward-looking technique with distinctive potential in modern prosthetics. While not without limitations, its ability to preserve natural proprioception and provide robust, intuitive control makes it a compelling candidate for further development. Yet the lack of contemporary evidence highlight the need for renewed research to determine whether its advantages outweigh its cosmetic and experiential drawbacks for today's users. The insights gathered here—technical, clinical, and experiential—lay the foundation for the Define and Develop phases, where the project will translate these findings into concrete design criteria and explore how cineplasty can be reimagined for contemporary use.

3. Define

Following the exploratory work of the Discover phase, the Define chapter consolidates the insights needed to establish a clear direction for the design process. This chapter examines the potential role of cineplasty within contemporary prosthetic care, by identifying the target group most likely to benefit from the technique, and outlining its key opportunities and limitations. By positioning cineplasty in relation to current prosthetic alternatives, the chapter states the core challenges that must be addressed and formulates a precise problem definition and design goal. These insights are then translated into a structured set of requirements, criteria, and practical design considerations that guide the subsequent Develop phase.

3.1 The role of cineplasty in the current prosthetics
3.2 Design direction
Conclusion

3.1 The role of cineplasty in the current prostheses

In this part, the role of cineplasty in the contemporary society will be sketched, by introducing the target group that could benefit most from this technique, providing an overview of cineplasty's opportunities and limitations and finally present the position of cineplasty compared to alternatives currently accessible for prosthetic users.

3.1.1 Target group

Findings from both the literature and expert consultations suggest that cineplasty may be most suitable for a clearly defined subgroup of prosthetic users. Given its limited cosmetic acceptability and the potentially mutilating appearance of the cineplastic tunnel, the technique appears more appropriate for individuals who have undergone an amputation rather than those with congenital limb deficiencies, whose musculature is often underdeveloped (U1, C2). Cosmetic considerations further indicate that **male patients** may be more inclined to accept the aesthetic consequences of the procedure (C4). In terms of age, **younger individuals** may represent a more favourable target group due to greater learning capacity and typically stronger muscle mass (P4). Cineplasty's preservation of proprioceptive feedback is particularly relevant for users with limited vision (Gillis, 1948; Kumar et al., 2025; C2) and for **bilateral amputees**, who lack a contralateral limb to compensate for reduced sensory input (U1). In such cases, cineplasty could even replace the mechanically controlled prosthesis (main function: feedback) commonly provided alongside a myoelectric device (main functions: force and motion diversity) in the United States, offering enhanced proprioceptive feedback and precision control (Hueston, 1959; Weir, 1995). Finally, successful application of the technique requires a clearly functional muscle belly with sufficient excursion (1.5 inch) and force generation (15 lbs) (Hueston, 1959).

Finally, limb amputations are rare and more common in the **military field** (Segura et al., 2024; Tropea et al., 2017; Weir, 1995). The assumption is made that military people are more likely to accept the cosmetic outcomes of cineplasty if the system is of high quality: **robust and functional**. Contact was initiated with the Military Rehabilitation Centre in Doorn, however within the time limit of this project it was not possible to set up interviews with (ex)soldiers. So unfortunately, it was not confirmed whether the assumption was correct.

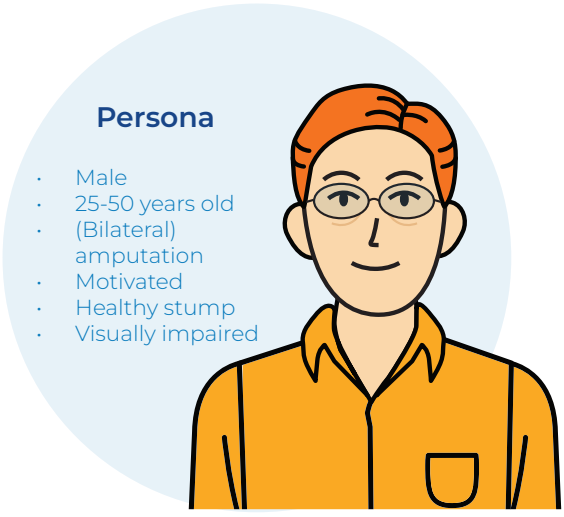


Figure 37. Persona of the target group

3.1.2 An overview of cineplasty's opportunities and limitations

Advantages of cineplasty

- Direct and **intuitive control**, as the muscle itself drives the prosthesis (Weir, 1995; C1, C2)
- Natural **proprioceptive feedback**, consistently identified as one of the greatest strengths (Brückner, 1992; Hueston, 1959; Weir, 1995; C1,C4).
- More **precision control** (Hueston, 1959; C2).
- Freedom from restrictive harnessing, increasing comfort and mobility (Brückner, 1992; Hueston, 1959; Weir, 1995; P1, P2, P4).
- **Mechanically robust and low maintenance**, suitable for intensive use and low resource settings (Hueston, 1959; Weir, 1995; P2, P3, P4, P5).
- Relatively simple and short surgical procedure (Gillis, 1948; Spittler & Woodard, 1953; C1, C2, C4, C5, C6).
- Lower costs compared to modern techniques focusing on regaining propioceptive feedback like TMR/TSR and advanced myoelectric systems (C1, C7).
- **Affordable** prosthesis, especially compared to myoelectric devices (Weir, 1995; *Chapter 2.5.3*)
- High **durability**, since less vulnerable components, change of stump has no influence on control (U3, C1, P1, U3)
- **Consistency and reliability**: no delay (C1, C3, P2, P3)
- Unaffected by electromagnetic interference, unlike myoelectric devices (C1, C2, C3, P2, P3, P4, P5).
- **Lighter** than myoelectric systems, improving usability (C1, C2, P5).
- Broader range of motion than body-powered: **independent of arm position** (Hueston, 1959; Weir et al., 2001; C1, C7)
- No extra physical load (on healthy side) (P1, C1, C9)
- Option to go back to other prosthesis (myo/body-powered/cosmetic) remains possible.

Disadvantages of cineplasty

- **Poor cosmetic appearance**: rod visible and alteration of biceps contour, does not meet modern expectations for aesthetics and multifunctionality (C1-C8, P1–4).
- **Need for surgery** (C1-C9, P1-P5, U1)
- Surgical risks and medical limitations (Brav et al., 1964; C1-C8):
  - Risk of infection, tunnel contraction, and skin complications.
  - **Risk of muscle atrophy** and shortening, especially of the biceps.
  - Risk of nerve injury.
  - Skin graft donor sites heal slowly and can be painful.
  - Pressure ulcers within the tunnel during frequent use.
- **Strict anatomical requirements**, including a clearly palpable muscle belly, at least 1.5 inches of excursion, and 15 lbs of force. Insufficient force or excursion in some cases (Spittler & Woodard, 1953; Weir, 1995).
- **Limited functionality** compared to modern multi-articulating prosthetic hands (Weir, 1995; C1, C2, C6).
- Lack of well developed prosthetic interfaces specifically designed for cineplasty, more so compared with current prosthesis offer (Spittler & Woodard, 1953; Weir, 1995).
- Conflicting outcomes of follow ups (Brav et al., 1957, Weir et al., 1995).
- **Lower acceptance rates** than conventional prostheses (62% vs. 82%) (Brav et al., 1957).
- **Longer rehabilitation** and training, especially for coordinated agonist–antagonist control (Weir, 1995).
- Need for **daily hygene** (Hueston, 1959; Weir, 1995).

3.1.3 The position of cineplasty compared to current alternatives

After a brief explanation and comparison of the prosthetics currently on the market in *Chapter 2.5.3*, it is now time to add cineplasty in this comparison, see Figure 38. The functions are derived from the literature review and interviews with experts, and are ordered on importance.

The primary reasons individuals use prosthetic devices relate to **comfort, function, feedback, and cosmetics** (Biddiss & Chau, 2007; Smit, 2020). Comfort is consistently rated as the most important factor, and cineplasty offers clear advantages in this regard through its low weight and intuitive control. Feedback is the next key consideration, followed by cosmetic appearance, which remains essential for ensuring users to be willing to use the device. Functional aspects such as precision, strength, and movement diversity are valued, although experts and users generally regard precision as more important than the breadth of available movements (U1, U2, C1, C2). Cineplastic control, particularly when combined with a Hüfner hand, enables a wider range of motion and greater precision than traditional shoulder powered systems (Smit, 2020; Hueston, 1959). In terms of strength, Smit (2020) notes that the maximum forces generated through a cineplastic muscle tunnel are comparable to (/slightly lower than) those achieved with other mechanically powered prostheses using shoulder straps. As advanced prosthetic technologies continue to compete on cost effectiveness, functionality, and quality of life (Kumar et al., 2025), cineplasty can occupy a meaningful position within contemporary prosthetic care, as illustrated in the Figure below.

Cineplasty mainly scores low on cosmetics and diversity of functions, however, the latter was mentioned not to be of great value for as well prosthetic experts as prosthetic users, with which we can conclude that **cosmetics is identified as the main challenge** when implementing cineplasty in the contemporary society.

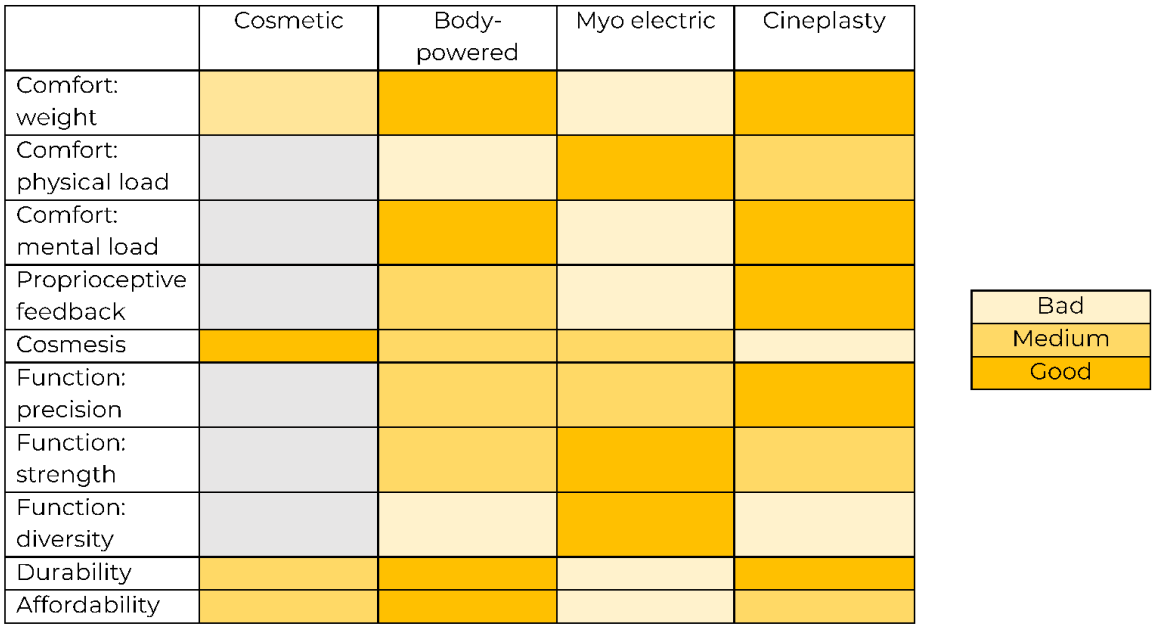


Figure 38. Overview of types of prostheses including cineplasty

3.2 Design direction

The design direction will be defined by presenting the new scope, stating the problem and goal and presenting the list of requirements and criteria

3.2.1 Scope adaptation

Findings from research and experts guide to narrow down the scope, where the terminal device falls out of scope since these are already diversely on the market (P5) and would be a whole project on itself to focus on, see *Appendix C.I* for a consultation with a mechanical expert that helped make the decision.

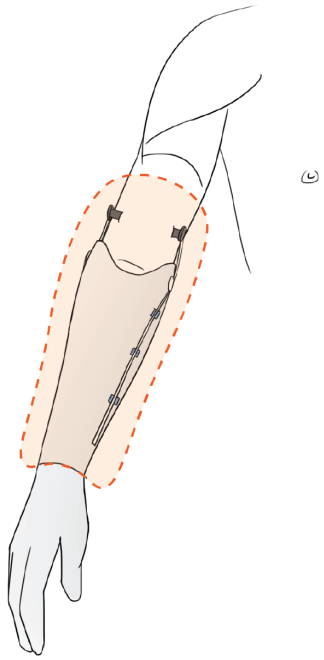


Figure 39. Scope adaptation

3.2.2 Problem definition

With all findings from research can be concluded that the problem of this scope is defined as follows:

Current prosthetic options lack the unique proprioceptive advantages of cineplastic prostheses, but cineplasty's poor cosmesis of as well the surgery as the prosthesis present the problem of whether cineplasty can effectively overcome these drawbacks and make the system viable for contemporary users, with the well-functioning alternatives in mind.

3.2.3 Design goal

Now that the problem is identified, the design goal can be reformulated.

Design a prototype based on the principle of cineplasty that perseveres the natural proprioceptive feedback and overcomes its original cosmetic challenges, to validate whether cineplasty is desireable for male (bilateral) lower arm amputees of age 25-50 in the contemporary society.

Focusing on improving the surgery technique and the prosthesis, creating a smooth connection from prosthesis to patient.

Design direction

3.2.3 Initial List of Requirements

This list acts as a **directive** while generating, developing and analying concepts based on the principle of cineplasty. This list is a **dynamic document**. Future findings could lead to adaptations of this list. That is why this list is not a solid given, but a basis for the first rounds of iterations.

Requirements are elements that the product must have and that can be tested, otherwise the product has failed. Criteria are aspects that would improve the concept, but are not required (van Boeijen et al., 2013; Roozenburg & Eekels, 2016). See *Appendix C.II* for the complete based on the findings at this point of the project.

Furthermore, conversations from experts in combination with literature lead to a list of general Design tips for designing a prosthesis, see *Appendix C.III*.

Requirements

Functional grasping performance
The prosthetic must enable a grasping motion with sufficient pinch force (>15 N) and opening range (>70 mm) to perform daily tasks (Smit, 2020; Blaschke & Taylor, 1953; Kumar et al., 2025).

Compatibility with biceps excursion
The prosthesis must function with 40 mm of biceps excursion (Hueston, 1959; Blaschke & Taylor, 1953).

Load-bearing capacity
The prosthesis and tunnel must withstand at least 1.4 kg (Blaschke & Taylor, 1953).

Daily usability
The prosthesis must remain connected for 8 hours and allow continuation of 80% of ADL activities.

Weight
The prosthesis must weigh <300 g (Belter & Dollar).

Skin-safe materials
Materials in contact with skin must not cause irritation, redness, or sweat-related discomfort (Hoogstraat; P3).

Durability and environmental resistance
The prosthesis must last ≥5 years, be water-resistant (IP68), and require ≤1 repair per year (P1; Hoogstraat).

Criteria

High-precision and low-discomfort control
The prosthesis should allow precise task execution with equal or less discomfort than average prostheses.

Natural muscle–function matching
The muscle used for control should match the prosthetic function (agonist) (Tropea et al., 2017).

Lightweight design
The prosthesis should be as light as possible.

Intuitive control and feedback
Control and feedback should feel intuitive and require minimal cognitive and physical load.

Ergonomic fit and interface
The prosthetic fit and control system should be experienced as ergonomic.

Natural appearance
The prosthesis should look natural, be available in the user's skin tone, and remain unnoticeable under clothing (U1, U2, U3).

Low cost and accessible production
The prosthesis should be affordable and ideally manufacturable or repairable in-house at orthopaedic centres.

Conclusion

The Define phase brings together the insights from the Discover phase and translates them into a clear design direction for a renewed interpretation of cineplasty. In doing so, it also identifies the user group most likely to benefit from the technique as motivated, generally younger male amputees with sufficient muscle mass, including bilateral or visually impaired users for whom proprioception is especially valuable. Across all analyses, one conclusion stands out: **proprioception remains cineplasty's most distinctive and valuable advantage**. This intrinsic feedback offers intuitive control, reduced cognitive load, and a sense of embodiment that users and experts repeatedly identify as highly valuable, which consistently differentiates the technique from contemporary prosthetic alternatives.

At the same time, cineplasty also carries several important disadvantages. These include the need for surgery, the associated medical risks, the loss of biceps flexion strength, strict anatomical requirements, limited functional diversity, and the longer rehabilitation period required to master coordinated control. These factors already narrow the potential user group and place clear constraints on feasibility.

However, among all disadvantages, cosmesis emerges as the most significant barrier. The **visible muscle tunnel, altered biceps contour, and overall aesthetic impact of the procedure strongly influence user acceptance**, especially in a prosthetic landscape where appearance plays a central role in daily use, identity, and social comfort. This creates a fundamental trade-off at the heart of cineplasty's contemporary relevance: its strongest functional benefit: natural proprioceptive feedback, is counterbalanced by its weakest experiential disadvantage: poor cosmetic appearance.

Finally, the chapter formulates a precise problem definition, a focused design goal, and a structured set of requirements and criteria. It is important to remain critical, and note that educated assumptions from experts and findings from (limited) literature form a basis for this list. Together, these elements establish a design direction aimed at **preserving cineplasty's unique proprioceptive advantage while directly addressing its cosmetic limitations**. This balance forms the core challenge for the Develop phase, where concepts and prototypes will explore how cineplasty can be reimagined to meet the expectations and needs of contemporary prosthetic users.

4. Develop

This chapter will show the development phase of the project. The reader will pass through several phases to find and create the best solution for the design problem. These phases are devided by ideation - conceptualisation - prototyping & testing and validation. Phases are in reality not linear, but continue in design processes a constant loop of iterations, as shown in the picture below (Roozenburg & Eekels, 2016).

This chapter mainly focuses in 2 iterations mainly on ideation and conceptualisation, where *Chapter 5* will include prototyping and validation in the third and final iteration. Three concepts will be presented and analysed with help of expert views, where the final design direction will be chosen.

4.1 First iteration: generating concepts
4.2 Second iteration: concept development
Conclusion

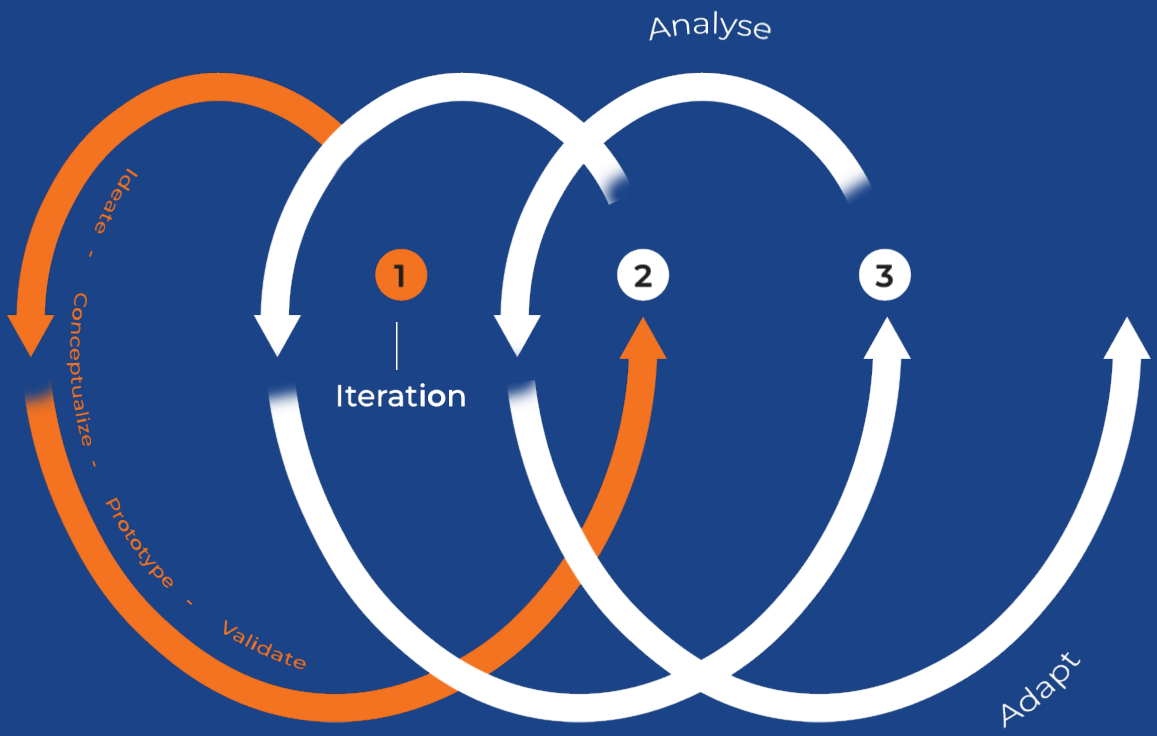


Figure 40. Design cycles

4.1 First iteration: generating concepts

In the ideation phase, the first step was to create a big quantity of ideas, where it later focuses on its quality. Multiple scientific methods from the Delft Design Guide were used to generate ideas, for example: WWWWH, How-Tos, brainstorming, brainwriting & drawing and a morphological chart was developed in order to generate concepts (van Boeijen et al., 2013).

4.1.1 Ideation

To start with the right questions to ideate with, the WWWWH method (Who, What (for), Where, When, Why, How) was used (van Boeijen et al., 2013). With help of this method, the problem definition was further examined and its results served as a foundation for questions for the 'How to' brainstorm (see *Appendix D.I* for the results of the WWWWH method). This resulted in the following How-To (H2) questions (Figure 41).

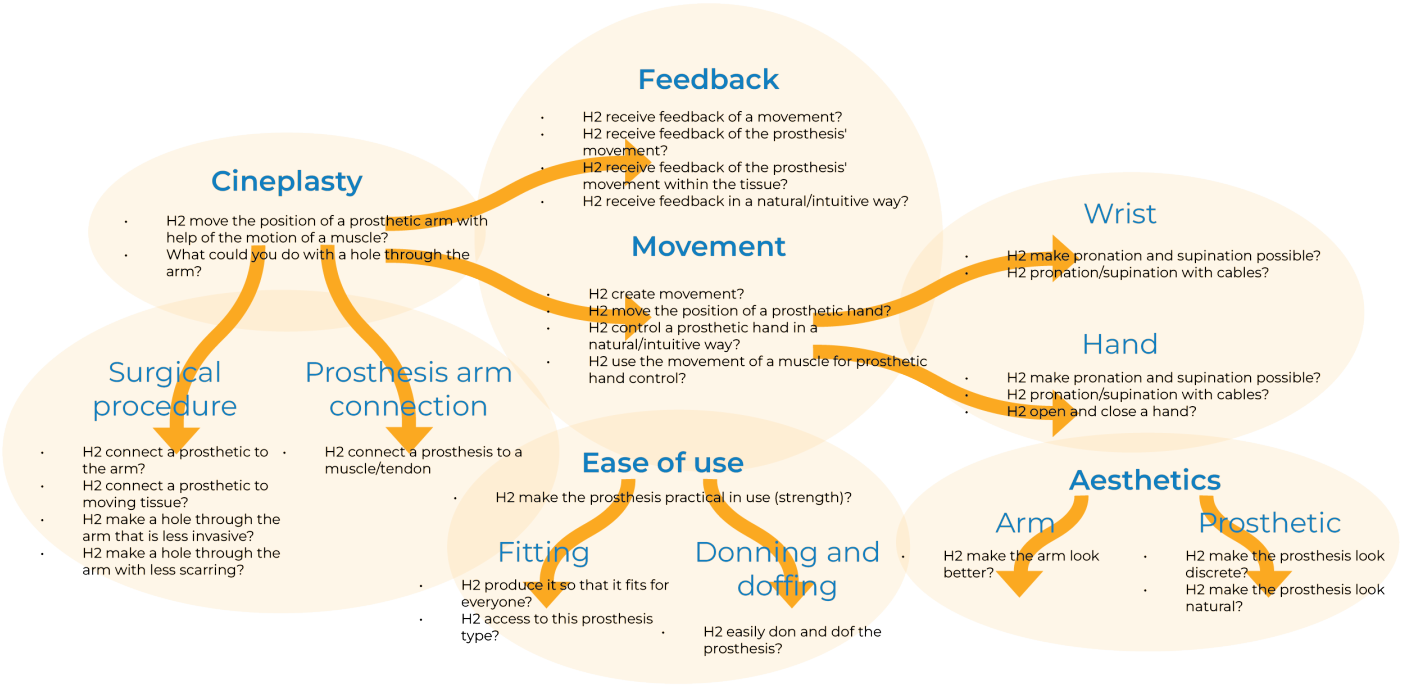


Figure 41. How to questions derived from the WWWWH method

Multiple brainstorm sessions were conducted in groups of 4 to 7 people (TU Delft students). Different techniques like brainstorming, brainwriting and mindmapping were executed (van Boeijen et al., 2013). Results of these sessions led to new ideas to generate further upon. Some interesting findings from these sessions and from literature which could have impressive applications in cineplasty are discussed.

Artificial muscles

Artificial muscles (shown in Figure 42) are a form of soft robotics inspired by the behaviour of natural muscle. Recent work introduced a 3D-printable soft actuator that works without bulky external equipment and can generate strong responsive movement: it shows a strain density of about fifteen times higher than a natural muscle, and is capable of lifting up to 1000 times its own weight (Yoder et al., 2024). Researchers at Columbia Engineering showed that combining a stretchy polymer with a material that expands when heated can create a simple, low-cost actuator that produces large, smooth movements using only electrical input. This approach avoids the high voltages, limited motion, or external compressors required by many traditional soft-actuation technologies (Miriyev, 2017).

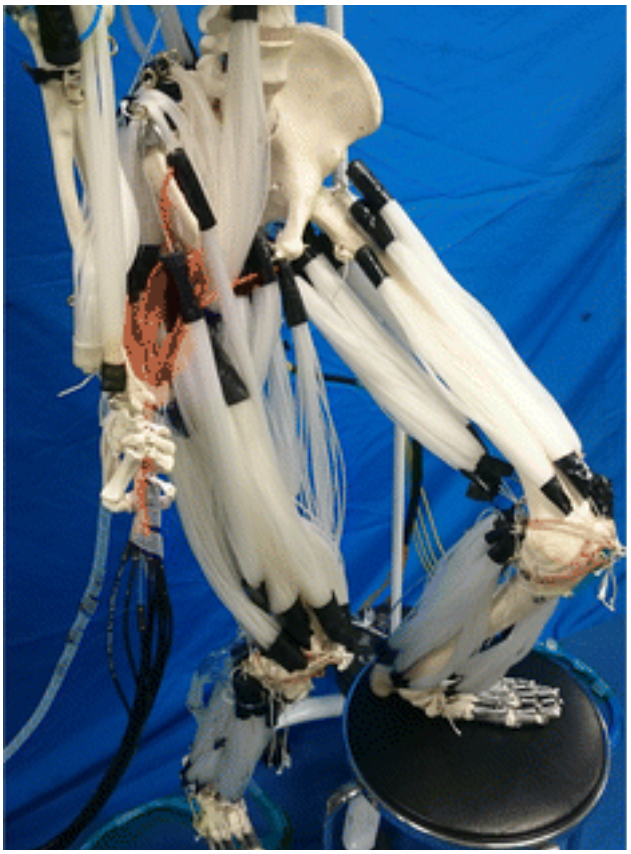


Figure 42. Artificial muscles by Kurumaya et al. (2016)

Magnets

It could be interesting to look into a magnetic connection between the muscle and the prosthesis (for example the myokinetic control interface (MYKI) by Grushko et al. (2019)), since this way a motion and feedback could be transferred without the presence of surgery. See Figure 43 for a sketch of this idea. Research done by De Boeck (2023) identifies a low boundary for magnets snapping together, which could cause for challenges when used in the human body.

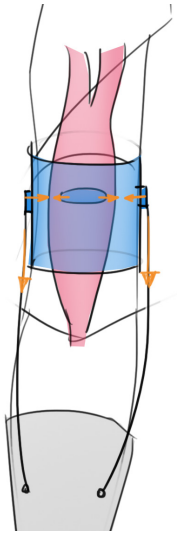


Figure 43. Force on magnets

Linear induction motor

There should be looked into the strength of different directions concerning the preferred prosthetic motion: magnets are strong in the direction of the poles, but they are not that persistent with forces perpendicular to this direction (Magnet Store, 2024). The concept of a linear induction motor could be a solution to this problem (NanoView Engineering, 2025).

Small cineplasties

Cineplasty has two functions: (1) controlling the prosthesis and (2) providing the user with feedback of this movement. Instead of completely executing the level of movement or feedback, small muscle tunnels or other procedures that externalise muscle force could be linked to prosthetic components that amplify this signal. Weir et al. (2001) presented the idea to use multiple forearm cineplasties to support independent finger control, while pectoral or deltoid cineplasties may enhance control options after higher-level amputations. A proof-of-concept electric hand demonstrated that such EPP-based systems can function effectively in practice, see Figure 44.

New surgery technique

The renewed surgery technique explained by Brückner et al. was presented in 1992, which is already over 30 years ago. By changing the surgery steps, orientation or measurements, the amount of skin transplant could be minimised which could lead to improved cosmetics.

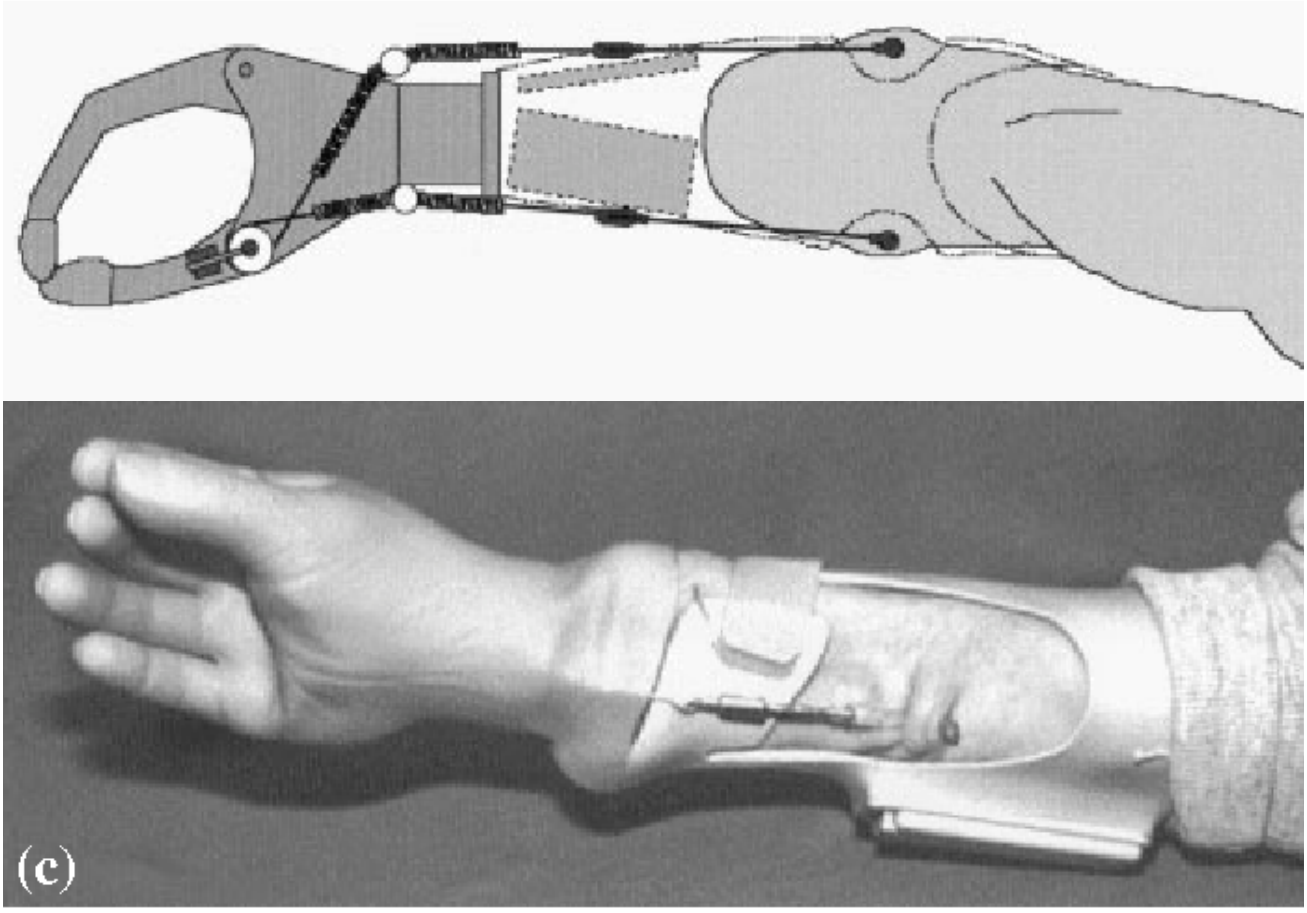


Figure 44. Small cineplasty in the lower wrist, including an amplifier in the prosthesis to strengthen the movement (Weir et al., 2001)

4.1.2 Conceptualisation

The generated ideas were analysed and selected based on it's potential and further developed into concepts with help of a morphological chart, where different solutions for several functions were found and combined. Three concepts will be presented.

The generated ideas were clustered to create an overview of the options, see Figure 45 for the clusters of the "How to control a prosthesis" (van Boeijen, 2013).

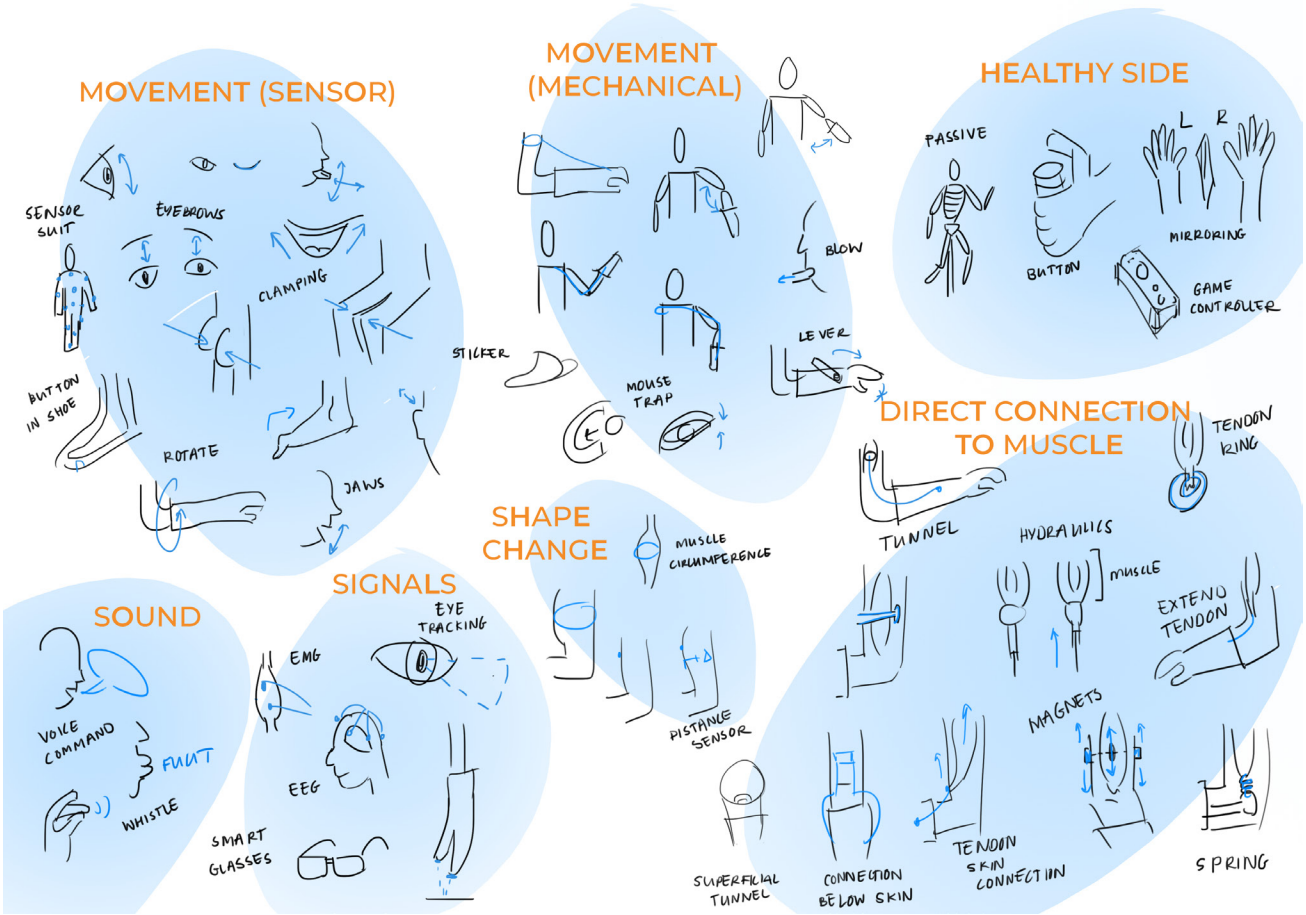


Figure 45. Cluster for ideas "How to control a prosthesis"

To identify which ideas were most promising, they were placed in C Boxes, axes were based on the List of Requirements and Criteria (*Chapter 3.2.3*) (van Boeijen, 2013). See *Appendix D.II* for C Boxes, with most promising ideas located in the upper right quadrant. These ideas are developed in further brainstorms and included in the Morphological Chart which are developed further into 3 concepts.

Some **preliminary tests** were done to check functionality and feasibility, see Figure 46. Strenght of magnets were checked in different directions and on different materials, including human tissue. In combination with literature research, preferences for partial solutions arose.

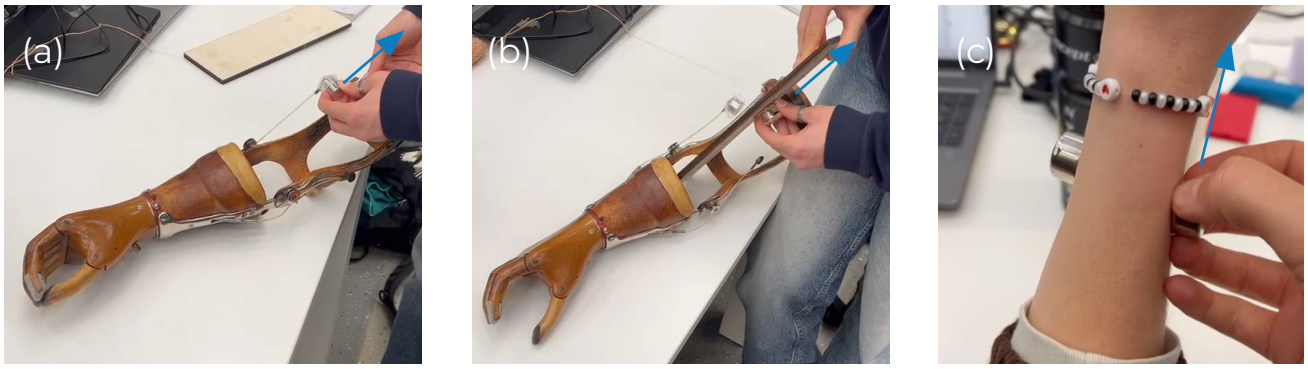


Figure 46. Testing magnetic behaviour with different materials

The magnets (neodynium) stayed connected when directly connected during pulling (a), but they were not strong enough in the pulling direction when a wooden plate of 1 cm thickness was added (b). Magnets followed with an arm in between, but **strength was also not sufficient** (c).

A **Morphological Chart** is an overview of several option of subfunctions. These chart could be used to generate principal solutions in an analytical and systematic way (van Boeijen, 2013).

Substantiation functions

In order to create a Morphological Chart, functions should be formulated (Roozenburg & Eekels, 2016; van Boeijen et al., 2013). These functions were based on the LOR.

- Control the prosthetic hand
- Provide feedback in the muscle
- Create a cosmetically acceptable view of the:
  - » prosthetic
  - » surgery
- ~~Provide grip strength~~
- Transfer motion from:
  - » muscle to prosthetic
  - » prosthetic to terminal device
- Connect the prosthetic to the stump
- ~~Supinate/pronate the hand~~

While the option of supination and pronation of the wrist is necessary to prevent injuries due to compensations of this movement in different parts of the body (C10, C9), this aspect as well as the provided grip strength is eliminated, since these are outside of the new scope's focus. These functions are the fundament of the Morphological Chart in Figure 47.

General features

In all concepts, a voluntary closing mechanism is incorporated. A voluntary closing system was selected rather than a voluntary opening system since it aligns with the value of the feedback of cineplasty. Specifically, the **voluntary closing approach** provides functionally meaningful feedback, as it enables the user to perceive and regulate the applied gripping force rather than merely the extent of opening (Brav et al., 1964).

The Hüfner hand, one of the most effective mechanical hands on the market will be used for all these concepts, since it is tested to be the hand with the highest pinch force with least force exerted. Besides, the Hüfner hand was often controlled by cineplasty and is thus a good option as terminal device (Smit, 2020).

Since these functions are already integrated in existing prosthetics, this is not included in the Morphological chart.

Most promising ideas per function are included in a morphological chart. Three different routes lead to 3 concepts, as shown in the following Figure.

Choice substantiation morphological chart concepts

For all concepts is chosen to provide the feedback through **muscle stretch**, since this concept is proven by cineplasty and thus most reliable. One concept uses vibration to induce the feeling of flexion with help of vibration. Aside from vibrotactile stimulation, electrotactile stimulation is another interesting option that is actively investigated. Nevertheless, vibrations seems to be associated with higher participant preference, improvement in user performances and good compatibility for myoelectric prosthesis (Guemann, 2019).

The trade-off between cosmetics and feedback remains challenging. For example, the suggestion to implant a linear force or position transducer on the controlling muscle and then use inductive methods to bring the control signal across the skin barrier to the controlled device would seem to provide a nice cosmetic result. Unfortunately, it defeats the purpose of having direct muscle feedback (Weir, 1995).

Since the feedback mechanism is thus directly connected to the muscle, a **combination of cables and electronics** is chosen for motion transfer, as shown in the Figure below.

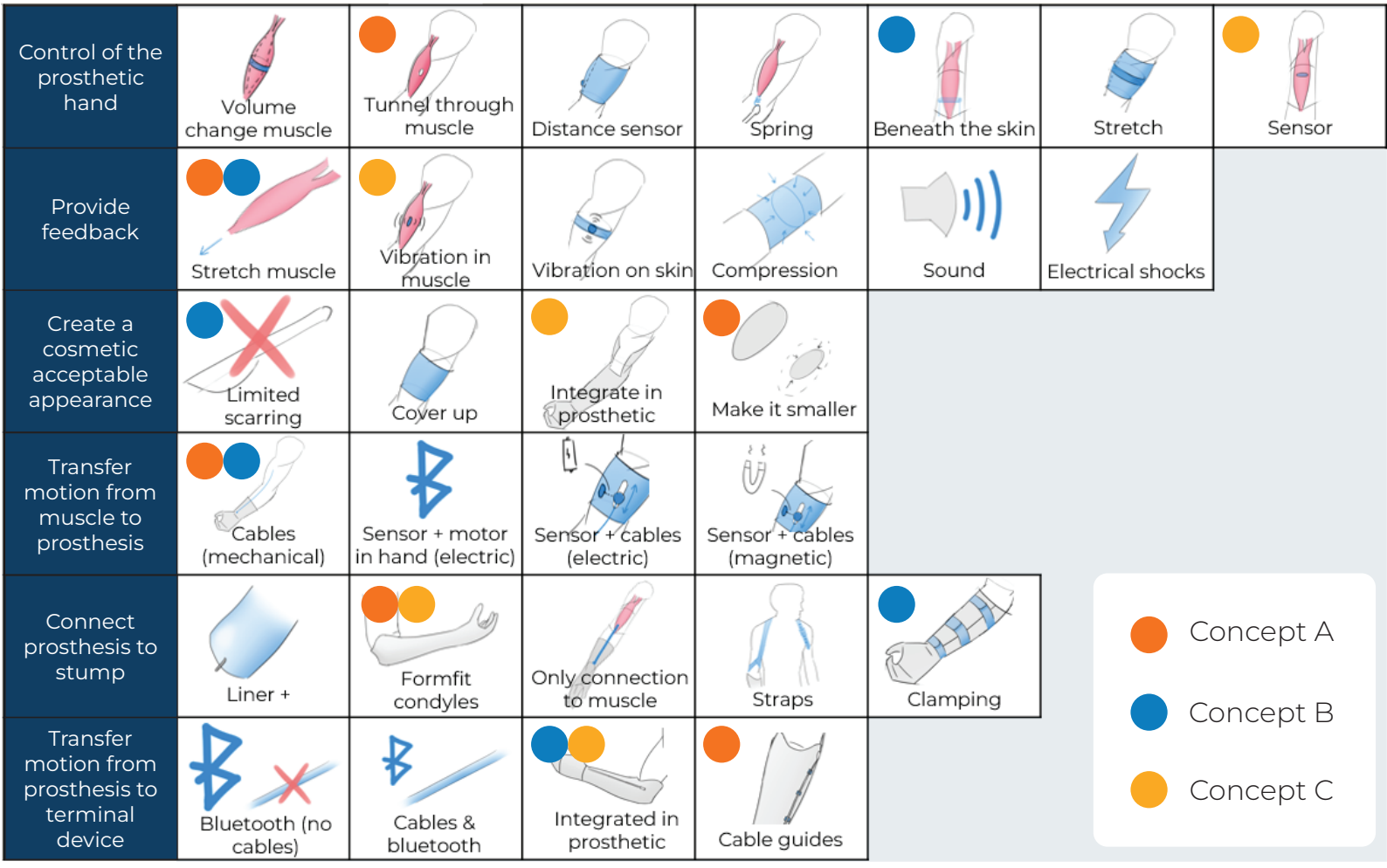


Figure 47.Morphological chart

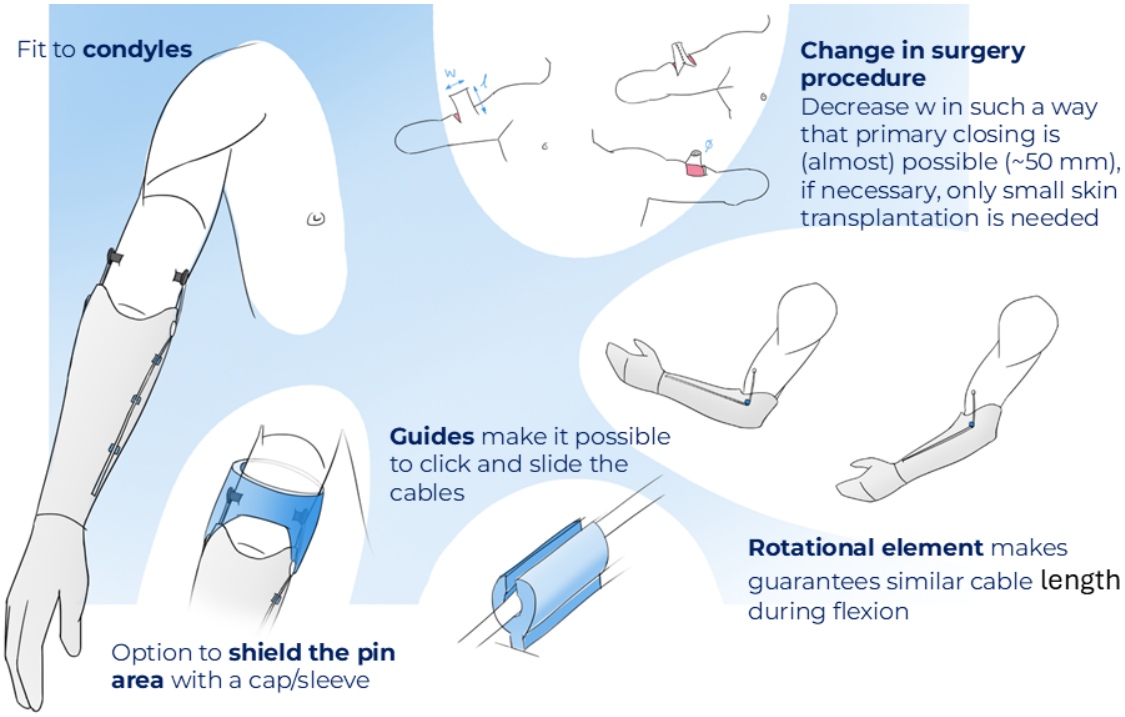
First iteration: generating concepts

4.1.3 'Prototyping'

Concepts were derived with help of the morphological chart. The concepts were developed in drawings with explanation. These concepts could be seen as a prototype that were presented to experts to gain their insights on the medical and technical feasibility, and identify certain limits and possibilities linked to their expertise (validation).

Interviews with multiple experts were conducted (1 prosthetist, 1 prosthesis user and 5 medical doctors: 2 plastic surgeons, 1 orthopaedic surgeon and 2 rehabilitation physicians, total of n=7) to identify limits and opportunities of the concepts that are taken into account in the decision making process. See *Appendix D.III* for the interview questions.

A. Cineplasty 2.0



Insights from experts
- Primary closing of the wound on the upper arm is possible around 50 mms, differs per orientation (C6, C7).
- Different orientation of the U flap could lead to scarring on a less notable location (C6).
- Cap is needed to protect the rod (C2)
- No guide needed from tunnel to rotational point elbow (P5)

Should be looked deeper into (if developed further):
- Orientation of U flap (C6)
- Different kinds of skin transplants (C2, C4, C6, C7)
- Additional feature to protect rod and improve cosmetics (C2)
- Random flap ratio conditions (C7)

Figure 48. Concept A: Cineplasty 2.0

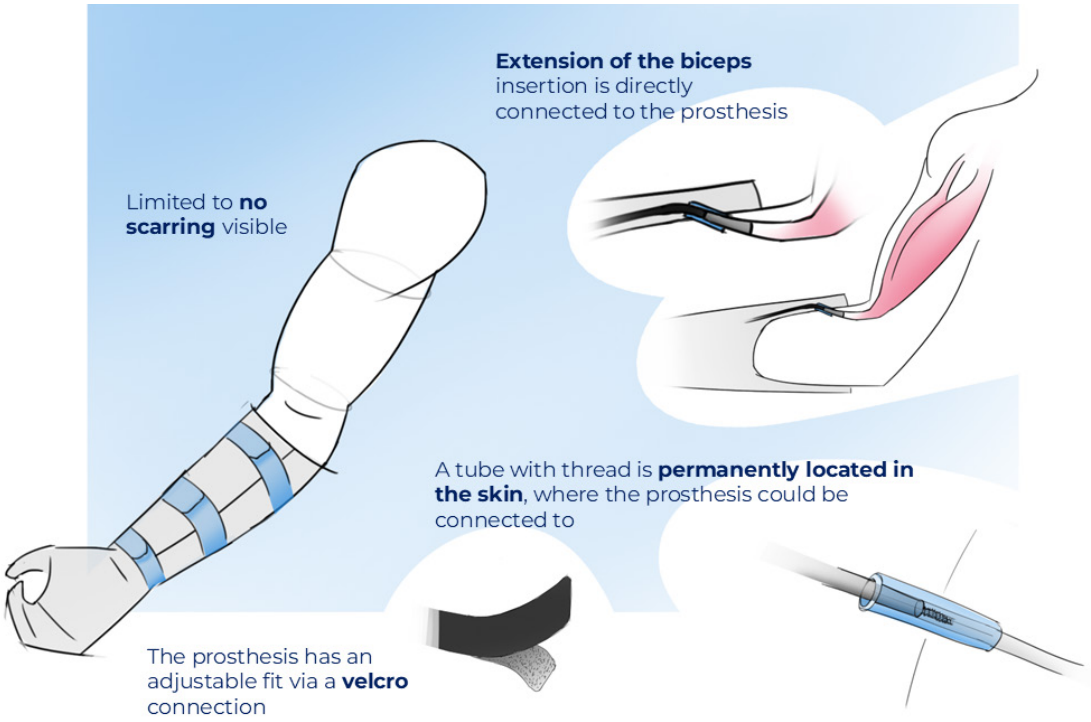
This concept is most similar to the already developed technique halfway the previous century. The prosthesis will be controlled by a rod in a tunnel through the biceps, that moves and thus shortens the cables which leads to closure of the prosthetic hand. The biggest change is the proposed change in surgery technique, where is suggested to **decrease the width of the U shaped flap with 1 cm**, decreasing the diameter of the tunnel from 2.2 cm to 1.9 cm. 71% of the experts said these adaptations will improve cosmetics (U1, C3, C5, C6, C7). Experts expect that this small reduction will not be of great influence on results (C5, C6), however, pressure distribution on the skin should be taken into account (C2, C3). Besides, there is some worry for tension on the skin transplant and sutures, which could impede wound healing (C2, C5)

Another adaptation to the original technique, is the **changed orientation of the flap** is as shown in Figure 48. This will lead to scarring and skin transplantation on a less visible location on the arm, improving cosmetics even more.

According to experts, closing an opening of around 5-6 cm, could be possible with primary closing in the medial direction, since skin on the arm is quite elastic (C5, C7, C6). When primary closing is not possible, a small unit of skin transplant could be inserted which is more preferable concerning recovery time as well as cosmetics, see *Chapter 4.2.1* for more information about this topic.
Finally, this concept suggests the addition of **a part to protect the rod** from getting stuck due to their surroundings (advice from C2) as well as to improve aesthetics. Moreover, the fit will be to the condyles, instead of the need to integrate a structure to the upper arm.

First iteration: generating concepts

B. SKINtegration



Insights from experts
- What happens when muscle contracts when no prosthesis is connected? (C6, C3)
- Permanent opening with the skin also in suprapubic catheters, feeding tubes and port-a-caths, but in those cases no movement is needed (C2, C5, C7).
- Velcro is not a favourable option to connect the prosthesis concerning universal applicability and cosmetics.

Should be looked deeper into (if developed further):
- Prevention of adhesions and preservation of sliding motion of tendon, colloid fibres? (C2, C5)
- Frequency of tube replacement (C5, C6, C7)
- Forces on inside of elbow during contraction, prone to flexion (C2, C3, C6, P5)

Figure 49. Concept B: SKINtegration

In this concept, the cable responsible for closing the prosthetic hand is directly connected to the biceps tendon. As in cineplasty, the distal insertion of the biceps is surgically detached. A p**lastic extension element is attached to the tendon beneath the skin** to increase its functional length. This element is permanently implanted subcutaneously and exits the body through a small tube positioned at the interface between skin and air, creating a permanent opening in the patient's forearm. The prosthetic cable can be connected to the externalised tendon extension via a threaded coupling. When the user contracts the biceps, the entire system shortens, resulting in closure of the prosthetic hand. In this way, the cable remains mechanically linked to the muscle, while avoiding visible scarring or deformation of the muscle itself. Experts anticipated that this configuration would provide a feedback experience similar to that of a traditional cineplastic tunnel, particularly regarding muscle stretch (C2 C6). However, the prosthetic user expressed concerns that the system appears vulnerable (U2).

The prosthesis is attached to the residual limb using a brace like Velcro fastening system. The prosthetic user emphasised that Velcro attracts unwanted attention due to its non anatomical appearance and the fact that it may be visible under tight clothing. Several prosthetic experts also noted that this attachment method is unsuitable for conically shaped residual limbs and carries an increased risk of the prosthesis detaching (C2, C3, P5).

One of the primary challenges associated with this concept is **the stoma like permanent opening** in the skin. Comparable techniques are used in procedures such as osseointegration, which has demonstrated functional success (C2, C3, C6). Nevertheless,

infection risk remains a significant concern. All medical experts highlighted the high likelihood of infection in this design. At the same time, they referenced several clinical examples in which permanent transcutaneous access is routinely used, including suprapubic catheters, feeding tubes, and port a caths (C2, C5, C6, C7). However, in those cases, the tube connects two hollow structures, which is not applicable to the present technique (C7).
This leads to another major challenge: **maintaining the sliding properties** of both the tendon and the integrated plastic cable within the patient's forearm. Surgical manipulation of the tendon frequently compromises the peritendineum, which in turn reduces tendon gliding capacity (C2, C5). This issue requires further investigation should this concept be selected for continued development.

Overall, all experts agreed that the concept offers a cosmetically favourable appearance. However, 40% of the medical experts expressed **doubts regarding its medical feasibility** (C3, C7).

C. Active control

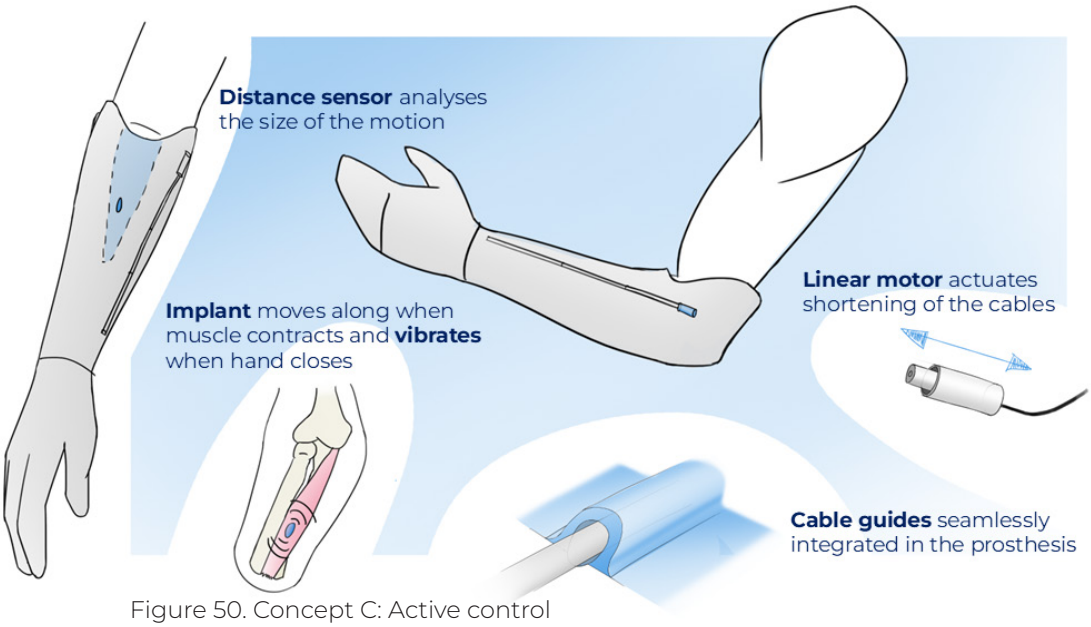


Figure 50. Concept C: Active control

Insights from experts
- Needs to be able to reach every component, should work with hatches (P5).
- Complications of adding electronics (delay, weight) (C5/P5/CS)
- Critical on the experience of proprioception (C6/C7/P5/CS)

Should be looked deeper into (if developed further):
- Proprioception by vibrations (C6/C7/P5/CS)
- Repeated exposure could lead to habituation or could be annoying (GS/CS)
- Effect of the delay in control and feedback (CS/P5/GS)
- Which motor and battery should be used (power and size)

This concept presents cineplasty in a modern guise: both control and feedback are directly linked to the muscle through an implant positioned within the flexor digitorum profundus of the forearm. When the user contracts this muscle, the implant changes position, which is detected by a sensor in the prosthetic arm. This signal is translated into cable shortening via a **motor located near the prosthetic elbow** -where all electronics (motor, battery) are housed- to minimise the moment arm, reduce perceived weight, and limit exposure to water. Once the prosthetic hand reaches its target position, the resistance encountered is converted into **vibration of the implant**. Vibration of the flexor digitorum profundus induces an illusory sensation of finger flexion through kinaesthetic feedback, specifically vibration induced movement illusions. Stimulation of muscles reinnervated by the median nerve has been shown to evoke various illusions of finger flexion (Grushko et al., 2020; Jones, 2025). Given that this effect has been demonstrated using TMR in the upper arm, it is reasonable to assume that direct stimulation of the flexor digitorum profundus could similarly evoke a sensation of finger flexion (Marasco et al., 2018).

Several experts indicated that this concept **aligns well with the expectations** and technological standards of modern society (C2, C3). However, the integration of electronics increases weight, cost, and maintenance requirements, and reduces suitability for low income settings or deployment in low resource environments such as frontline contexts (C3, C5, P5). Additionally, the prosthetic user mentioned it to be ‘a strange idea’ to have a moving implant inside of the arm. Some experts questioned whether this approach offers added value, given the existence of established methods such as EMG and TSR (C3, C7). **Concerns were also raised regarding the reliability of proprioceptive experience**, as vibration induces an illusion of movement rather than true muscle extension. Precise localisation of the perceived stimulus is challenging (C3, C6, C7, P5), and repeated exposure may lead to **habituation** or become bothersome (C3). Multiple experts also warned that **delays** may occur in both control and feedback pathways (C3, P5).

4.1.4 Validating

Expert input

All in all, experts were most enthusiastic about concept A (C5, C7, P5, CS,P5) since it is seen as most functional, the concept is already proven, and proprioception works. However, the technique remains its challenges concerning cosmetics.
The experts in favour of C (C2, C5, C6, C7) argued that it is the most elegant option in the modern society and in line with the future and current research (for example AMI Hugh Herr, connected tendons). Concept B is praised by its mechanical feedback directly to the muscle, but experts remain critical about the stoma-like opening in the skin (P5).

The prosthetic user spoken with (U2) prefers concept A, since it seems least vulnerable. However, experts often in contact with patients stated that the preference will probably differ per patient (C5, C7, C6).

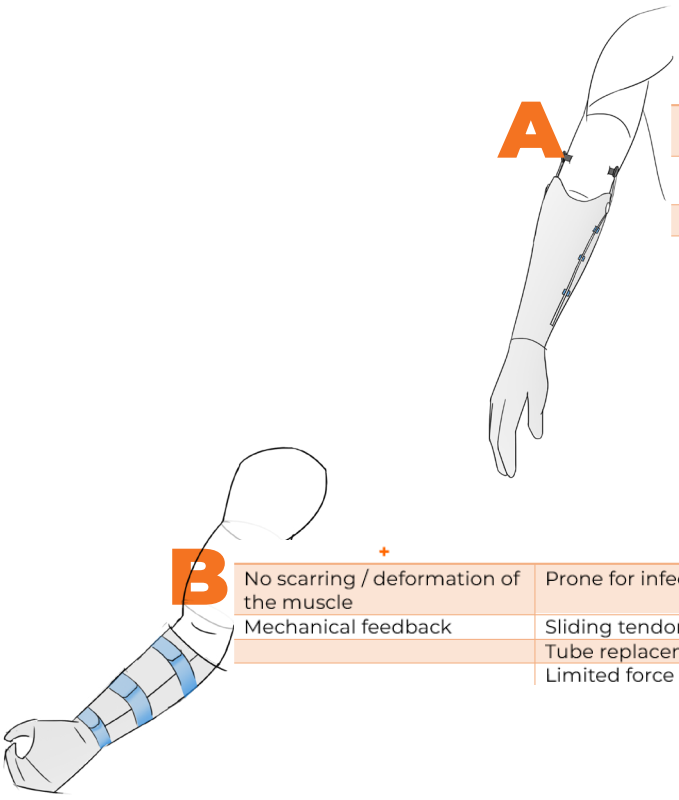
See Figure 51 for an overview of the expert views per criteria.

Category	Concept A	Concept B	Concept C
Comfort	Experts expect the reduced tunnel diameter to have little negative impact, though permanent reinforcement and tension on the skin graft and sutures may affect comfort (C2, C3, C5).	Tendon manipulation may reduce gliding and therefore comfort (C2, C5). The permanent opening may feel uncomfortable to the user (U2).	Added electronics increase weight and maintenance burden, reducing comfort; experts' main concern is the idea of a moving implant being "strange" (U2).
Proprioceptive feedback	Proprioception is expected to function well, similar to traditional cineplasty (C3, C5, C7, P5).	Experts expect feedback similar to a cineplastic tunnel, especially regarding muscle stretch (C2, C6).	Feedback relies on vibration-induced illusions; experts question reliability, localisation, and possible habituation (C3, C6, C7, P5).
Cosmesis	71% expect improved cosmesis due to the narrower flap (U2, C3, C5, C6, C7). New flap orientation places scarring in a less visible area, though tension on grafts remains a concern (C2, C5).	Considered cosmetically favourable overall, but Velcro attachment is seen as visually undesirable and attention-drawing (C2, C3, P5).	Considered modern and aligned with current technological expectations (C2, C5), though the idea of internal movement may be unsettling (U2).
Functionality	Seen as the most functional and already proven option; experts are most enthusiastic about this concept (C3, C5, C6, C7, P5).	Direct mechanical linkage offers strong feedback, but infection risk, gliding issues, and attachment concerns limit functional reliability (C2, C3, C5, P5).	Some experts doubt added value compared to EMG or TSR (C3, C7). Possible delays in control and feedback are noted (C2, C3, P5).
Durability	Pressure distribution and tension on grafts may affect long-term durability (C2, C3).	Permanent opening increases infection risk, threatening long-term durability (all medical experts). Reduced tendon gliding may also limit longevity (C2, C5).	Electronics increase maintenance needs and reduce suitability for low-resource environments (C3, C5, P5).
Affordability	No explicit cost concerns mentioned; based on an existing technique.	No explicit cost comments, though the permanent opening may bring additional medical care.	Electronics increase cost and reduce suitability for low-income settings (C3, C5, P5).

Figure 51. Overview of the expert views per criteria

Pro's and cons

The pro's and con's of the different concepts are summarised in the Figure below. As well expert opinions as own insights are taken into account.



+	-
Improved cosmetic outcome	Surgery and scarring
Proved principle of propriocepsis	Pressure distribution concerns
	Limited force

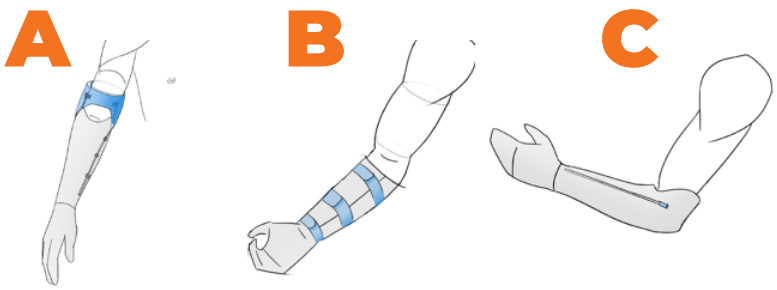
+	-
No scarring / deformation of the muscle	Prone for infection
Mechanical feedback	Sliding tendon
	Tube replacement
	Limited force

+	-
No scarring / deformation of the muscle	Critical on the experience of propriocepsis: exact location identification is hard
Higher force generation	Delay in control and feedback
	Electronics: maintenance, weight, price, applicability

Figure 52. Pluses and minuses of different concepts

Weighted Objective Method

With all aspects considered, a Weighted Objectives Method was performed, as shown in Figure 53 (van Boeijen, 2013). The criteria were first ranked on its importance and specific weights (a total of 100) were connected. Then, every concept was rated on those criteria with a value of 0-10. The scores were multiplied and summed up to a total score with a maximum of 1000.



Criteria	Weight	A		B		C	
Propriocepsis	25	8	200	7	175	5	125
Comfort	20	7	140	6	120	8	180
Reliability	15	10	150	10	150	6	90
Maintenance	10	8	80	3	30	5	50
Costs	10	7	70	5	50	3	30
Aftercare by patient	10	8	80	4	40	10	100
Produceability	5	7	35	7	35	5	25
Donning and doffing	5	6	30	6	30	9	45
Total	100		**785**		**630**		**645**

Figure 53. Results of Weighted Objective Method (van Boeijen, 2013)

Concept A resulted in the highest score, with quite some distance to B and C. This result, in combination with the comments from experts, made the project continue with concept A, with focus areas:

- *Orientation of U flap (C6)*
- *Different kinds of skin transplants (C2, C4, C6, C7)*
- *Additional feature to protect rod and improve cosmetics (C2)*

Some functions from the other concepts that are interesting are the seamless integrated cables (B and C) and the full integration of all parts in one prosthetic (C). These will be taken along in the further development of concept A: Cineplasty 2.0.

4.2 Second iteration: concept development

In this chapter, concepts will be further developed, prototyped and tested. Since cineplastic users are scarce, a test setup needed to be designed. Ideas with most potential were modelled in Siemens NX and 3D printed. They could be tested on the test setup, afterwards the final direction of the final product was chosen with Harris profiles (van Boeijen et al., 2013).

Scope determination

With all new findings in mind, a new iteration started. Concept A is the concept closest to the original cineplasty. As identified in the Discover phase, the main issue with this technique is the cosmetics. Concept A solves this issue with as well improving the **cosmetics of the surgery**, as the **aesthetics of the prosthetic**. It is chosen to fully focus on the prosthesis to arm connection, since this is where cosmetics need to be improved most, see the adapted scope adaptation in Figure 54. A body-powered prosthesis could easily be changed into a cineplastic prosthesis, so modern versions of the cineplastic prosthesis are closely available. This is why the prosthesis itself has fallen out of scope, and the connection of the rod to the arm will be the main area of focus, for as well the surgery technique as an improvement to elevate aesthetics of the whole system.

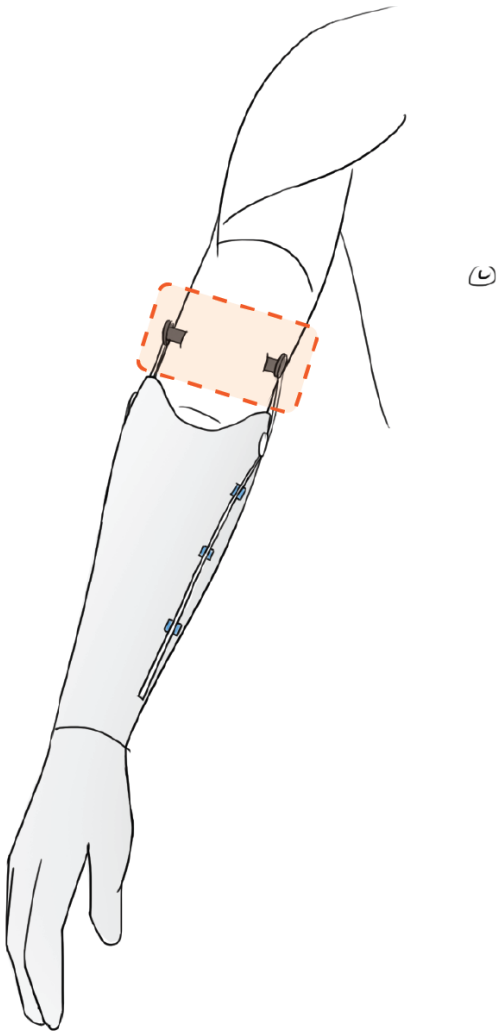


Figure 54. Second scope adaptation

Because of this shift in focus, a **refined set of Requirements and Criteria** is drawn up and listed below. This list acts as a directive for designing a product covering the arm. The proposal for change in surgery technique will be developed parrallel.

Requirements

Maximum weight
The extension of the prosthesis should weigh less than 30 g (10% of prosthetic weight).

Skin-safe materials
The extension of the prosthesis should not cause discomfort after wearing it for 6 hours, regarding material (P3).

Visibility
The extension of the prosthesis should not be visible underneath clothing (U2)

Durability and environmental resistance
The extension of the prosthesis should be able to withstand water repeatedly for a period of 5 years without damaging the prosthesis (P1).

The extension of the prosthesis should have a lifetime of at least 5 years.

Daily usability
Donning and doffing of the extension of the prosthesis should be doable in under 30 seconds.

The extension of the prosthesis should be able to be donned and doffed with one hand.

Criteria

Impedance control
The extension of the prosthesis should not impede the prosthesis' function (P5).

Skin or clothing could not get stuck in the extension of the prosthesis (C2, P5).

Use and comfort
The extension of the prosthesis should not be in the user's way in any way.

Product lifetime and maintenance
The extension of the prosthesis should be as durable as possible.

The extension of the prosthesis should need as little maintenance as possible.

Daily usability
Donning and doffing of the extension of the prosthesis should be experienced as easy.

Natural appearance
The prosthesis should look natural, be available in the user's skin tone, and remain unnoticeable under clothing (U1, U2).

Appearance
The extension of the prosthesis should be cosmetically acceptable.

The extension of the prosthesis should be aesthetically pleasing.

Low costs
The extension of the prosthesis should be as affordable as possible.

4.2.1 Ideation

Surgery technique
As well the functional (conditions, risks and impact on patient) as the cosmetic argument (skin transplant and scarring) lead to the goal of **limiting the size and use of skin transplants**, aiming for least visible results of the surgery.

To achieve this goal, quick brainstorms were done with plastic and orthopaedic surgeons. This led to different ideas, of which the one with most potential is discussed.

Some important aspects to take into account are:
- Stressless closing necessary to prevent wound healing disorders (C2, C5)
- Different **types of transplantations** of the skin could have different impact on patients and different cosmetic results (C4, C5, C7)
- Primairy closing is possible for an opening of approximately 50-60 mm, and differs per location and direction (C6, C7)

Figure 55 shows closure options for a defect. This schematic outlines how reconstructive surgeons think through different treatment options, ranging from the least to the most invasive (Macneal et al., 2024).
Closing by secundary intention or primary closing is most optimal, since there are no complications or risks involved related with skin transplants (C2, C6, C7). Since the wound openings are too big, closure by secundary intention is not an option (C6). When small to medium sized wounds can not be closed primarily, the option for free skin grafts or local flaps derives (Macneal et al., 2024).

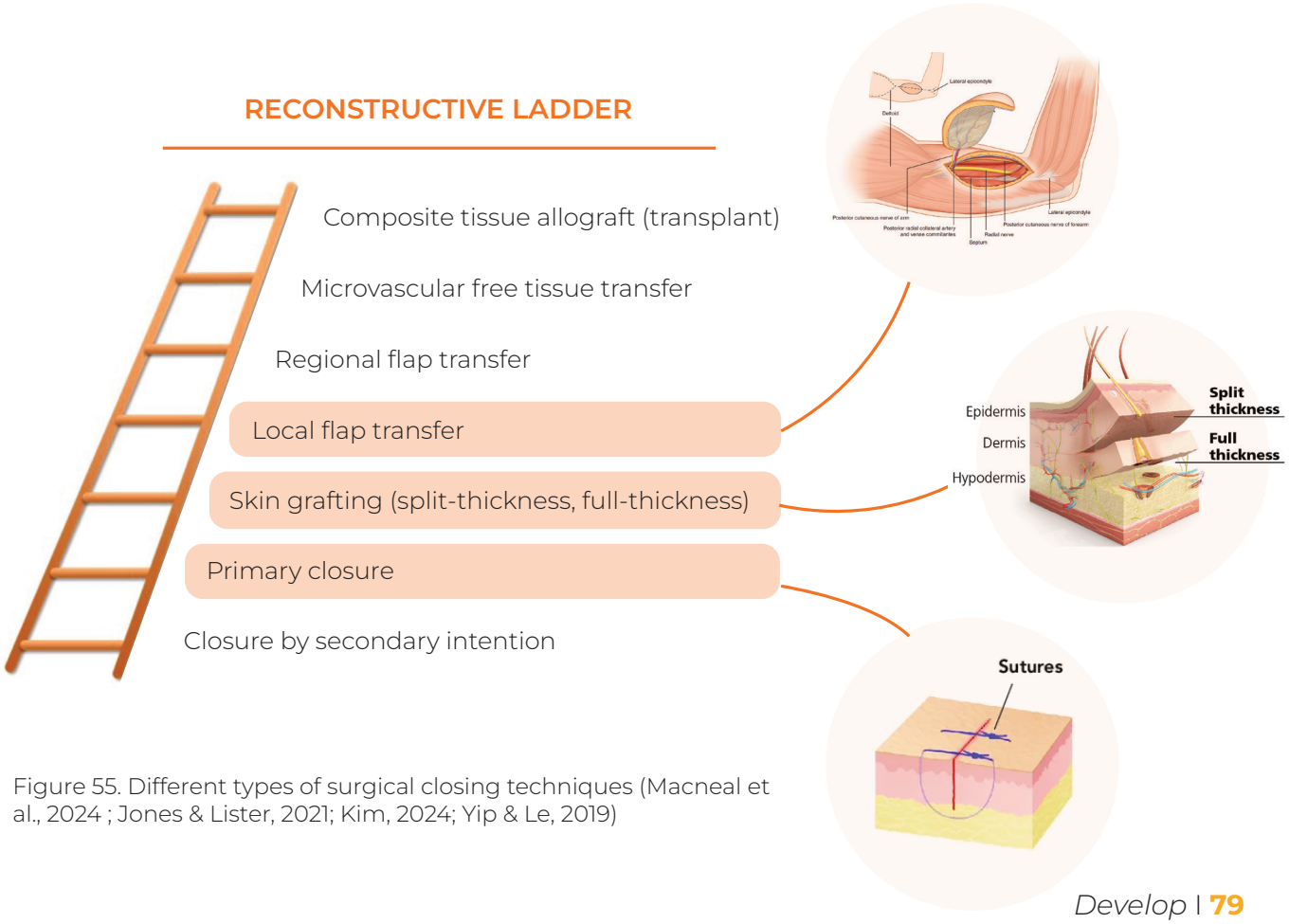


Figure 55. Different types of surgical closing techniques (Macneal et al., 2024 ; Jones & Lister, 2021; Kim, 2024; Yip & Le, 2019)

- **Primary closure** is only possible in limited wound sizes and result in high cosmetic outcomes (C7).
- **Skin grafts** need a vascularised layer underneath for bloodsupply, which is the case for covering the biceps.
- **Free flaps** have their own bloodsupply and have a higher cosmetic outcome than skin grafts, since color and texture match better with the surrounding skin. However, this technique takes a deeper skin tissue, which causes the need for a skin graft to close the donor site (Jones & Lister, 2021 Macneal et al., 2024).

Concluding that when primary closing is not a possibility, using a small split thickness skin graft remain the optimal closing technique, since the minor advantages of cosmetics do not outweight the higher impact on the patient.

When further exploring the options for the **flap orientation**, different options were drawn up and consulted with a plastic surgeon (C6). When purposing the different drawings, it was concluded that option 2 would lead to the least visible scarring, with potential of primairy closing in medial direction, since skin is slightly more elastic in this direction (C6). There are no additional disadvantages compared to the first orientation: scarring tissue and transplant tissue are not expected to influence the skin's behavior during excursion (C6, C7) and the closing of the tunnel on the inside is not located in the pulling direction, where perception of pressure is most important (C4). That is why the proposed surgery technique is changed in its orientation as visible as option 2 shown in Figure 56.

Primary closing is expected to be possible, however, this should be tested by performing the surgery with human tissue at that exact orientation before this claim could be made. When primary closing is not possible, a small split thickness skin graft will be used to close the wound.

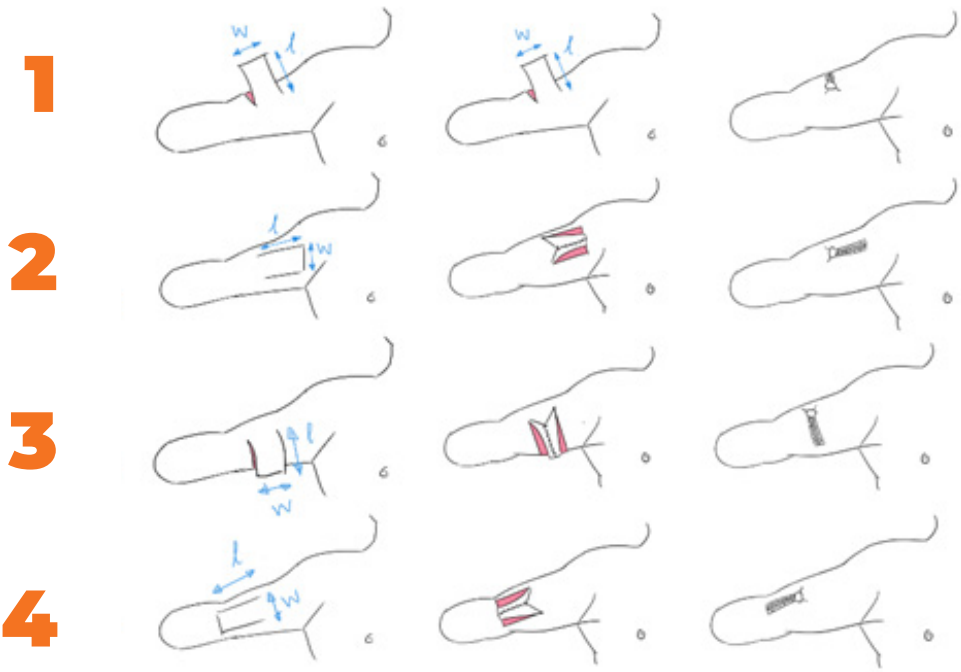


Figure 56. Surgery orientation of the flap

Prosthesisadaptation
Improvements on the part of the prosthetic - from now on referred to as “the extension of the prosthesis” - could lie in different aspects as for example the shape and colour of the rod, adding a cap or stocking to hide the connection mechanism or even change our view towards the rod: it could also be seen as a piece of jewelry, since it actually is a big piercing. See Figure 57 for some sketches.

Different ideas were drawn up, which led to quick and functional **sketches**, see Figure 57.

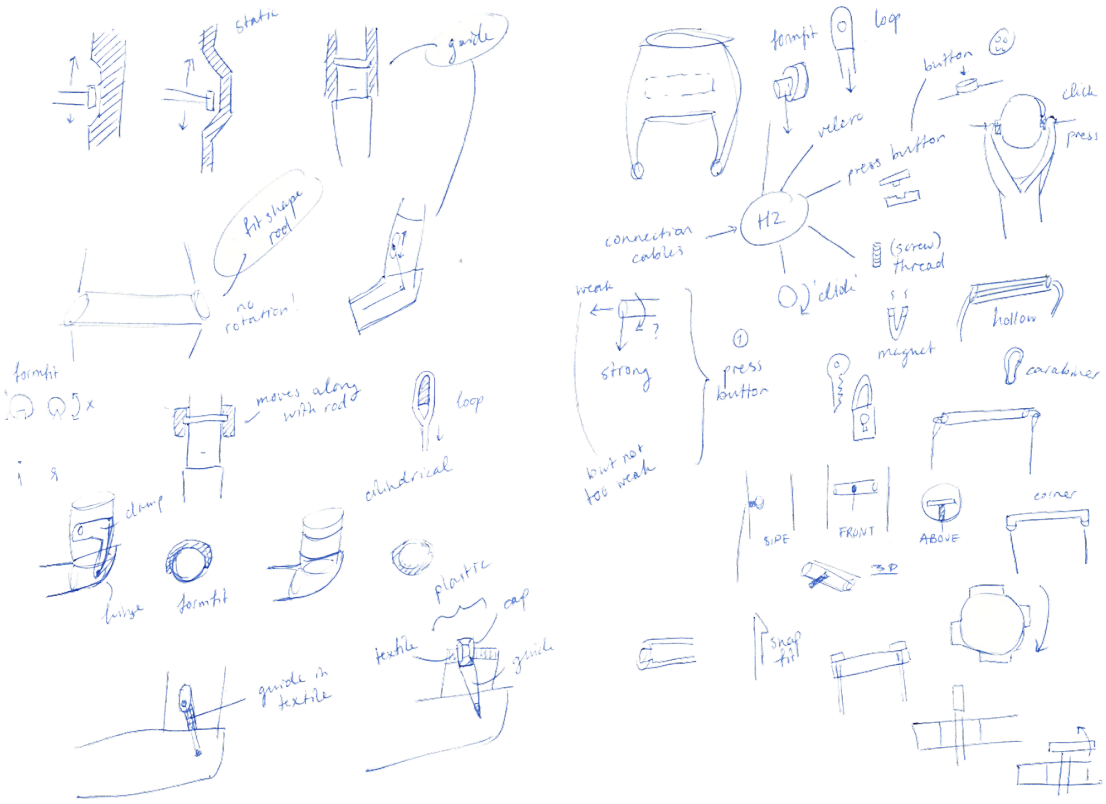


Figure 57. Quick sketches on improving the cosmetics of the connection area

4.2.2 Conceptualisation

Focus of this chapter is on development of the prosthetic extension, since at this stage, the surgery technique is proposed and only needs to be visualised (these visualisations can be found in *Chapter 5.1*), however, the prosthetic extension deserves more time to be developed further. Ideas were selected and developed into the drawings from Figure 58.

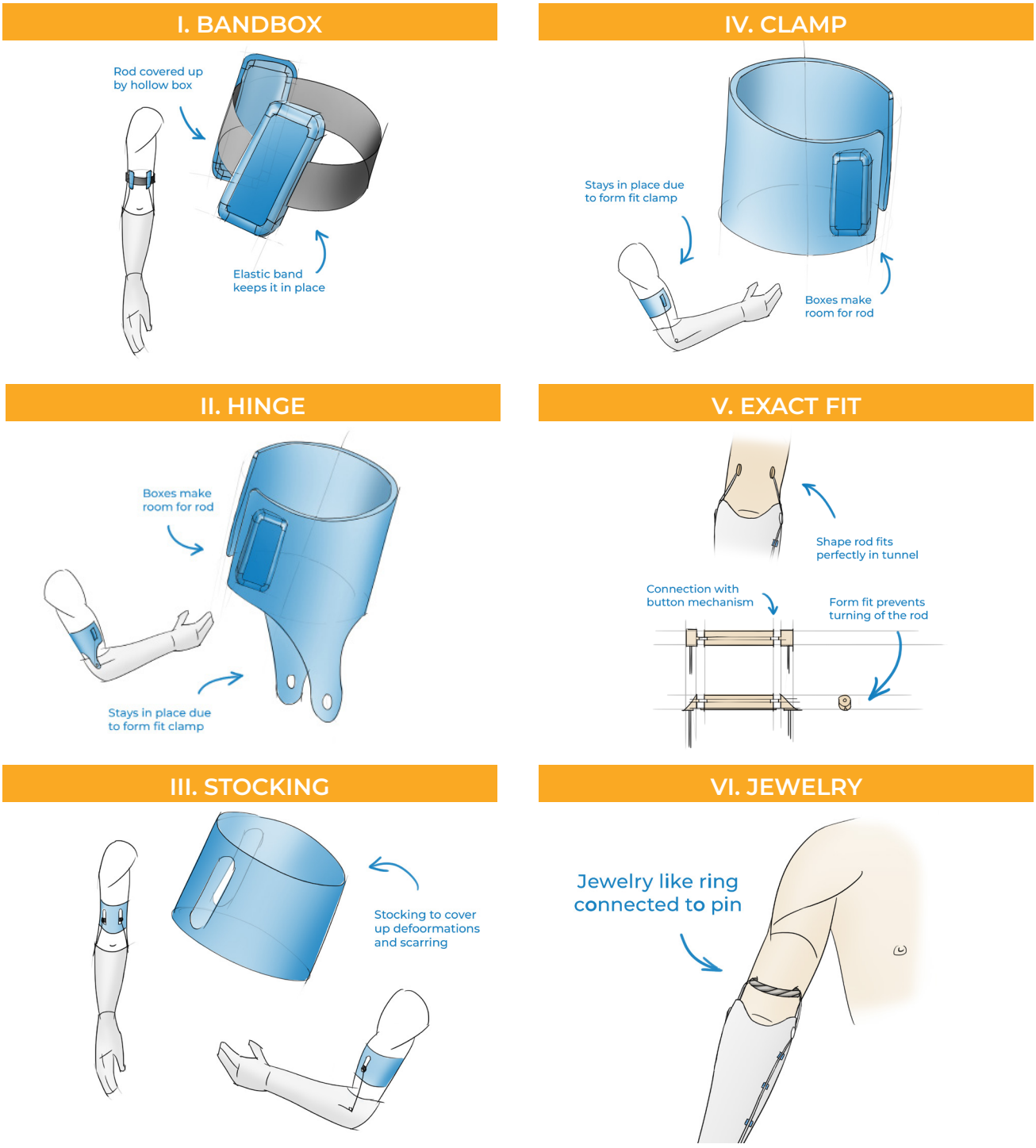


Figure 58. Concepts on improving the cosmetics of the connection area

4.2.3 Prototyping

In order to validate or test the ideas, a **test set up** was designed and printed, since there were no people with cineplastic surgery found willing to volunteer in tests. This test set up consisted of an upper arm (including elbow joint) where a prosthesis could be connected to. Since concepts are anatomy based, an **anatomical model** from DINED was generated (Figure 59 and 60), with the following properties (DINED, n.d.):

- CEASAR database (p50)
- Male
- Age 18-65
- Europe & North America

A cut out was created in the area where the rod would be located. A hole of 4 cm (needed excursion found by Blaschke & Taylor (1953)) was created, so that the rod could make the full motion normally generated by the biceps muscle. The hole is located on two third of the biceps (based on visual estimation of U3). The direction of the hole is based on the direction of the biceps. See Figures 59 and 60 for the substantiation for the location of the hole in the test setup.
The rod could be changed in position manually by the connection via the top of the arm (Figure 61b).

The PLA from the 3D print filament -obviously- behaves different than human skin, which should be taken into account during testing. For example, the rod will not always move perfectly horizontal, as in **soft tissue there is room for play**.

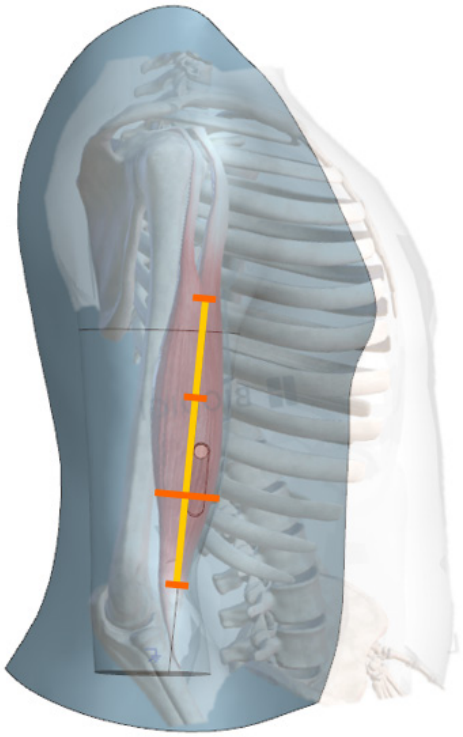


Figure 59. Substantiation hole location (side) (*Left biceps brachii,* n.d.)

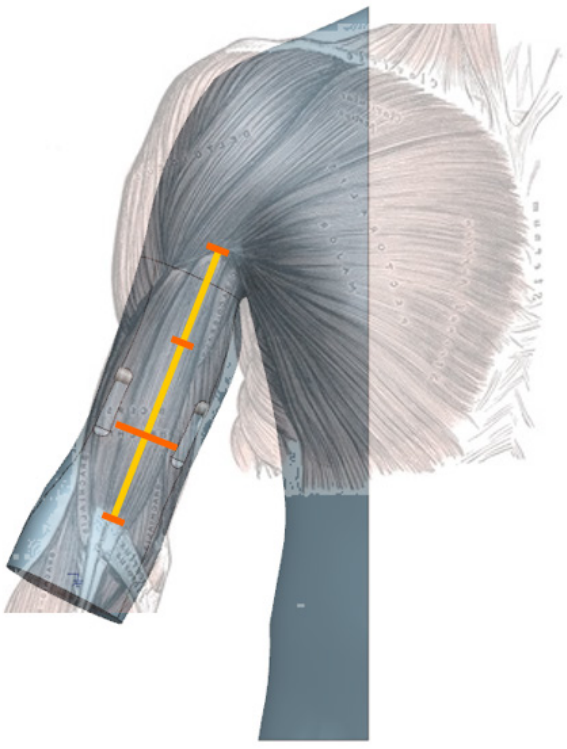


Figure 60. Substantiation hole location (front) (Satsia, 2015)

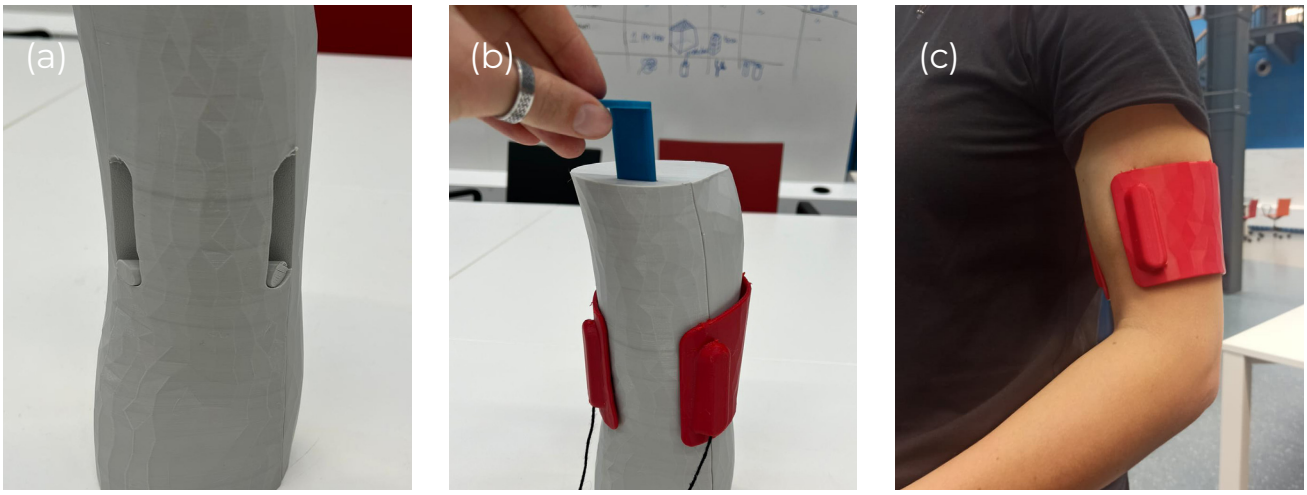


Figure 61. Preliminary tests of test set up (a), prototype on test set up (b) and prototype on arm (c)

Some small tests show proof of concept: dimensions for thee box around the rod are tested and confirmed (only on the test setup, more tests should be done on the skin), and some shapes of the rod were printed and tested in the test set up (see *Appendix E.III* for more about the test set up). These tests also led to some notes: the clamping mechanism worked sufficiently on the test setup, on the skin however, the formfit was not enough to keep the cover in place due to the deformation of soft tissue. This could be solved by adding a strap or directly connect it to the prosthetic like in concept II.

Concepts II and IV are based on the anatomical shape of the upper arm, which could be created with help of **3D scanners**, similar to the technique used by the company Manometric to produce personalised orthotics (Manometric, n.d.). This way, the exact location of the tunnel and the rod could also be scanned and integrated in the model, to guarantee smooth motion of the rod.

4.2.4 Validating

In order to chose the best option, Harris profiles are used (van Boeijen et al., 2013). For this method, criteria are ordered on level of importance (high = important, low = less important) as shown below:

a. The prosthetic should **not impede** the prosthetic's function (flexion + cables)
b. Skin or clothing could **not get stuck** in the extension of the prosthetic
c. The extension of the prosthetic should be **cosmetically acceptable**.
d. Donning and doffing of the extension of the prosthetic should be easy
e. The extension of the prosthetic should be as **durable** as possible.
f. The extension of the prosthetic should be as **affordable** as possible.

According to the Harris profiles, the following are favorable:

- II. Hinge
- V. Exact fit
- VI. Jewelry

When analysing the concepts with prothetists from Rijndam Orthopedietechniek, it was found that an upper arm machette was a preferred quality to prevent rotation of the lower arm (supination and pronation). This finding presses the choice for the "Hinge" concept. This could be combined with "Exact fit". The jewelry concept is a different track of ideas, which could be interesting in the future research (*Chapter 6.3* for further recommendations).

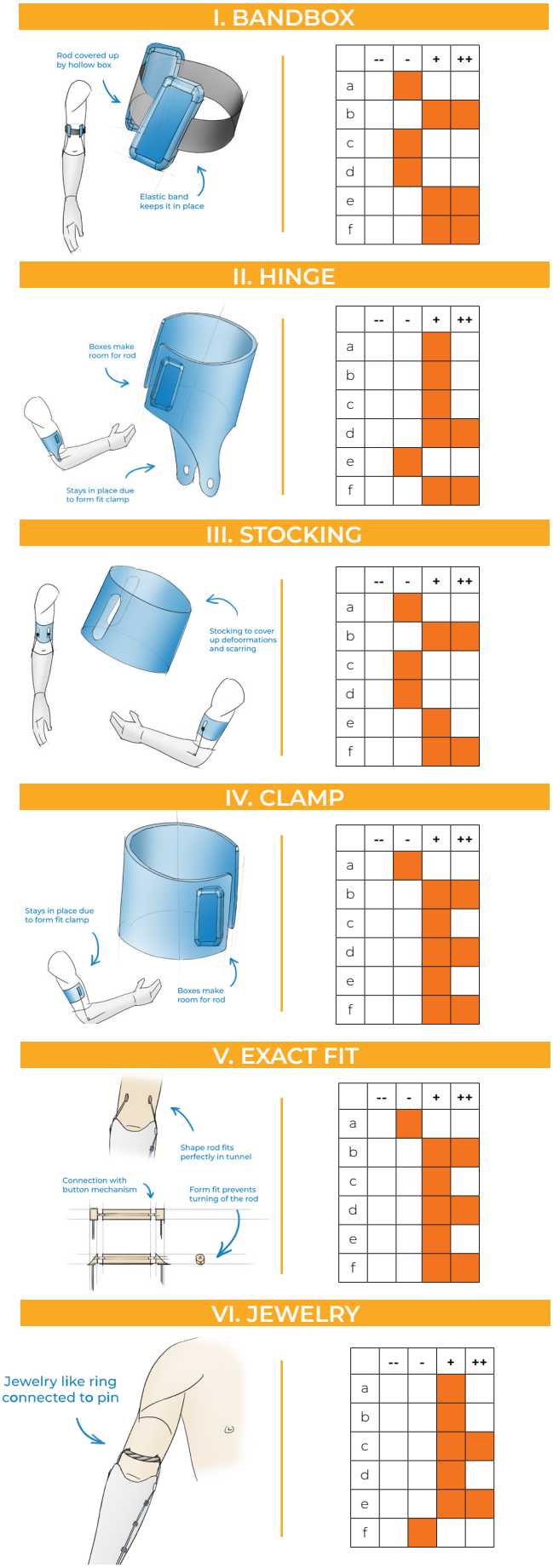


Figure 62. Harris profiles

Final direction

Rijndam Orthopedietechniek shed some light on how they produce their prostheses in house, and provided some main parts frequently used by prosthetists. With these parts, a basis prosthetic is created, to validate whether the final hinge cap functions in the context of a prosthetic.

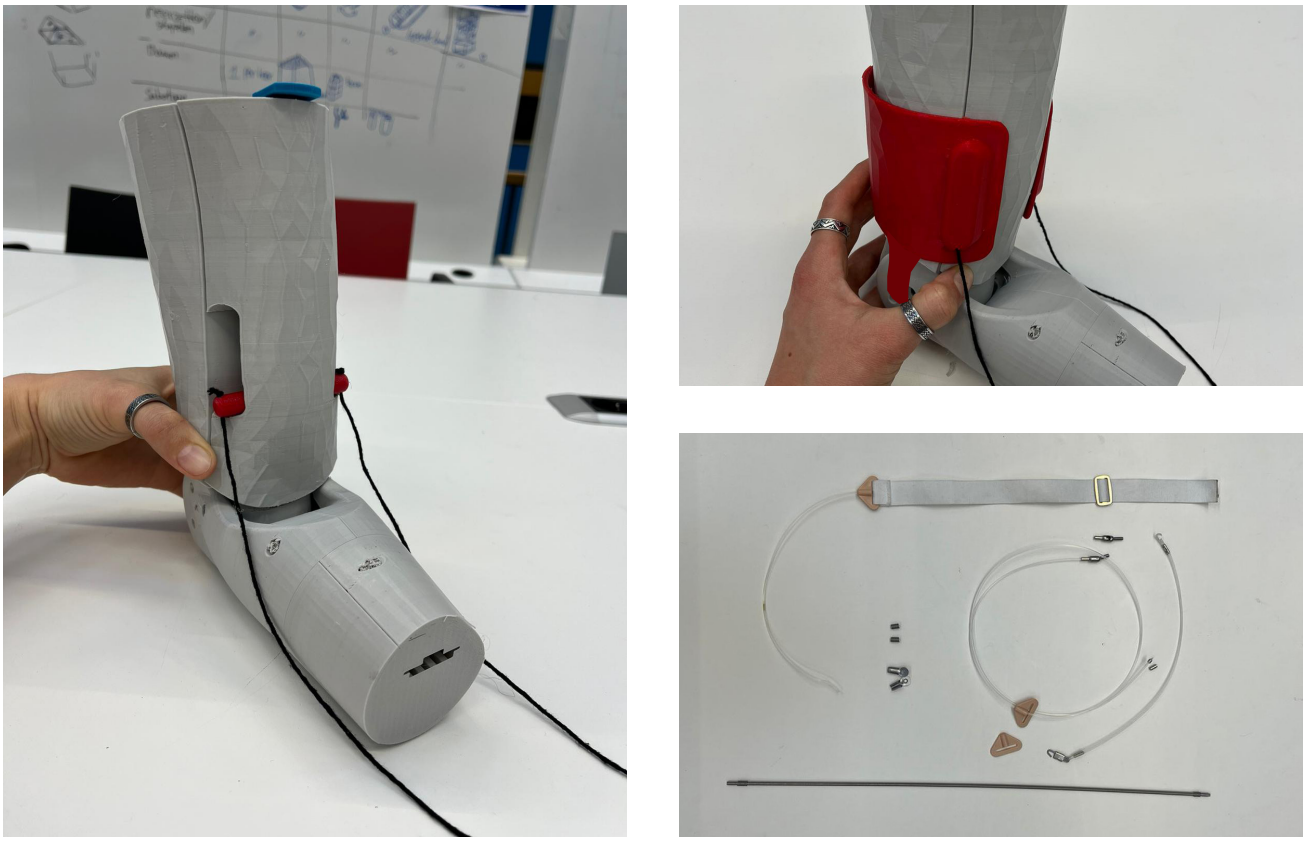


Figure 63. Prototypes of the test setup and parts received from Rijndam

Conclusion

The Develop phase explored a broad range of ideas and gradually distilled them into three concrete concepts, each representing a different interpretation of how cineplasty could be modernised.

- Concept A (Cineplasty 2.0) built directly on the original technique with targeted surgical refinements
- Concept B (SKINtegration) proposed a subcutaneous tendon extension with a small external interface
- Concept C (Active Control) introduced an electronically mediated system combining implanted sensors and vibration-based feedback.

Together, these concepts reflect the full spectrum of possibilities—from traditional mechanical control to technologically advanced hybrid solutions.

Through expert validation, Concept A emerged as the option with the most potential. Experts consistently emphasised that it is the most functional, most reliable, and most aligned with the proven strengths of cineplasty, particularly its natural proprioceptive feedback. While Concepts B and C offered appealing cosmetic or technological advantages, they also introduced significant medical risks, mechanical uncertainties, or experiential drawbacks. Concept B raised concerns about infection risk and tendon gliding, while Concept C introduced delays, maintenance demands, and uncertainty about the quality of proprioceptive experience. In contrast, Concept A builds on a technique with decades of clinical precedent, making it the most feasible and predictable foundation for further development.

Following this choice, the redefined scope of the project shifted focus specifically towards improving the surgical technique and enhancing the cosmetic appearance of the cineplastic connection. This included exploring **adjustments to the flap** to reduce tunnel diameter, repositioning scars to less visible areas, and investigating possibilities for **covering or protecting the rod** to create a more discreet and acceptable interface. These refinements directly address the central trade-off identified in earlier chapters: preserving cineplasty's unique proprioceptive advantage while mitigating its greatest limitation—cosmesis.

The final design direction therefore centres on a modernised version of cineplasty that maintains the direct mechanical link between muscle and prosthesis, but with **improved surgical aesthetics** and a **more integrated, visually acceptable connection between body and device**. This direction forms the basis for the next phase, where the final iteration shows the refined concept will be validated in with experts and users to assess whether these improvements make cineplasty a viable and desirable option within the contemporary prosthetic landscape.

5. Deliver

The Deliver phase brings the project's development work into its final, tangible form. Building on the chosen design direction, this chapter focuses on refining the renewed cineplasty concept into a realistic, testable prototype. The work centres on two key elements: an adapted surgical technique that reduces scarring and improves cosmetic outcomes, and a discreet Cover designed to conceal and protect the cineplastic rod while maintaining comfort and functionality. Through iterative sketching, CAD modelling, 3D printing, and material testing, these components were shaped into a coherent final design. The chapter concludes with expert validation, assessing whether the improved appearance and reduced invasiveness meaningfully increase cineplasty's potential and analysing its applicability within contemporary prosthetic care.

5.1 Finalizing
5.2 Final results
5.3 Expert validation
Conclusion

5.1 Finalising

Now that the concept for the product is there, finalising starts by looking for the matching appearance of the preferred product. See Figure 62 for a **moodboard**, that indicates the product style of the to be developed product. Insights from the moodboard will be integrated in new sketches.

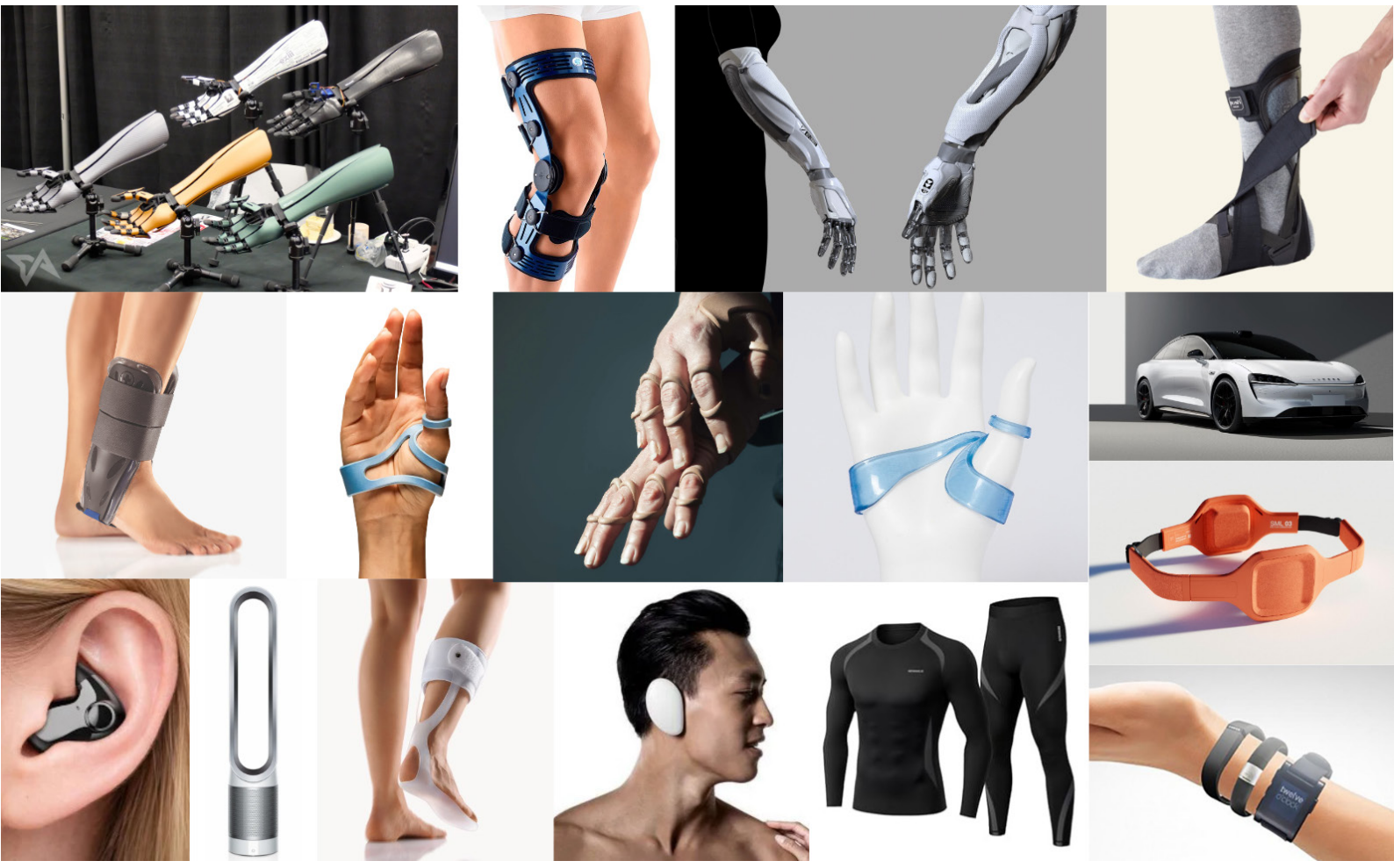


Figure 64. Moodboard of the prosthesis' appearance

Cover design

With help of the moodboard, some sketches were drawn up to create the highest cosmetic outcome. Three ideas were drawn out to perform a small aesthetics test (n=10), of which option B shown in Figure 65 resulted in the highest score. See *Appendix E.I* for more information on this test.

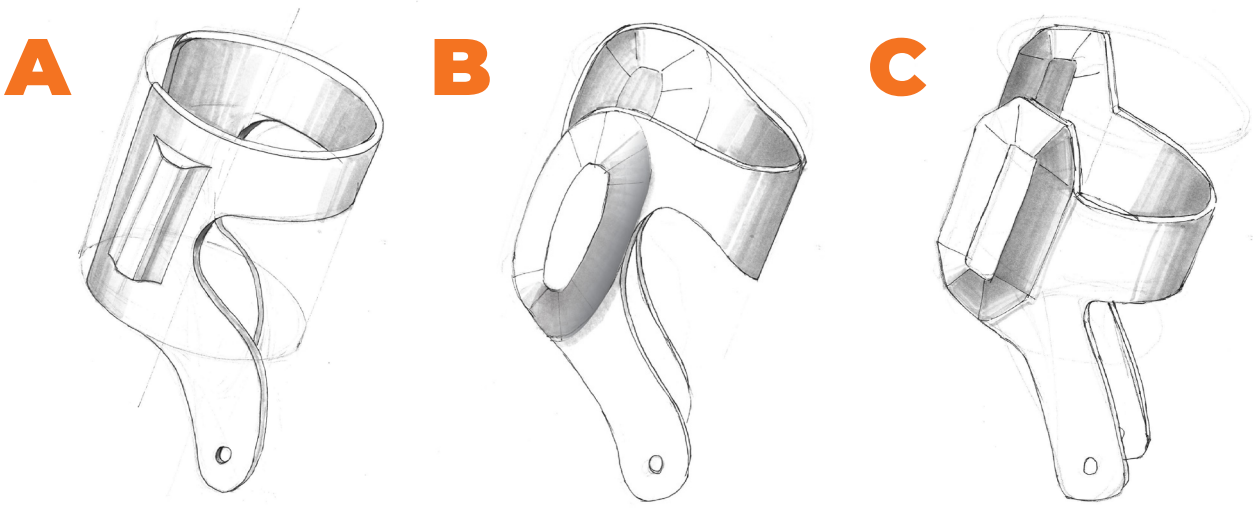


Figure 65. Sketches of different options for the Cover's appearance

Most important **parameters** that needed to be identified were:

- The space between Cover and rod
- The wall thickness and height for optimal clamping strength for a comfortable fit
- Minimalising Cover size for optimal discrecy

The final sketch was then created in CAD modelling software (Siemens NX).

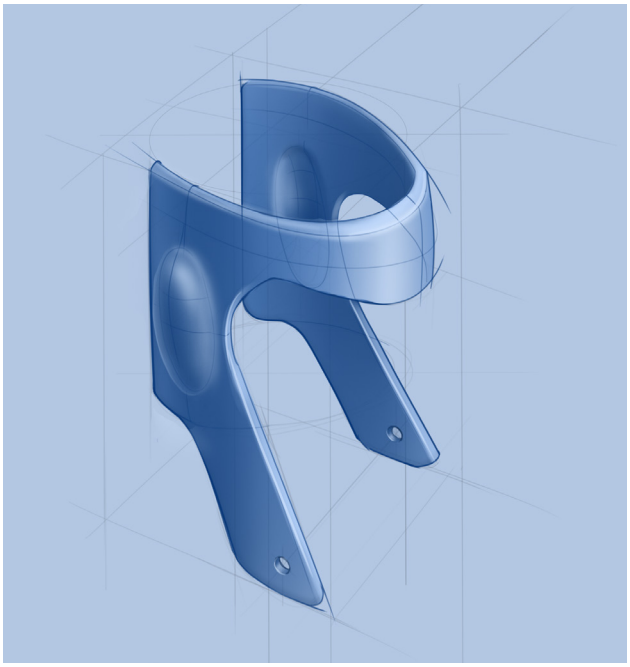


Figure 66. Visualisation of the final design choice (visualisation by Lica Niessen)

These designs were then 3D printed with Bambu Lab printers. See Figure 67 for some **model developments** during the iterations.



Figure 67. Development of different models of the 3D printed Cover

To as well increase comfort as guarantee perfect fit, a soft **layer of silicone** is added. This layer with 0.2 cm thickness was created by filling a 3D printed mould with silicone (Dragon skin 30) at the Phantom Lab from Mechanical Engineering at the Delft University of Technology, see Figure 68 and 69.



Figure 68. The process of moulding silicone



Figure 69. Result of the silicone mould

Surgical procedure

The proposal for the adapted surgery technique to create the cineplastic tunnel is shown in Figure 70.

Two changes are proposed:

1. **Reducing the width** of the flap with 1 cm leads to a decrease of the tunnel diameter, from 2.2 to 1.9 cm, and increases chances to close the wound primarily (without the use of a skin transplant).
2. **Rotating the flap** towards the armpit causes the location of the scarring to move to the medial side of the arm, which is more discrete location on the arm. Besides, change the closing direction of the skin increases the potential of closing the wound primarily (without the use of a skin transplant).

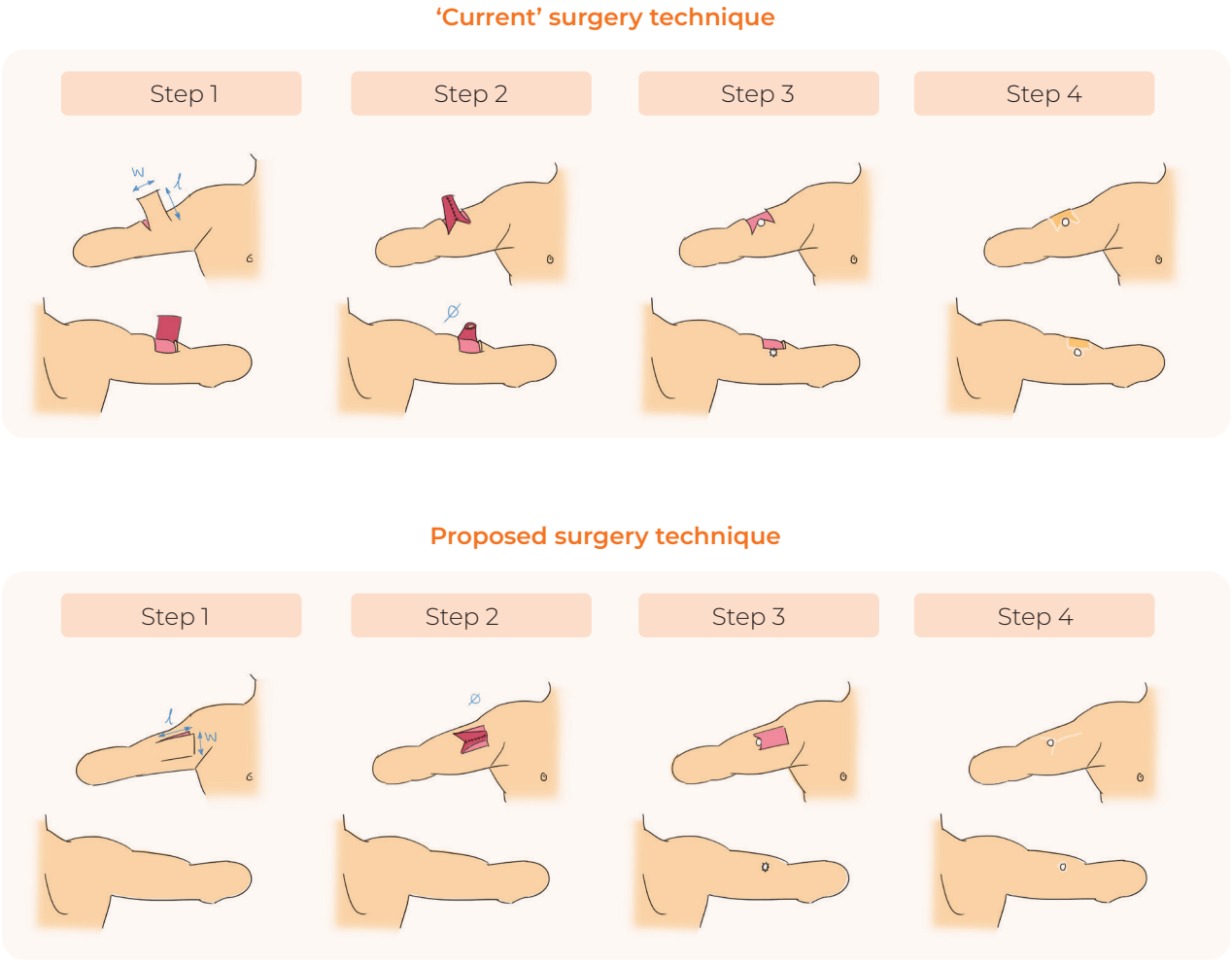


Figure 70. Visualisation of 'current' cineplastic surgery technique (up) the proposal for the new cineplastic surgery technique (down)

5.2 Final results

The final result of the Cover is presented in Figures 71 and 72. This Cover, combined with the proposed surgery technique, guarantees that all aspects from the cineplastic tunnel are covered: as well the small arod as the scarring is discretely hidden, whith the goal to improve the cosmetic outcome while preserving the unique quality of cineplastic feedback. The Cover's shape is designed to protect and conceal the rod in the arm, while keeping it as small as possible to maximise descretion. The Cover is not visible underneath clothing, as tested in *Appendix E.II*. The Cover consists of a resin molded shape (material similar to socket production), perfectly fitting the patients anatomy with help of a 3D scan. The vertical extensions are strengthened with carbon, to increase durability of the product. Low stiffness at the back of the Cover guarantees easy donning and doffing. The layer of silicone on the inside of the Cover is added for optiomal wearing comfort.

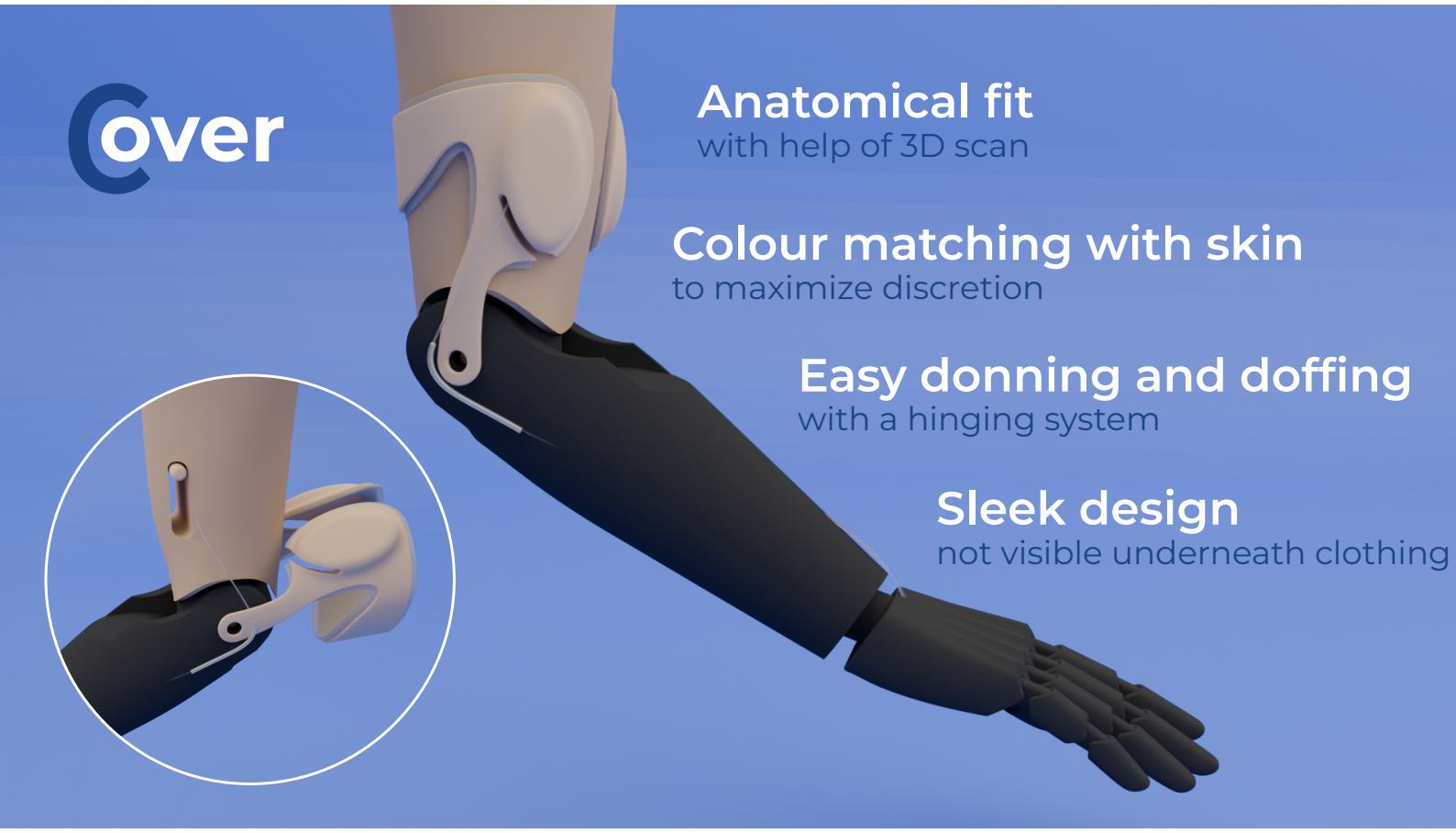


Figure 71. Render of the final product Cover and its properties

The name Cover comes from the fact that it goes ‘over’ the rod from the cineplastic prosthesis, where the C is from cineplasty. Besides, the product is in fact a cover, which makes the name intuitive and easy to remember.

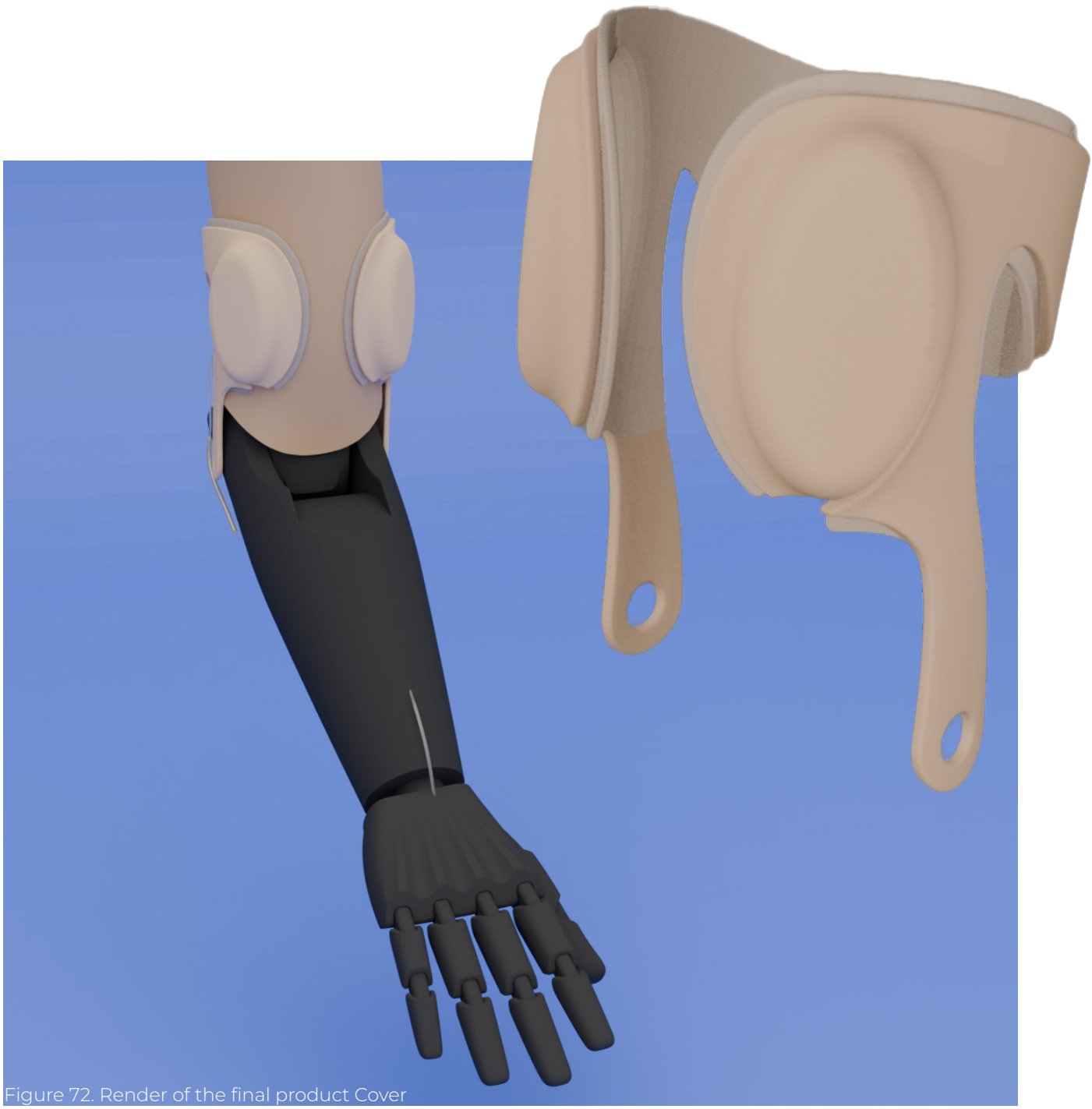


Figure 72. Render of the final product Cover

Surgery result

The proposed surgery technique **prevents the need for a skin transplant** and reduces the amount of scarring. The end results of the 'current' compared to the proposed surgery technique are shown in Figure 73.

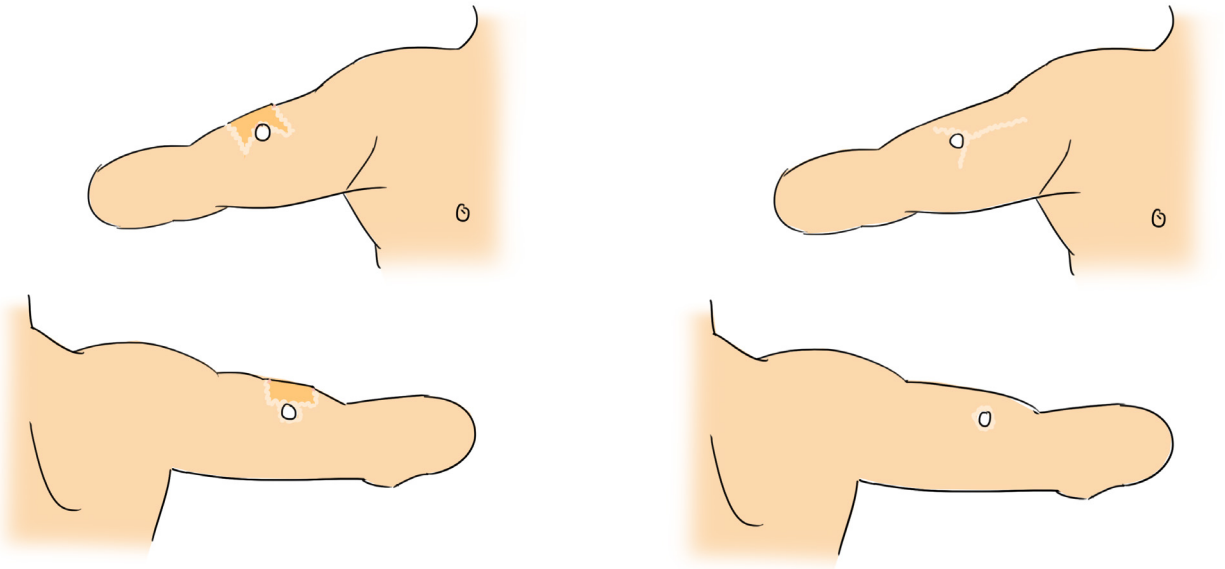


Figure 73. Visualisation of results of the 'current' cineplastic surgery technique (left) and results of the proposal for the new cineplastic surgery technique (right)

Prototype

In this prototype, the focus was on the Cover shown in Figure 74. The prototype includes the arm previously used as test set up, on which a prosthesis was connected. This way, the Cover was showed in the **accurate context**, which was an important aspect of the Validation Interviews (more information in *Chapter 5.3*).

A hinge was created to simulate the elbow function and show the principle of cineplasty on a lower arm amputee, see Figure 75. Besides, with the presence of an **elbow hinge**, it was possible to test the fit and function of the Cover on the arm somewhat realistically in different positions of flexion.

The prosthesis was painted in a color similar to the hand on loan from Dr. ir. G. Smit, to create a more obvious link between the hand and the prosthesis and create a nudge of where the prosthesis ends compared to the arm. In the case of this prototype, the 100 Dollar hand was used. More research should be done to look into the optimal terminal device.

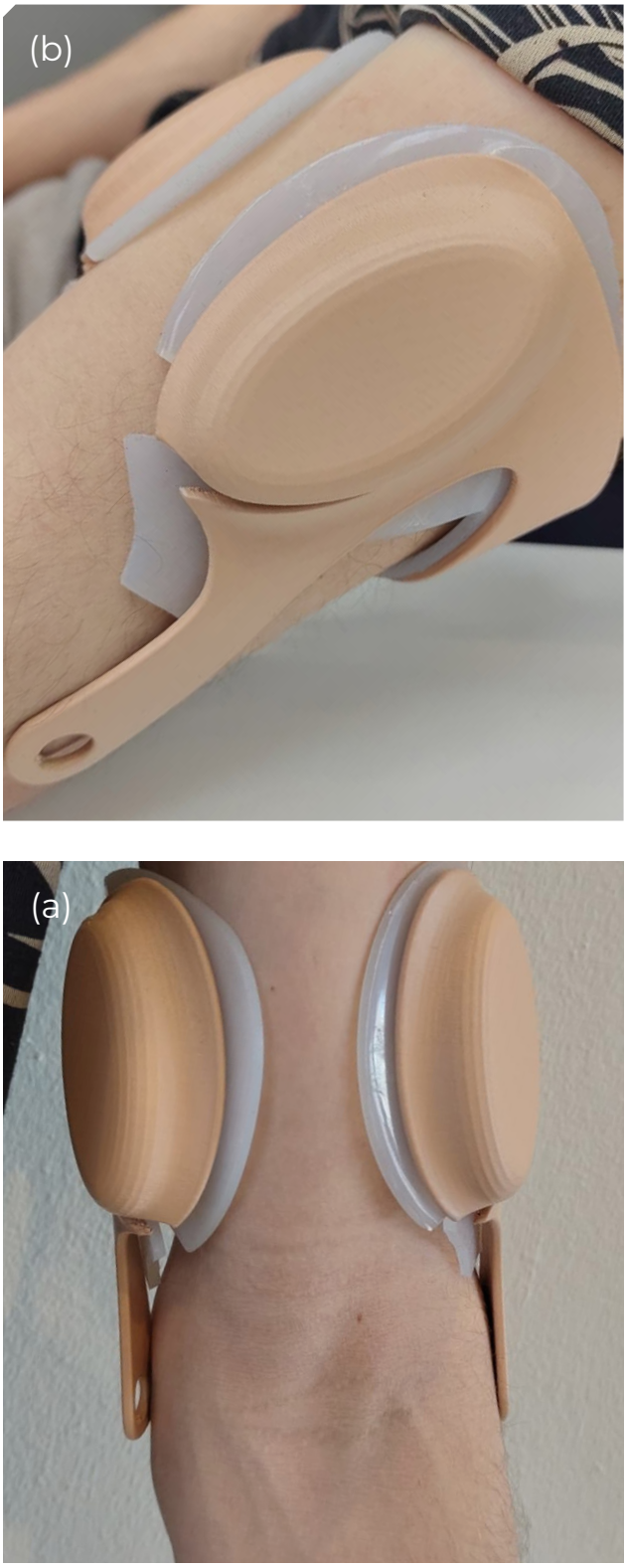


Figure 74. Prototype of the Cover on a upper arm (male)

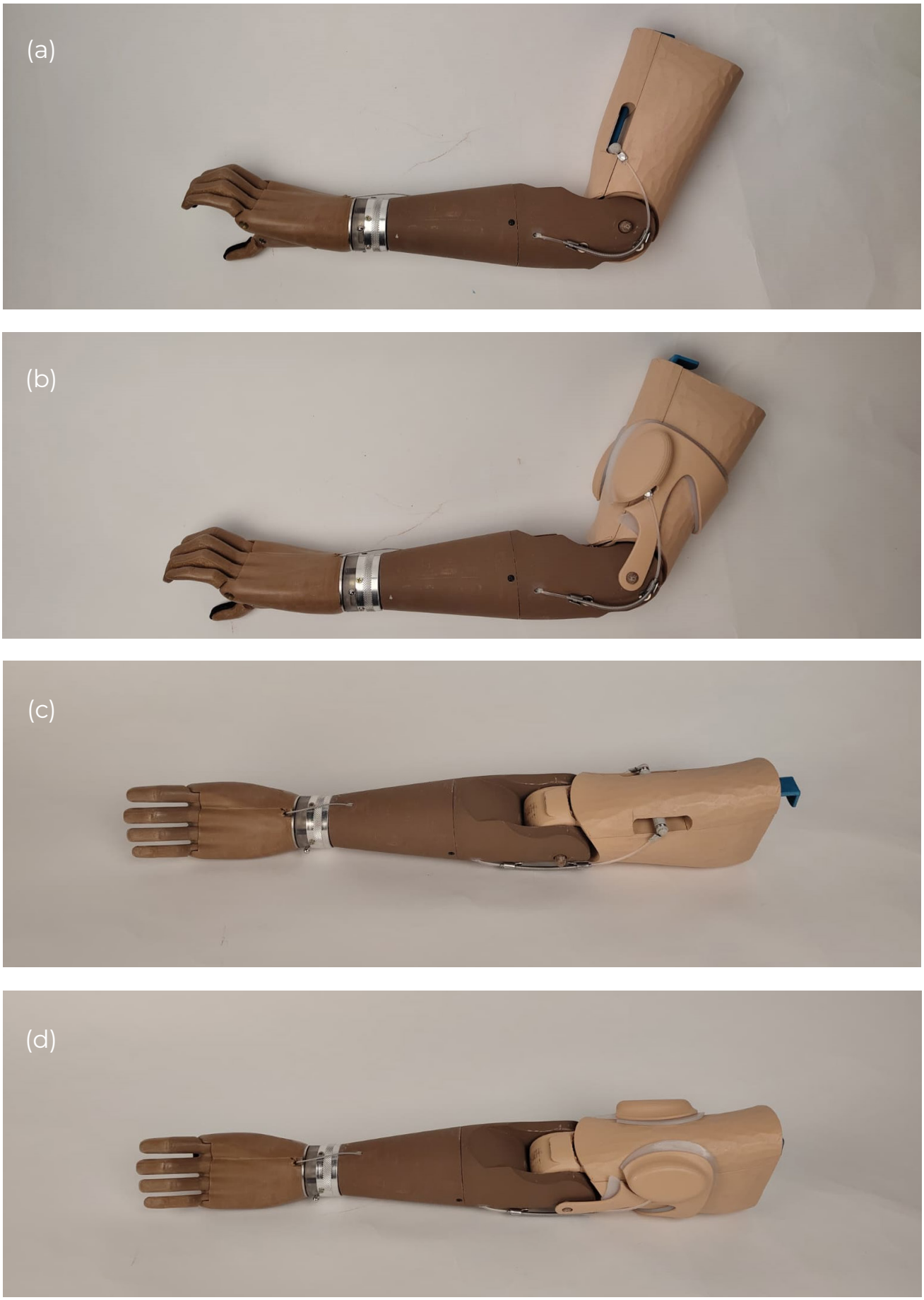


Figure 75. Prototype in flexion (a and b) and in extension (c and d), without Cover (a and c) with Cover (b and d)

5.3 Expert validation

In an ideal scenario, this study would have included direct testing with end-users. However, because the surgical procedure on which this work is based was performed many decades ago, the number of potential users is extremely limited. Attempts to trace former patients were unsuccessful: the few individuals whose cases are documented have since passed away, and the one cineplasty user interviewed was no longer willing to participate in practical evaluations. As a result, the validation process relied exclusively on expert input, supported by a number of carefully considered assumptions. This phase could be seen as the refinements before testing with patients could be set into motion.



Figure 76. Interview setting with C2

5.3.1 Interview set up

During the interviews, the prototype was used to investigate whether a modernised version of cineplasty could have potential in the contemporary society, with current alternatives in mind. This round of interviews was seen as validation of the improvements made to the **cosmetic appearance of cineplasty**, and an estimation **whether patients would be open for this technique** nowadays.
The interviews were executed with the help of the prototype and a slide show. See *Appendix E.III* for more information about the interview set up.

All stakeholder groups were represented: 2 prosthesis users, 4 clinical experts and 2 prosthetists were interviewed (a total of 8 experts). Questions were derived specifically for each stakeholder group, consisting of different parts:

- Stakeholder specific questions, comparing the two versions of cineplasty in their area of expertise
- General questions about the Cover, based on questions about the satisfaction rate of medical devices from the D-Quest (Wessels, de Witte & Knops, 2003) and a similar questionnaire focused on prosthetics called TAPES (Gallagher & Maclachlan, 2000). An overview of how these questions were derived *Appendix E.IV*
- General potential of the improved concept of cineplasty questions.

An overview of the interview answers could be found in *Appendix E.V* .



Figure 77. Experts involved in validation interviews

5.3.2 Interview results

All stakeholders confirmed that the renewed concept offers a noticeably improved cosmetic outcome compared to the original cineplasty design. One clinical expert described the previous version as “deterring,” whereas the new approach was associated with being “fancy” (C2). A prosthesis user similarly expressed: “I am surprised by how beautiful it can look and how functional it can be” (U2). Despite this, overall enthusiasm regarding the broader applicability of cineplasty remains moderate. An overview of the interview responses from this third round can be found in *Appendix E.IV.*

Surgery level and risks

Clinical experts generally expect the proposed procedure to involve **fewer risks** than the current technique, primarily due to the omission of a skin transplant (C2, C5, C6, C7). For instance, C5 noted that the operation may become slightly more straightforward for this reason. Conversely, C7 anticipated a modest increase in difficulty, as the revised technique results in a narrower tunnel. Overall, experts indicated that the new surgical approach is unlikely to substantially affect the technical complexity or duration of the procedure. All experts acknowledged the value of the improved technique, highlighting two main advantages: **reduced impact on the patient** and **enhanced cosmetic outcomes**. Additionally, one clinical expert emphasised that the absence of a skin transplant prevents loss of skin sensibility (C2).



Figure 78. P2 analysing prototype



Figure 79. P2 analysing Cover

	U	C	P	Average
Color	6.5	5.5	5	**5.7**
Shape	6	5.8	5	**5.6**
Appearance	6	5.8	6	**5.9**
Measurements	6	4.7	5	**5.2**
Safety	6	5	5	**5.3**
Sustainability	6.5	4.7	6	**5.4**
Ease of use	6.5	5.3	4	**5.3**
Average	**6.2**	**5.3**	**5.1**	

Figure 80. Average scores for various properties of the Cover (scale 1-7)

Cover analysis

When evaluating the Cover independently, experts were generally positive about both its function and appearance. The Cover not only enhances aesthetics but also prevents the mechanism from catching on clothing or environmental objects, and reduces the likelihood of dust entering the tunnel (C2, C5). Figure 80 presents the average scores (1–7) for the various properties of the Cover. Notably, **prosthesis users rated these properties significantly higher** than other experts. Since prosthesis users are closest to the target group and most likely to use the Cover, these findings may warrant particular attention. However, given the small sample size (n=2), all expert perspectives are considered equally.

The perceived value of the new surgical technique and the addition of the Cover varied among experts. Some expected prosthesis users to eventually neglect the Cover (C6, P5), whereas others believed its concealing function would be highly valuable (C2, U1). The modularity of the concept was widely appreciated: users who prefer the Cover can easily adopt it, while those who do not see its value can simply opt out (C5).

Potential of the renewed version of cineplasty

Both prosthetists agreed that the **cosmetic appearance has improved** compared to the previous version. However, they remained uncertain whether prosthesis users would be receptive to the technique: “It should be explained really well to the prosthesis user” (P5). They also emphasised the importance of clinical and prosthetic professionals being fully informed about the advantages and disadvantages of the technique to provide a complete and balanced perspective to potential users (C2, P5). All experts noted that the suitability of cineplasty would vary from person to person.

The prosthesis users were more open to the renewed version than to the original technique. They appreciated that the rod is no longer visible, and one user even stated that she would have considered the procedure had this version been available when she was younger (U2). Both agreed that **cineplasty could hold value for prosthesis users today**—a sentiment shared by 5 out of 8 experts (the remaining experts were uncertain but did not reject

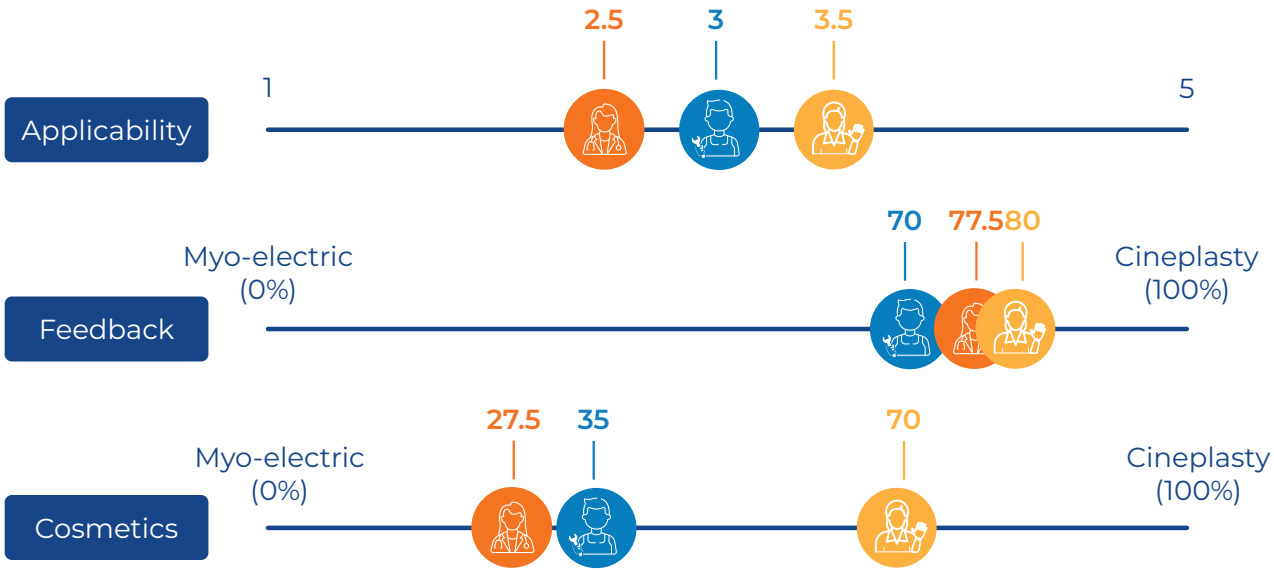


Figure 81. Estimation of the applicability of cineplasty in the contemporary society and comparison of myoelectric and cineplastic prostheses by stakeholder groups

the idea).
Figure 81 presents the expert ratings comparing the new cineplasty technique with a myoelectric prosthesis in terms of feedback and cosmetics. When focusing on feedback, cineplasty was preferred (77.5%). In contrast, regarding cosmetics, the myoelectric prosthesis remained the favored option (40%). Interestingly, prosthesis users rated the cosmetic value of cineplasty substantially higher than other experts (70% compared to 27.5% and 35%), mirroring their higher ratings for the Cover.

Experts also expressed several concerns. The overall applicability of this version of cineplasty for contemporary patients was rated at 2.6 out of 5 (Figure 81). Again, prosthesis users provided the highest estimates. Responses ranged widely from 1 to 4, even within the same expert group, indicating that **expectations regarding cineplasty's potential vary considerably**.

Reasons for criticism included the persistent presence of a hole through the arm despite the improvements (C7, P2), and the fact that surgery remains necessary, which is a major disadvantage compared to non-surgical alternatives (C6, P2). Another drawback mentioned was that the Cover creates an upper-arm "machete" shape, whereas prosthetists prefer to keep as much of the arm uncovered as possible for lower-arm prostheses (P2). Additionally, some experts questioned whether prosthesis users prioritise cosmetics to the extent suggested, as prosthetists reported little experience with users complaining about aesthetics (they have had contact with a total of 4 cineplastic prosthesis users) (P2, P5).

This raises an important point. When experts were asked to rate functionality, cosmetics, and comfort, their responses differed markedly. Surgeons and prosthetists generally ranked cosmetics last, whereas the three prosthesis users rated cosmetics first and second. Conversely, all prosthesis users ranked functionality last, while other experts

consistently placed it first. This discrepancy is noteworthy and may warrant further investigation.

Suggestions for further research

Experts proposed several avenues for refinement and future investigation. Some suggested exploring alternatives to the current Cover to improve cosmetics, such as a foam-based filler shaped to mirror the contralateral arm, as maintaining bilateral symmetry is often important to patients (C2), or a simple sleeve placed over the pin (U2). Others recommended enhancing realism by adding a thin cosmetic skin layer (C5).

Several technical improvements were also identified, including **enabling pronation–supination** by allowing the cable to glide through the rod (C7). Additional suggestions focused on usability in low-maintenance contexts (C2) and on investigating the potential fo integrating the rod in the forearm muscles instead of the biceps, as arlier cases demonstrated successful direct incorporation into the prosthesis. This may require reconsidering cable routing to avoid sharp angles, potentially returning to a leather strap system or exploring triceps-based actuation, with steel cables to reduce friction (P2). Further opportunities include **supporting forearm elevation** by eliminating the outer cable and reconsidering the pivot point to support flexion, which may be particularly beneficial for very short residual limbs (C7, P2).

Material-based improvements—such as resin casting with carbon reinforcement, elastic front closures, and ensuring stability during muscle contraction while maintaining ease of donning and doffing—were also highlighted (P5). Together, these insights point to a rich set of technical and user-centred directions for continued development.

Conclusion: analysis of the new version of cineplasty

Overall, the expert validation indicates that the renewed cineplasty concept offers clear improvements in cosmetic appearance and reduces the invasiveness of the surgical procedure, primarily due to the **omission of a skin transplant**. While clinical experts acknowledge minor differences in technical difficulty, they agree that the revised technique does not substantially alter surgical risk or duration and provides meaningful benefits for patients. The Cover is generally regarded as a valuable addition, enhancing both aesthetics and usability, although opinions differ regarding its long-term adoption by prosthesis users.

The perceived potential of the renewed cineplasty technique varies considerably across stakeholders. **Prosthesis users are notably more positive**—particularly regarding cosmetic outcomes—than clinicians and prosthetists, who remain cautious about its applicability in contemporary practice. This divergence highlights an important discrepancy between professional expectations and user perspectives. Although cineplasty is not universally viewed as suitable for all patients, the findings suggest that, for selected individuals, the renewed approach could offer a meaningful alternative, warranting further exploration and user-centred evaluation.

Conclusion

The Deliver phase finalises the renewed version of cineplasty by combining two key developments: an adapted surgical technique and a cosmetic Cover designed to conceal and protect the cineplastic rod. Together, these elements directly address cineplasty's greatest historical limitation—its poor cosmetic appearance—while preserving its defining advantage: natural proprioceptive feedback.

The adapted surgical procedure reduces the tunnel diameter and repositions the flap toward the medial side of the arm, **decreasing the need for skin transplantation** and placing scarring in a more discreet location. In parallel, the Cover was developed through iterative sketching, CAD modelling, 3D printing, and silicone moulding. The final design is anatomically shaped, advised to make use of 3D scanning, reinforced for durability, and discreet under clothing, **offering both protection and improved aesthetics**.

Validation with experts (prosthesis users, clinicians, and prosthetists) confirmed that the renewed version of cineplasty offers a **substantial cosmetic improvement** over the historical technique. The Cover was generally well received for its protective and aesthetic qualities, though opinions varied regarding long-term user adoption. Experts also agreed that the adapted surgical technique reduces invasiveness and improves cosmetic outcomes, while maintaining comparable surgical complexity. Importantly, prosthesis users were consistently more positive about the renewed concept than clinicians or prosthetists, particularly regarding appearance, highlighting a notable **divergence between professional expectations and user perspectives**.

Despite these improvements, **experts remain cautious about cineplasty's broader applicability.** Surgery remains a significant barrier, and the presence of a hole through the arm -even when concealed- continues to raise concerns compared to current alternatives. Yet the renewed concept demonstrates that meaningful progress can be made toward addressing cineplasty's cosmetic limitations while preserving its unique proprioceptive benefits. For selected users, especially those who value intuitive control and natural feedback, this modernised approach may offer a viable alternative within the contemporary prosthetic landscape.

Overall, the Deliver phase presents a coherent and validated direction: a refined surgical method combined with a discreet, functional Cover that together elevate cineplasty closer to the standards of modern prosthetic care. These outcomes form a strong foundation for future work, including user testing, further material optimisation, and exploration of additional cosmetic and functional refinements.

6. Evaluate

This chapter evaluates the project by discussing its strengths and limitations, concluding the main findings and recommending future researchs. Finally, with help of a reflection, the complete project is wrapped.

6.1 Discussion
6.2 Conclusion
6.3 Recommendations
6.4 Reflection

6.1 Discussion

Interpretation of results

The results suggest that cineplasty may hold value for a specific subgroup of users who prioritise intuitive control and robustness over aesthetics or surgical avoidance. However, the strong variation in responses, particularly between prosthesis users and clinical experts, indicates that acceptance is highly individual and shaped by personal priorities, lived experience, and expectations. The renewed concept appears promising, but its applicability is not universal.

Relation to historical literature

While it is challenging to compare these findings to historical literature due to differences in surgical standards, user expectations, and technological context, a tentative conclusion states that the findings align with early cineplasty literature, which consistently emphasised the technique's exceptional proprioceptive feedback and mechanical reliability. Historical concerns like cosmesis, invasiveness, and user acceptance also reappear in this study. The renewed concept demonstrates that several of these historical limitations can be mitigated with modern materials and surgical refinements, yet **the fundamental trade-off between proprioception and cosmetic acceptability remains**.

Strengths and limitations

The strengths of this research lie primarily in the relatively **large number of interviews** that were conducted for such a specialised topic (29 interviews with 18 experts) which resulted in rich qualitative data. In addition, the study draws on a highly diverse pool of experts, including plastic and orthopaedic surgeons, rehabilitation physicians, prosthetists, prosthesis users, and ergotherapists, ensuring that the topic was examined from all clinically and practically relevant perspectives. Frequent contact with experts throughout the design process strengthened the iterative development and increased ecological validity. The combination of design research, prototyping, and medical consultation further provided a multidisciplinary perspective that is rarely achieved in studies on prosthetic control.

Another unique aspect of this project is the exceptional access to a long-term cineplastic prosthesis user—an extremely rare opportunity given the age and niche nature of the technique—which provided unique insights into the lived experience and long-term functionality of cineplasty. Because contemporary literature on cineplasty is scarce, the findings contribute valuable new knowledge to an underexplored field.

Despite these strengths, several limitations must be acknowledged. The relatively large number of interviews, are still **small absolute numbers**. Besides, acceptance of cineplasty varies strongly between individuals, shaped by personal expectations, priorities, and previous prosthetic experience, which complicates generalisation. Ratings of comfort, appearance, and desirability differed most notably between experts and prosthesis users, revealing perceptual gaps that may influence interpretation. Some experts questioned whether prosthesis users truly prioritise cosmetic appearance to the extent suggested, as prosthetists rarely hear complaints about aesthetics in practice. It also remains **uncertain whether the surgical threshold and cosmetic improvements are sufficient for broad acceptance**, as this threshold is highly individual.

Another note that should be made is the fact that all prosthesis users

interviewed were female, whereas the anticipated target group for cineplasty is predominantly male, meaning **gender-related differences** in cosmetic priorities may have influenced the results. The sample size—particularly on the user side—was small, limiting generalisability. The study focused on Dutch experts, which may not reflect perspectives in regions with different prosthetic needs, resources, or cultural attitudes.

Finally, one clinical expert that was interviewed in the context phase was involved in the project as a supervisor, which could have led to **conflicted interests**. Later on in the project, this stakeholder was not included in interviews anymore.

Reliability of expert feedback

The expert feedback provides valuable insight into feasibility, risks, and clinical considerations, but it cannot fully predict real-world usability for amputees. Experts can assess surgical risk and mechanical feasibility, but only users can judge long-term comfort, embodiment, and daily practicality. The absence of current cineplasty users limits the ability to validate experiential aspects, meaning that **expert feedback should be seen as indicative rather than definitive**, highlighting promising directions but not guaranteeing user acceptance. Because experts contributed ideas during development, their later positive evaluation may partly reflect confirmation bias, as they were responding to a concept shaped by their own input. Similarly, prosthesis users were friendly and cooperative, which may have introduced social desirability **bias**, while experts may have been influenced by enthusiasm for the project. A critical view remains important throughout the project.

Future work

To move toward clinical application or user validation, several steps are required. First, the adapted surgical technique should be tested on anatomical specimens (either cadaveric or synthetic models) to evaluate tunnel closure, flap tension, and rod mobility under realistic anatomical conditions. In this study, the functional performance of cineplasty was cautiously assumed to be sufficient based on historical literature, but this **assumption must be re-examined** using modern materials and surgical techniques to determine whether these functional advantages still hold true today. In parallel, biomechanical testing of the Cover and rod interface is needed to assess durability and behaviour under load. Early pilot studies with amputees could then be initiated, beginning with non-invasive simulations before progressing toward any surgical trials. Further optimisation may also be achieved by exploring alternative materials, attachment methods, and terminal devices to enhance comfort and long-term usability. Additionally, a clinical protocol outlining indications, contraindications, and rehabilitation guidelines will be essential for safe implementation. However, the most important first steps involve gaining a deeper understanding of preferences and expectations amongst dependent on genders, cultural factors, and user priorities in cosmetic acceptance, as these factors are likely to strongly influence the real-world adoption of a renewed cineplasty technique.

6.2 Conclusion

This thesis set out to explore whether cineplasty -a century-old technique that directly links muscle contraction to prosthetic control- could hold renewed value in contemporary prosthetic care. Through historical analysis, expert consultation, iterative design, and prototyping, the project examined what a modernised version might offer to today's prosthesis users.

The findings show that a renewed form of cineplasty, combining an adapted surgical technique with a cosmetic Cover, can substantially improve the aesthetic outcome of the method while preserving its defining advantage: natural proprioceptive feedback. A property that remains difficult to replicate with current technologies and continues to distinguish cineplasty within the broader landscape of prosthetic control.

Experts agreed that the revised approach reduces invasiveness, improves scarring, and offers a more discreet interface, and prosthesis users responded more positively to the cosmetic improvements than clinicians anticipated. At the same time, **enthusiasm for widespread adoption remains moderate**, largely due to the surgical threshold and the low cosmetic outcome, compared to contemporary prosthetic alternatives such as myoelectric and body-powered systems, that offer better cosmetic outcomes without requiring surgery. These non-invasive options set a high baseline for appearance and convenience, making it more challenging for cineplasty to compete despite its functional strengths.

When viewed in relation to historical literature, the results cautiously align with early reports that emphasised cineplasty's exceptional proprioceptive performance and mechanical reliability. Historical concerns regarding cosmesis, invasiveness, and user acceptance reappear in this study, though modern materials and surgical refinements demonstrate that several of these limitations can be mitigated. Nevertheless, the fundamental trade-off between proprioception and cosmetic acceptability remains. The renewed version represents a **meaningful improvement over the original technique, yet it does not fully resolve the tension between functional benefit and aesthetic demand.**

Results suggest that cineplasty may be valuable for a specific subgroup of users who prioritise intuitive control, robustness, and proprioceptive feedback over cosmetic appearance or avoidance of surgery. However, **acceptance is highly individual and shaped by personal priorities, lived experience, and expectations**. Responses varied most strongly between prosthesis users and clinical experts, underscoring that the perceived value of cineplasty depends heavily on what users consider most important. As a result, the overall applicability of the renewed technique is expected to be moderate: promising for a niche group, but unlikely to become a mainstream alternative without further evidence and refinement.

Ultimately, while expert feedback has been invaluable in shaping and evaluating the renewed cineplasty concept, it cannot fully predict real-world usability; only prosthesis users themselves can judge long-term comfort, embodiment, and daily practicality. This thesis demonstrates that cineplasty—when modernised—still holds meaningful potential, but its future depends on creating a deeper understanding of user expectations and priorities and careful, evidence-based development. Cineplasty remains a

compelling concept: historically grounded, functionally unique, and capable of offering intuitive control that current technologies struggle to replicate. The renewed version developed in this project represents **a significant step forward,** yet its ultimate value will depend on whether its functional advantages can outweigh its aesthetic and surgical demands for the users who may benefit most. With thoughtful refinement and continued research, cineplasty may find its place as a specialised but valuable option within the broader landscape of prosthetic care.

6.3 Recommendations

Building on the insights gained throughout this project, several recommendations can be made to guide design refinement, future research, and potential clinical exploration of a renewed cineplasty technique.

Refinements of the current design

The renewed design provides a promising direction, where several aspects could be improved to optimise both functionality and cosmetic acceptance. Experts suggested exploring alternative Covers to enhance appearance, such as a **foam-based filler** shaped to mirror the contralateral arm (C2) or a simple sleeve placed over the pin (U2). On the other side, framing the pin as jewelry as drawn in *Chapter 4.2.2* could be an interesting approach. Because of aesthetic considerations the colour of the silicone should be more transparant.
Technical refinements were also proposed, including **enabling pronation–supination** by allowing the cable to glide through the rod (C7). There should also be looked more closely to the cable management, since friction is high, which should be prevented around the Cover. Another idea mentioned by experts was **facilitating forearm elevation** by removing the outer cable and reconsidering the pivot point—particularly relevant for very short residual limbs (C7, P2). Together, these expert insights highlight clear opportunities for further user-centred and mechanical development of the renewed cineplasty system.

Deeper understanding of patient expectations and priorities

Like mentioned before, more research should be done in patient selection and user-centred validation. Before any surgical trials, non-invasive simulations or virtual prototypes should be used to explore user acceptance, perceived control, cosmetic expectations, and willingness to undergo surgery. This research should include a broader and more diverse group of participants to validate whether the identified target group is appropriate. Special attention should be given to gender differences, cultural factors, and lifestyle-related priorities, as these strongly influence cosmetic acceptance and decision-making.

Additionally, several experts noted potential relevance for low-resource settings, but this should be approached with caution. Any implementation in such contexts must ensure that surgical expertise, prosthesis fabrication, and long-term support are available—either through travelling specialists or dedicated local clinics—to avoid shifting responsibility without adequate infrastructure.

Promoting awareness and informed

Many experts were unfamiliar with cineplasty prior to this project and initially reacted with hesitation or discomfort. Their attitudes shifted significantly after receiving clear explanations and seeing the renewed design. This highlights the importance of proper education and communication (C2, C6, C7, P2, P3)—not only for clinicians, but especially for potential users. Moreover, the need for collaboration with a prosthetist, doctor and patient advised (also by Sauerbruch), to have a clear view in options for the optimal clinical pathway (Weir, 1995). If cineplasty is to be reconsidered in modern practice, it should be integrated into prosthetist training programmes to ensure that professionals understand the technique and can fabricate appropriate prostheses. Clear, accessible information for patients will also be essential to support informed decision-making.

Level of amputation

A first recommendation concerns the anatomical level of application. Historical literature and expert input could suggest that cineplasty may be **more suitable for upper-arm amputees** than for lower-arm amputees. Earlier studies by Brav et al., (1957) and Weir (1995), already questioned the usefulness of cineplasty in long above-elbow amputations, as the a valuable advantage, freedom from constricting harnessing, does not apply in the same way. At the same time, prosthetists in this study emphasised that upper-arm amputees have fewer viable alternatives, face more fitting challenges, and often struggle with myoelectric control due to limited signal sites (P1, P4). Future research could therefore prioritise the upper arm as the primary target group and investigate whether the renewed technique can meaningfully address their specific functional needs.

Elbow lock versus hand control

A second recommendation relates to the functional role of cineplasty. Both historical accounts and contemporary expert interviews indicate that cineplasty has often been repurposed from hand actuation to elbow-lock control. This pattern was observed in U3 and in multiple cases described by P5. Further investigation is needed to understand why this shift occurs—whether it reflects limitations in force generation, challenges in hand control, or simply user preference. Clarifying this will help determine whether cineplasty should primarily support terminal device actuation, elbow control, or a hybrid approach.

Force enhancement

A fifth recommendation is to investigate force enhancement and terminal device optimisation. Literature reports inconsistent findings regarding force output, and initial hands-on testing in this project suggests that generating high pinch forces may be challenging. Further biomechanical research is needed to quantify force transfer, identify limiting factors, and explore whether new terminal devices or mechanical configurations could improve performance.

This could be explored by **hybrid systems** that combine cineplasty with electric control. Prior research by Weir et al. (2001) suggests hat if the prosthesis is externally powered, the cineplastic tunnel no longer needs to generate high force but can instead function as a control signal. This approach could reduce surgical demands while preserving intuitive control. Investigating such hybrid systems may open new pathways for integrating cineplasty into modern prosthetic technology.

Prosthesis design

A fourth recommendation is to continue improving the prosthetic interface. Material and design innovation will be crucial to enhance comfort, durability, hygiene, and cosmetic appearance. Opportunities include exploring alternative Covers, such as foam-based fillers shaped to mirror the contralateral arm, or simple sleeves that conceal the rod. Technical refinements—such as enabling pronation–supination by allowing the cable to glide through the rod, or adjusting the pivot point to support forearm elevation—could further improve usability, especially for short residual limbs. These improvements can draw inspiration from existing body-powered prostheses, which operate on similar mechanical principles.

Together, these recommendations outline a clear path forward: deepen understanding of user priorities, refine the technical and cosmetic aspects of the design, validate the surgical technique through anatomical testing, and explore both mechanical and hybrid control possibilities. These steps will be essential to determine whether cineplasty can evolve into a safe, functional, and desirable option within contemporary prosthetic care.

6.4 Reflection

This chapter reflects on the process, outcomes, and personal development that shaped this graduation project. Throughout the past months, the project evolved in ways I had not fully anticipated, shifting from an expected design-driven trajectory toward a more **research-intensive exploration**. This transition brought challenges, learning moments, and opportunities for growth. By examining both the process and the results, as well as my progress in relation to the IDE learning goals and my own preset objectives, this reflection aims to provide an honest and critical account of how the project unfolded and what I learned along the way.

Process evaluation

At the start, I expected the project to focus more on design and prototyping. However, it quickly became clear that substantial research was needed before any meaningful design work could begin. Accepting this shift took time, but ultimately it strengthened the project. Still, in hindsight, I should have been **more decisive in cutting tasks** earlier. Looking back on the process, I recognise that I initially approached the project too broadly. Out of uncertainty and a desire to be thorough, I tried to include every possible angle, which made it difficult to narrow the scope early on. I spent a long time searching for literature (much of which was simply not available), which caused delays and frustration. The practical side of the research also took far more time than anticipated: sending emails, arranging interviews, preparing materials, and waiting for responses all consumed large parts of my days. I often overestimated what I could achieve in a single day and **underestimated the logistical overhead of qualitative research**.

I also invested many hours in shadowing days, which were incredibly valuable for understanding the clinical context but perhaps disproportionate in time investment relative to the project timeline. For my personal development, these experiences were invaluable; for the project, a more balanced approach might have been more efficient.

Another challenging aspect of this project was the HREC approval process. The requirements were unclear to me, and I had to revise my application extensively, even though the study involved only interviews. This was demotivating and time-consuming, especially because I struggled to understand what level of detail was expected. It taught me patience and the importance of documenting ethical considerations thoroughly, even when the study seems low-risk.

The contact with my supervisors were a stable factor troughout the whole project. My experience in collaboration with supervisors was very positive. I experienced to be in control of the project, and could ask them for guidance or advice when necessary. Meetings were well prepared, and the feedback was constructive and motivating. At times, their enthusiasm made me hesitant to ask for more critical input, which could have helped sharpen my direction earlier. Midway through the project, I experienced a setback because I had placed too much pressure on myself. This withheld me from showing results and actively asking for feedback, since I was convinced it was not good enough. I learned to put this pressure into perspective and to **accept that a six-month project cannot cover everything**. I started to see that making choices is not a weakness but a strength, and I became increasingly confident in doing so.

My view on achieved results

Although I would have liked to redesign the entire prosthesis using modern materials and production techniques, this was not feasible within the available time. Such a redesign would have allowed experts to evaluate the renewed concept more realistically, but narrowing the scope was ultimately the right decision. Experts already have a good understanding of contemporary prosthetic materials, so a full redesign was not essential for validation.

The project naturally shifted toward research rather than prototyping, and in retrospect **I am proud of this direction**. The strong research foundation allowed me to formulate grounded recommendations and identify meaningful design opportunities. I particularly enjoyed the extended research phase: speaking with many different stakeholders, identifying patterns, and connecting insights across disciplines. Although the prototype itself remained of limited level, the evaluation of the concept was thorough and provided a clear direction for future development.

Reflecting on IDE Learning Goals

Possess deep disciplinary knowledge

Throughout the project, I applied a range of theories, methods, and tools from the IDE domain (see *Appendix B.II* for a compendium). When more time for ideation and prototype would be available, a wider variation of methods could have been used. I engaged with historical literature, qualitative research methods, medical design principles, and prosthetic technology. This combination strengthened my disciplinary foundation and broadened my understanding of prosthetic systems.

Apply design thinking in context

I analysed the problem within a realistic, complex, and interdisciplinary setting. The project required me to integrate technological aspects (cineplasty), social perspectives (users and experts), and ethical considerations (careful interview design and HREC approval). Although I would have liked to explore the technological side of prostheses more deeply, time constraints required prioritisation.

Generate and evaluate designs and prototypes

The project placed more emphasis on evaluation than on developing a fully refined prototype. As a result, the outcome is more of a design direction than a near-final product. Several improvements could still be made to the Cover in terms of aesthetics and mechanical performance. However, I believe I performed strongly in evaluating the prototype and validating the design direction with experts.

Communicate and collaborate effectively

Communication with stakeholders generally went well, though scheduling was challenging. Meetings were often rescheduled or cancelled, and once an expert expressed dissatisfaction with the planning process. I learned the importance of double confirmation, ensuring that stakeholders personally receive meeting details, and planning several weeks in advance, especially with busy clinicians. I also found an effective balance between reminding participants and avoiding excessive follow-up.

Demonstrate personal attitude & professionalism

My enthusiasm for the project was contagious, but it **sometimes led me to take on more than was realistic**. This occasionally created chaos in planning,

especially around shadowing days. I learned to recognise my limits and to prioritise more effectively. Despite these challenges, I maintained a professional attitude and remained committed to producing high-quality work.

Balance feasibility, sustainability, and innovation
The proposed design direction is both innovative and feasible. Sustainability was considered in terms of long-term use, modularity, and low maintenance. However, the Cover is not as innovative as I initially hoped. Future work should explore redesigning the entire prosthesis to achieve a more transformative outcome.

Reflecting on preset personal goals
Personal goals were drawn up in the beginning of the project, and could be found in *Appendix X A.I* Project Brief.
Develop and strengthen interview skills
I improved significantly in **formulating interview questions, probing deeper during conversations, and identifying underlying factors** behind participants' remarks. I learned to uncover the "problem behind the problem" and to handle difficult or unfriendly interactions professionally.

Develop and strengthen research skills
Conducting a scoping review was entirely new to me and particularly challenging due to the age and scarcity of the literature. The historical analysis was also new to me but extremely valuable. At times, I found the research demanding and could have asked for more guidance. I still plan to document the literature more thoroughly for potential publications.

Expand interdisciplinary knowledge
This goal was fully achieved. I **collaborated with professionals from many fields**: surgeons, prosthetists, rehabilitation physicians, and prosthesis users. I learned about surgical techniques, prosthetic fitting, and patient experiences. Shadowing at RHOC and observing prosthesis fittings provided deep contextual understanding and strengthened the medical reliability of my work.

Enjoy and learn from stakeholder engagement
I found the interviews highly enjoyable. **Experts were enthusiastic and supportive**, contrary to my initial fear that they might see me as a burden. Their openness made the research phase particularly rewarding.

Learn from the research process
I gained extensive experience in literature analysis, qualitative interviewing, synthesising large amounts of data, and assessing the reliability of findings. These skills will be valuable in future research and design work.

Reflecting on this project highlights how much **I have grown as a researcher, designer, and collaborator**. The process taught me to make deliberate choices, manage uncertainty, and mostly balance ambition with feasibility. Although the project shifted toward research more than initially planned, this ultimately strengthened the quality and depth of the outcomes. I gained valuable experience in interdisciplinary collaboration and qualitative research. This reflection not only summarises what I achieved, but also marks an important step in my development as a professional within the field of multidisciplinary research and design.

AI statement

Microsoft Copilot was used to summarise information from articles and to structure the sentences on a higher academic level. Moreover, AI was a contributing factor in generating conclusions out of big pieces of text. Output was checked by the researcher. The researcher takes full responsibility for the content of this report.

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Appendix

A. Introduction

A.I Project Brief

DESIGN FOR our future

TU Delft

Personal Project Brief – IDE Master Graduation Project

Name student Nynke Heeringa **Student number** 5072697

PROJECT TITLE, INTRODUCTION, PROBLEM DEFINITION and ASSIGNMENT
Complete all fields, keep information clear, specific and concise

Project title The potential of a fully mechanical upper limb prosthesis with the use of cineplasty in the 21st century

Please state the title of your graduation project (above). Keep the title compact and simple. Do not use abbreviations. The remainder of this document allows you to define and clarify your graduation project.

Introduction

Describe the context of your project here; What is the domain in which your project takes place? Who are the main stakeholders and what interests are at stake? Describe the opportunities (and limitations) in this domain to better serve the stakeholder interests. (max 250 words)

The project takes place in the medical technology domain, focusing on prosthetic design for individuals with lower-arm amputations. Losing a limb due to trauma or illness has a profound impact on a person's independence and quality of life. Prostheses can help restore functionality (Diaz-Garcia & Cederna). Yet, many users still struggle with limited control and lack of sensory feedback (G. Kraan, personal communication, 20 June 2025; Jansen & de Vries, 2018).

Cineplasty is a surgical technique where the prosthesis is mechanically controlled by a rod connected to the muscle belly, typically in the biceps, once offered a direct way to move and feel the prosthesis, see Figure 1 (Brückner, 1992). After World War II, it enabled thousands of people to regain functional us of the limb. However, with the rise of electromyography (EMG) and other contributing factors, cineplasty fell into obscurity (G. Smit, personal communication, 17 September 2025; Childress, 2002).

Revisiting this technique in a modern context could provide new opportunities. Cineplasty offers natural proprioceptive feedback, which is essential for intuitive control and handling (Jansen & de Vries, 2018). The main stakeholders include patients, surgeons, rehabilitation professionals, and healthcare providers. For patients, improved feedback could enhance daily usability and confidence. For healthcare systems, the technique's potentially lower cost and durability could be economically advantageous.

At the same time, there are limitations: cineplasty provides fewer degrees of freedom, less cosmetic appeal, and lower pinch strength than modern EMG prostheses (Diaz-Garcia & Cenderna, 1992). Exploring how these limitations affect all stakeholders will be key to determining whether cineplasty deserves reintroduction in contemporary prosthetic care.

→ next available for images / figures on next page

Figure 1. Project Brief (1)



Problem Definition

What problem do you want to solve in the context described in the introduction, and within the available time frame of 100 working days? (= Master Graduation Project of 30 EC). What opportunities do you see to create added value for the described stakeholders? Substantiate your choice.
(max 200 words)

When someone loses a limb, the impact on their life is profound. A prosthesis could help them regain a lot of their independence and functionality (Diaz-Garcia & Cenderna). The cineplastic mechanical prosthesis has a relatively simple design, which brings benefits such as reduced costs and increased durability (G. Kraan, personal communication, 20 June 2025; Diaz-Garcia & Cederna). Perhaps its most significant benefit, however, is the direct proprioceptive feedback it provides, allowing users to feel the movements of the prosthesis (Jansen & de Vries, 2018). This has great advantages in controlling and handling the prosthesis (Brückner, 1992; Jansen & de Vries, 2018). On the other hand, cineplasty has some serious drawbacks: the prosthesis' degrees of freedom are limited, it has quite poor cosmesis and a low pinch strength compared to EMG prostheses (Diaz-Garcia & Cenderna).

The challenge of this project is to explore which of these limitations could be mitigated using modern materials and technologies, and whether an improved cineplastic prosthesis would be desirable in today's context.
By addressing these issues, the project could create added value for patients by enhancing control, usability, and confidence, while potentially offering economic and practical benefits for healthcare providers and rehabilitation teams.

Assignment

This is the most important part of the project brief because it will give a clear direction of what you are heading for.
Formulate an assignment to yourself regarding what you expect to deliver as result at the end of your project. (1 sentence)
As you graduate as an industrial design engineer, your assignment will start with a verb (Design/Investigate/Validate/Create), and you may use the green text format:

Design a prototype based on the principle of cineplasty to validate whether cineplasty is desireable for lower arm amputees in the contemporary society.

Then explain your project approach to carrying out your graduation project and what research and design methods you plan to use to generate your design solution (max 150 words)

To investigate whether cineplasty is desirable in contemporary society, I will first broaden my knowledge of hand prostheses. This will involve conducting interviews with healthcare professionals (surgeons, physiotherapists) and patients, shadowing both surgeons and prosthesis users, and reviewing the relevant literature. My initial focus will be on understanding why cineplasty fell into obscurity and identifying which aspects could be improved so that these limitations no longer pose obstacles. Additionally, I aim to explore the current methods available for providing proprioceptive feedback to prosthesis users.

Based on these insights, my goal is to design a prototype of a modern mechanical prosthesis, to be able to give an updated vision on cineplasty. Ultimately, I intend to validate whether such a modernized cineplastic prosthesis would be desirable to both patients and healthcare professionals. This way, I aim going to assess the potential value of reintroducing cineplasty from both the patient's and the clinicical's perspective.

Figure 2. Project Brief (2)

Project planning and key moments

*To make visible how you plan to spend your time, you must make a planning for the full project. You are advised to use a Gantt chart format to show the different phases of your project, deliverables you have in mind, meetings and in-between deadlines. Keep in mind that all activities should fit within the given run time of 100 working days. Your planning should include a **kick-off meeting**, **mid-term evaluation meeting**, **green light meeting** and **graduation ceremony**. Please indicate periods of part-time activities and/or periods of not spending time on your graduation project, if any (for instance because of holidays or parallel course activities).*

Make sure to attach the full plan to this project brief.
The four key moment dates must be filled in below

Kick off meeting	10 October 2025
Mid-term evaluation	6 jan
Green light meeting	3/10/2025
Graduation ceremony	4/7/2025

In exceptional cases (part of) the Graduation Project may need to be scheduled part-time. Indicate here if such applies to your project

Part of project scheduled part-time	✓
For how many project weeks	4
Number of project days per week	2

Comments:
During the first 4 weeks, I am still following electives. However, I am planning on graduating before May, since I have planned a trip for May and June.

Motivation and personal ambitions

Explain why you wish to start this project, what competencies you want to prove or develop (e.g. competencies acquired in your MSc programme, electives, extra-curricular activities or other).

Optionally, describe whether you have some personal learning ambitions which you explicitly want to address in this project, on top of the learning objectives of the Graduation Project itself. You might think of e.g. acquiring in depth knowledge on a specific subject, broadening your competencies or experimenting with a specific tool or methodology. Personal learning ambitions are limited to a maximum number of five.
(200 words max)

The capabilities of the human body in terms of motion and movement fascinate me. When something in this complex system is not functioning properly, a striking amount of a person's freedom is taken away. I want to contribute to solutions that focus on regaining functionality through technology, particularly in areas where it can have the greatest impact: healthcare.

During this project, I aim to develop and strengthen my interview and research skills, while expanding my interdisciplinary knowledge through collaboration with professionals from different fields. Additionally, I hope to gain a deeper understanding of prosthetic design, orthopedic and assistive devices, and relevant surgical techniques, in order to better assess and contribute to technological solutions that enhance mobility and independence for patients.
Part of this process will involve designing and building prototypes, to as well test the principle as create a better understanding of its functions. By combining practical experience, literature research, and interdisciplinary teamwork, I aim to build the foundation to make meaningful contributions in the field of healthcare technology.

Figure 3. Project Brief (3)

A.II Planning

A Gantt chart was drawn up to create an overview of the tasks within the time phrame of the graduation (Figure 4).

This planning was divided in phases. Each phase had a more detailed planning, see Figure 5.

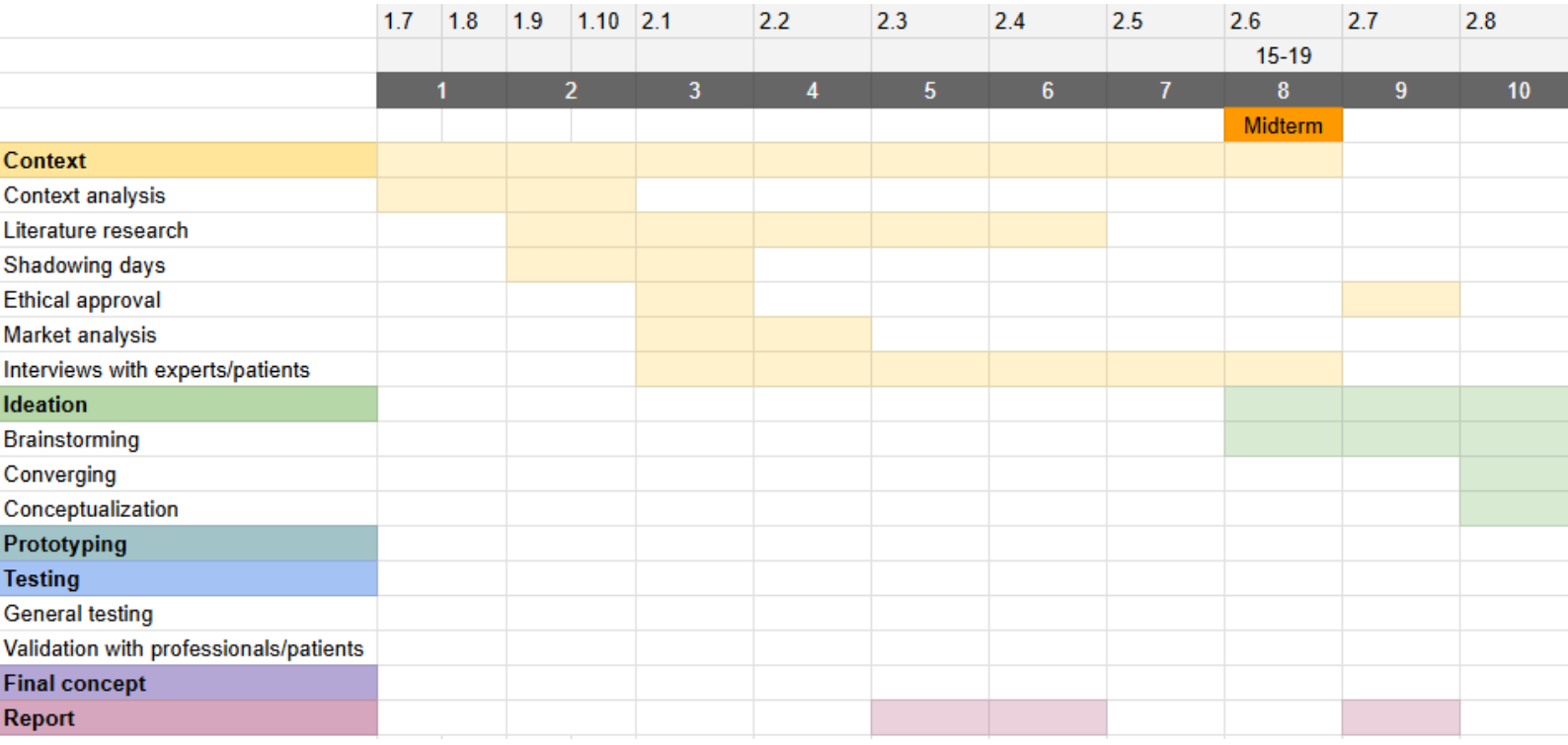

Figure 4.a. Gantt chart project planning (pt. 1)

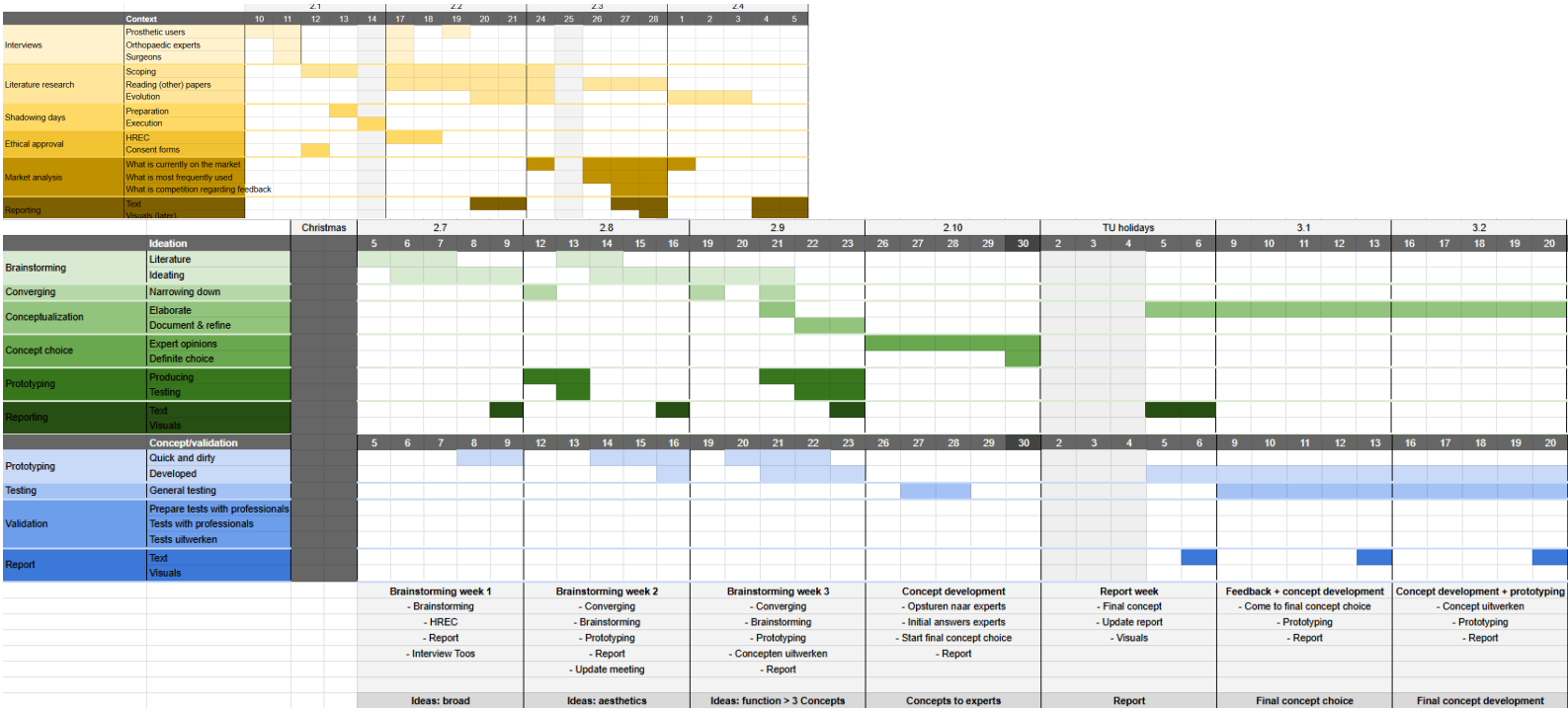

Figure 5. Detailed planning per phase

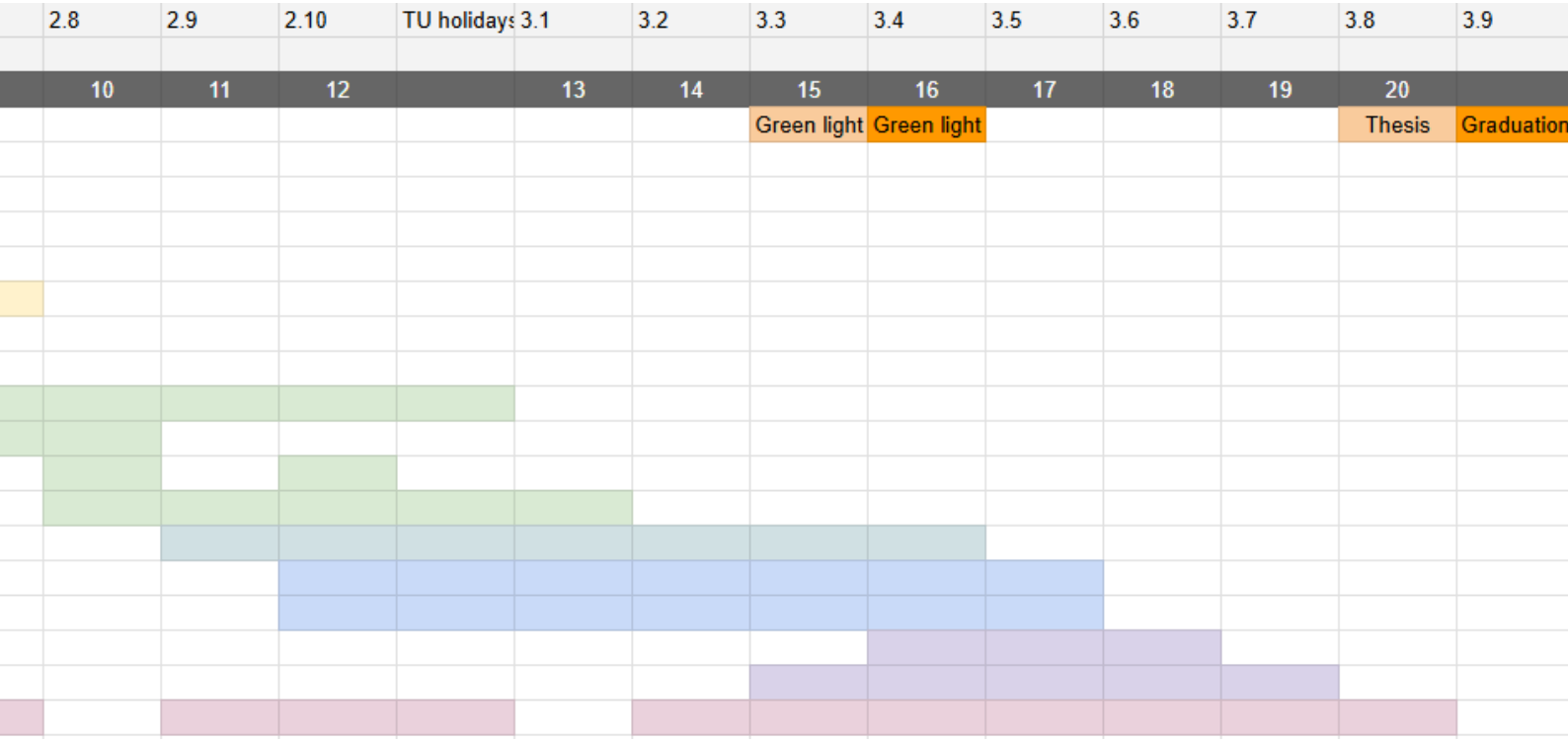

Figure 4b. Gantt chart project planning (pt. 2)

B. Discover

B.I Interview cineplastic prosthesis user (U3)

General questions

Achtergrond informatie

Q. Gender
Vrouw
Q. Leeftijdsrange
80+

Q. Wat is de oorzaak van uw verkorte arm?
Verkeersongeluk
SQ. Wat is de hoogte van uw prothese (onderarm/bovenarm)?
Boven de ellenboog.
SQ. Hoe lang heeft u al een prothese?
Rond 61, 62. 21, 22 jaar. Deze prothese nu 4 jaar, nieuwe ligt boven.
SQ. Wat waren uw overwegingen om een prothese te nemen?
Dit was toen de enige optie zeiden ze.
Q. Wat voor protheses heeft u al gehad?
Eerst hulpstokken. Tunneltje pas later gemaakt. Geopereerd door dokter Bosserds in SMK Nijmegen.
SQ. Welke prothese die u heeft gebruikt vond u het prettigst en waarom? Welke vond u het onprettigst en waarom?
Moet het doen met wat je hebt. Naar Leiden gegaan want meer in de buurt van protheseboumers.
SQ. Kunt u mee meenemen door de ervaring van het leren gebruiken van de prothese?
Best logisch hoe dat werkt, ging wel of ging niet. Dacht er niet zo bewust over na.

Prothese ervaring

Q. Hoe vaak gebruikt u uw prothese? Hoe veel uur per dag is dat ongeveer?
Eigenlijk altijd, sochtends bij opstaan aandoen en savonds voor slapen gaan uit.
SQ. Bij welke handelingen gebruikt u uw prothese vooral?
Doe bijna alles met gezonde hand, wanneer nodig klemmen erg handig.
SQ. Bij welke activiteiten gebruikt u uw prothese liever niet?
Gebruik hem niet bij fietsen, doe dat met één hand. En douchen zonder. Wanneer ze buiten loopt geen korte mouwen, want geen zin in bekijk of vragen. Bij zwemmen ook zonder.
Q. Wat vindt u voor- en nadelen van uw prothese?
SQ. Wat vindt u beperkend aan het gebruik van uw prothese? / Waar ziet u ruimte voor verbetering van de prothese?
Prima, doet het alleen niet altijd.
SQ. Wat vindt u fijn aan de prothese?

Hebben van een arm ziet er ‘gewoon’ uit als je anders een arm mist.
Q. Kunt u de volgende aspecten op volgorde van belang zetten?
- Een prothese die veel verschillende bewegingen kan maken met de hand en pols (4)
- Een prothese die tegen een stootje kan en lang mee gaat (2)
- Een prothese die intuïtief aangestuurd kan worden (3)
- Een prothese die er “mooi” uitziet (1)
- Normaal uitzien
- Niet snel stuk
- Aansturen
- Veel bewegingen

SQ. Wat vindt u belangrijk in het uiterlijk van een prothese?
Uiterlijk prothese zoveel mogelijk op echte huid lijken, kleur. Zo realistisch mogelijk.

Aansturing
Q. Welke bewegingen vindt u het belangrijkst om te kunnen?
Vastzetten van een houding van de ellenboog. Grijpen niet nodig. Ellenboog flexie meest interessant.

Cineplasty
Algemeen
Q. Wanneer heeft u de cineplastische operatie gehad?
Rond 61, 62. 21, 22 jaar.
SQ. Hoe lang maakt u al gebruik van de cineplastische prothese?
Bijna 60 jaar

Beweging
Q. Wat vond u van de grijpfunctie van de cineplastische prothese?
Niet nodig, ellenboog vastzetten veel nuttiger.
Q. Wat vindt u van het vast kunnen zetten van de ellenboog met de cineplastische prothese?
Prima.
Q. Hoe heeft u het leertraject ervaren om de prothese aan te sturen?
Prima, ging goed. Even wennen maar intuitief.
Q. Hoe ervaart u het aansturen van de prothese met de bicep?
SQ. Kunt u proberen te omschrijven hoe het voelt?
Heel normaal. Ben het gewend.
SQ. Wat vindt u van de aansturing vergeleken met andere protheses die u heeft gehad?
Nooit anders gehad.
SQ. Hoe ervaart u de manier van aansturing op het gebied van vermoeiing en precisie en zwaarte en gevoel in de bicep tijdens aansturen?
Niet heel precies, alleen vastzetten van ellenboog. Vermoeiing valt mee, niet zwaar.
Q. Hoe ervaart u de feedback van de cineplastische prothese? Ellenboog vs. hand
Nooit handbeweging gehad. Gebruikt ellenboog en duim om te klemmen. Aantrekken kabeltje via biceps zet ellenboog op slot.

Gebruik

Q. Kunt u mij meenemen door het proces om een prothese aan en uit te doen?
Prothese aan, staafje in het tunneltje, knoopjes aan drukken en klaar.
SQ. Wat is hierbij uitdagend en wat vindt u dat goed werkt?
Werkt prima. Zit goed vast. Sluitingkje soms met jas aan los, verder niet.
Doet het niet altijd. Als het heel zwaar is zakt ie wel eens door. Dan schiet het er doorheen. Ondersteun gauw met andere hand om te voorkomen dat het valt.

Q. Wat zijn uw taken rondom de dagelijkse hygiene van uw cineplasty?
Soms met een wattenstaafje als het wat vochtig is, eigenlijk niet zo vaak en niet echt nodig.
SQ. Wat vindt u daarvan?
Q. Heeft u last van huidklachten/andere ongemakken/pijn?
Nee en anders dagje niet. Ander materiaal minder fijn. Iets dikker en zat niet lekker. Stomp soms beetje rood.

Cosmetiek
Q. Wat vindt u van het cosmetische aspect van cineplasty?
Je doet het met wat je hebt. Is prima. Het is functioneel en ik weet niet beter. Zit niet in de weg. Mooi is geen item je doet het met wat er kan.
Q. Wat vindt u van het standaard gat (soort piercing) in uw arm waar het staafje doorheen kan voor de aansturing?
Prima. Bij zwemmen ziet niemand de tunnel.

Waarde van cineplasty
Q. Als u cineplasty vergelijkt met bestaande alternatieven, wat zijn dan in uw ogen de voor- en nadelen van cineplasty?
Het werkt en is de enige manier die kon.
Q. Ziet u waarde in de techniek van cineplasty voor anderen?
Ja, het werkt.

Moderne cineplasty
Q. Wat ziet u graag veranderd of verbeterd in cineplasty?
SQ. Littekenweefsel
SQ. Kracht
Dat het constant werkt.
SQ. Betere connectie prothese + cineplasty
SQ. Mooiere prothese
Nee, prothese zelf is al mooi.
SQ. Hoeveelheid bewegingen
SQ. Huidproblemen
SQ. Pijn/ongemak
SQ. Hygiene
SQ. Onderhoud
Nee, in 4 jaar keer kabeltje (2).

TAPES (Gallagher & Maclachlan, 2000)

Graduation Project Nynke Heeringa
Integrated Product Design – TU Delft

Trinity Amputation and Prosthesis Experience Scales (TAPES)

Set 1
Gender
Leeftijd
Hoe lang heeft u al een prothese?
Wat voor prothese heeft u (type + welke hoogte)?
Wat is de oorzaak van uw verkorte arm?

Set 2
Ik ben gewend geraakt aan een prothese.

1	2	3	4	5
O	O	O	O	●

Naarmate de tijd verstrijkt, accepteer ik mijn prothese beter.

1	2	3	4	5
O	O	O	O	●

Ik heb het gevoel dat ik dit trauma in mijn leven succesvol heb verwerkt.

1	2	3	4	5
O	O	O	O	●

Hoewel ik een prothese heb, voelt mijn leven compleet.

1	2	3	4	5
O	O	O	O	●

Ik ben gewend geraakt aan het dragen van mijn prothese.

1	2	3	4	5
O	O	O	O	●

Het maakt mij niet uit of iemand naar mijn prothese kijkt.

1	2	3	4	5
O	O	O	O	●

Ik vind het makkelijk om over mijn prothese te praten.

1	2	3	4	5
O	O	O	O	●

Ik vind het niet erg als mensen naar mijn prothese vragen.

1	2	3	4	5
O	O	O	O	●

Ik vind het moeilijk om in een gesprek over het verlies van mijn arm te praten.

1	2	3	4	5
●	O	O	O	●

Figure 6. TAPES (p.1)

Een prothese belemmert mijn werk.

1	2	3	4	5
O	O	O	O	X niet

Het hebben van een prothese maakt me afhankelijker van anderen dan ik zou willen.

1	2	3	4	5
O	O	O	O	X

Het hebben van een prothese beperkt het soort werk dat ik kan doen.

1	2	3	4	5
O	O	O	O	X nee

Omdat ik een amputatie heb, kan ik niet doen wat ik wil.

1	2	3	4	5
O	O	O	O	X nee

Een prothese beperkt de hoeveelheid werk die ik kan doen.

1	2	3	4	5
O	O	O	O	X nee

Set 3

Zware activiteiten, zoals hardlopen, zware voorwerpen tillen, deelnemen aan inspannende sporten.

Heel erg beperkt	Een beetje beperkt	Helemaal niet beperkt
O	O	O

Sport en recreatie.

Heel erg beperkt	Een beetje beperkt	Helemaal niet beperkt
O	O	O

Vriendschappen onderhouden.

Heel erg beperkt	Een beetje beperkt	Helemaal niet beperkt
O	O	O

Vrienden bezoeken.

Heel erg beperkt	Een beetje beperkt	Helemaal niet beperkt
O	O	O

Hobby's beoefenen.

Heel erg beperkt	Een beetje beperkt	Helemaal niet beperkt
O	O	O

Naar het werk gaan.

Heel erg beperkt	Een beetje beperkt	Helemaal niet beperkt
O	O	O

Figure 7. TAPES (p.2)

Graduation Project Nynke Heeringa
Integrated Product Design – TU Delft

Set 4

Wat vindt u van de kleur van de prothese?

Heel ontevreden				Heel tevreden
o	o	o	o	o

Wat vindt u van de vorm van de prothese?

Heel ontevreden				Heel tevreden
o	o	o	o	o

Wat vindt u van het geluid van de prothese?

Heel ontevreden				Heel tevreden
o	o	o	o	o

Wat vindt u van het gehele uiterlijk van de prothese?

Heel ontevreden				Heel tevreden
o	o	o	o	o

Wat vindt u van het gewicht van de prothese?

Heel ontevreden				Heel tevreden
o	o	o	o	o

Wat vindt u van de bruikbaarheid van de prothese?

Heel ontevreden				Heel tevreden
o	o	o	o	o

Wat vindt u van de betrouwbaarheid van de prothese?

Heel ontevreden				Heel tevreden
o	o	o	o	o

Wat vindt u van de passing van de prothese?

Heel ontevreden				Heel tevreden
o	o	o	o	o

Wat vindt u van het comfort van de prothese?

Heel ontevreden				Heel tevreden
o	o	o	o	o

Wat is uw algehele mening over de prothese?

Heel ontevreden				Heel tevreden
o	o	o	o	o

Figure 8. TAPES (p.3)

Graduation Project Nynke Heeringa
Integrated Product Design – TU Delft

Set 5

1. Hoeveel uur per dag draagt u uw prothese gemiddeld? Hele dag

2. Zou u over het algemeen zeggen dat uw gezondheid zeer slecht, slecht, redelijk, goed of zeer goed is?

Zeer slecht	Slecht	Redelijk	Goed	Zeer goed
o	o	o	o	o

3. Zou u over het algemeen zeggen dat uw fysieke mogelijkheden zeer slecht, slecht, goed vallen of zeer goed zijn?

Zeer slecht	Slecht	Redelijk	Goed	Zeer goed
o	o	o	o	o

4. Ervaart u pijn aan uw stomp (pijn in het resterende deel van uw geamputeerde ledemaat)?

Hoe vaak heeft u de afgelopen week stomppijn ervaren? nee

Hoe lang duurde elke pijnaanval gemiddeld? nee

Geef de gemiddelde mate van stomppijn aan die u de afgelopen week heeft ervaren: nvt

Ondraaglijk	Verschrikkelijk	Pijnlijk	Onaangenaam	Licht
o	o	o	o	o

In hoeverre heeft stomppijn uw normale levensstijl (bijv. werk, sociale en gezinsactiviteiten) de afgelopen week belemmerd (veel, behoorlijk veel, matig, een beetje of helemaal niet)? nvt

Veel	Behoorlijk veel	Matig	Een beetje	Helemaal niet
o	o	o	o	o

5. Ervaart u fantoompijn (pijn in het deel van het ledemaat dat geamputeerd is)?

Hoe vaak heeft u de afgelopen week fantoompijn ervaren? nvt

Hoe lang duurde elke pijnaanval gemiddeld?

Geef de gemiddelde mate van fantoompijn aan die u de afgelopen week heeft ervaren

Ondraaglijk	Verschrikkelijk	Pijnlijk	Onaangenaam	Licht
o	o	o	o	o

In welke mate heeft fantoompijn uw normale levensstijl (bijv. werk, sociale en gezinsactiviteiten) de afgelopen week beïnvloed (veel, behoorlijk veel, matig, een beetje of helemaal niet)?

Veel	Behoorlijk	Matig	Een beetje	Helemaal niet
o	o	o	o	o

Figure 9. TAPES (p.4)

6. Heeft u naast stomppijn of fantoompijn nog andere medische problemen ervaren? Geef aan welke problemen u ervaart.

nvt.

Hoe vaak heeft u de afgelopen week last gehad van deze medische problemen?

Hoe lang duurde elk probleem gemiddeld?

Geef aan hoeveel pijn u de afgelopen week als gevolg van deze problemen heeft ervaren

Ondraaglijk	Verschrikkelijk	Pijnlijk	Onaangenaam	Licht
o	o	o	o	o

nvt.

In hoeverre hebben deze medische problemen uw normale levensstijl (bijv. werk, sociale en gezinsactiviteiten) de afgelopen week verstoord?

Veel	Behoorlijk veel	Matig	Een beetje	Helemaal niet
o	o	o	o	o

Heeft u andere pijn ervaren die u nog niet eerder heeft genoemd? Zo ja, specificeer deze dan.

Figure 10. TAPES (p.5)

OPUS (Rehabilitation Institute of Chicago, 2011)

Patient ID# Datum / /

OPUS UPPER EXTREMITY FUNCTIONAL STATUS

I. Wat is uw aangedane zijde? ☒ Linker arm ☒ Rechter arm ☐ Beide armen

II. Hoeveel uur per dag draagt u uw prothese?

III. Gebruik de schaal rechts om aan te geven met hoeveel gemak u deze taken uitvoert	Erg eenvoudig	Eenvoudig	Beetje ingewikkeld	Erg ingewikkeld	Ik kan deze taak niet uitvoeren	Niet van toepassing	IV. Gebruikt u meestal uw prothese bij deze taak? Ja	Nee
1. Gezicht wassen	○	○	○	○	○	○	○	○
2. Tandpasta op tandenborstel doen en tanden poesten	○	○	○	○	○	○	○	○
3. Haar kammen	○	○	○	○	○	○	○	○
4. T-shirt aan en uit doen	○	○	○	○	○	○	○	○
5. Hemd met knopen vooraan dichtknopen	○	○	○	○	○	○	○	○
6. Jas dichtritsen	○	○	○	○	○	○	○	○
7. Sokken aandoen	○	○	○	○	○	○	○	○
8. Veters strikken	○	○	○	○	○	○	○	○
9. Drinken uit een plastic beker	○	○	○	○	○	○	○	○
10. Vork of lepel gebruiken	○	○	○	○	○	○	○	○
11. Vlees snijden met mes en vork	○	○	○	○	○	○	○	○
12. Een blikje leeg schenken	○	○	○	○	○	○	○	○
13. Leesbaar uw naam schrijven	○	○	○	○	○	○	○	○
14. Knippen met een schaar	○	○	○	○	○	○	○	○

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Figure 11. OPUS (p.1)

Patient ID#

OPUS UPPER EXTREMITY FUNCTIONAL STATUS

III. Gebruik de schaal rechts om aan te geven met hoeveel gemak u deze taken uitvoert	Erg eenvoudig	Eenvoudig	Beetje ingewikkeld	Erg ingewikkeld	Ik kan deze taak niet uitvoeren	Niet van toepassing	IV. Gebruikt u meestal uw prothese bij deze taak?	
							Ja	Nee
15. Open deur met deurknop	⊗	○	○	○	○	○	○	⊗
16. Doe sleutel in slot	⊗	○	○	○	○	○	○	⊗
17. Draag een wasmand	⊗	○	○	○	○	○	⊗	○
18. Bellen via een drukknoptelefoon	⊗	○	○	○	○	○	○	⊗
19. Hamer en spijker gebruiken	○	○	○	○	⊗	○	○	○
20. Handdoek vouwen	⊗	○	○	○	○	○	○	⊗
21. Envelop openen	⊗	○	○	○	○	○	○	⊗
22. In een kom roeren	⊗	○	○	○	○	○	○	⊗
23. Prothese aan en uit doen or orthosis	⊗	○	○	○	○	○	○	⊗
24. Chips zak openen met beide handen	○	○	○	○	⊗	○	○ Schaar	⊗
25. Dop van kleine fles draaien	⊗	○	○	○	○	○	○	⊗
26. Puntenslijpen	○	○	○	○	○	⊗	○	○
27. Aardappels schillen	⊗	○	○	○	○	○	○	⊗
28. Biljet uit portemonnee pakken	⊗	○	○	○	○	○	⊗	○

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Figure 12. OPUS (p.2)

B.II Compendium

Research methods

- Semi-structured interviews with prosthesis users, rehabilitation physicians, surgeons, prosthetists, and therapists to gather experiential, clinical, and technical insights
- Scoping review to map historical and contemporary evidence on cineplasty.
- Literature research across prosthetics, surgery, biomechanics, and proprioception.
- Shadowing / contextual inquiry during clinical days to observe prosthetic fitting and rehabilitation workflows.
- Stakeholder mapping to identify key actors and their influence within the prosthetic ecosystem.

Conceptualising methods

- Double Diamond framework to structure the overall design process.
- WWWWH method to structure the exploration of the problem space.
- Mindmapping to visualise relationships between themes.
- Clustering to identify patterns and synthesise insights.
- How-Tos to translate challenges into actionable design opportunities.
- Morphological chart to systematically explore solution directions.
- Brainstorming, brainwriting & sketching/drawing to generate a broad range of ideas.
- Requirements & criteria formulation to guide concept development.
- Expert consultation to validate assumptions and refine design decisions.
- Iterative prototyping (low- to mid-fidelity) to explore mechanical feasibility and user interaction.

Concept evaluation methods

- Weighted objective method to compare concepts against predefined criteria.
- Semi-structured interviews with experts to assess feasibility, desirability, and clinical relevance.
- Harris profile to evaluate and select the most promising design direction.
- User- and expert-based evaluation to assess functionality, comfort, and perceived value.
- Scenario-based use case analysis to understand real-world applicability.

B.III Biceps tendonesis

Since the tendon will be cut at the insertion as shown by Brückner (1992), it cannot contribute to flexion anymore. This creates a worry for strength loss (C2, C5, P5).

The **loss of strength for elbow flexion** is not significant compared to the gain for the canal, as we know from comparative cases. The strength of the trained brachialis and condylar muscles is entirely sufficient for good function (Ramsay et al., 2009).
Since the biceps are the main flexor in the upper arm (~50% in supination, ~30% in neutral and ~15% in pronation), it raised the concern for C2 and C5 that cutting the biceps insertion would take away an important part of the flexion moment strength (Ramsay et al., 2009). However, the position of the lower arm has a high influence on the distribution of force by the upper muscles, so certain positions creating strength is more challenging than in others, which could be something to include in the rehablitation. Moreover, Kukla (1962) states loss of strength for elbow flexion is not significant compared to the gain for the canal, as they have seen in comparative cases.

B.IV Technologies stimulating proprioception

Implanted **neural interfaces** can evoke tactile and proprioceptive sensations by stimulating peripheral nerves. Intraneural stimulation has enabled amputees to regain natural-like proprioceptive acuity and discriminate object properties, improving prosthetic control (Diaz-Hernandez, 2025). Although promising, these approaches remain invasive and face regulatory and practical barriers to widespread clinical use (Leskovar et al., 2026).

Non-invasive electrical stimulation can also evoke proprioceptive-like sensations, though with less precision. **Transcutaneous stimulation** requires more power and produce sensations that "are generally not the same as a natural feeling," but they still show potential for providing functional feedback (Leskovar et al., 2026).

The **proprioception illusion**—vibration applied to a tendon to simulate muscle stretch—has recently been tested in people with limb differences. Leskovar et al. (2026) demonstrated that 87% of participants experienced illusory movement when vibratory stimulation was applied to the residual limb. Importantly, this included both congenital and acquired limb differences, suggesting broad applicability. The study concludes that proprioception illusions "could have application in persons with limb difference" as a non-invasive feedback method (Leskovar et al., 2026, p. 15).

Artificial Proprioception (AP) systems Artificial Proprioception refers to engineered systems that replicate natural proprioceptive cues using electrotactile, vibrotactile, or neural stimulation. These systems aim to provide real-time feedback on limb position, movement, and force (Diaz-Hernandez, 2025). AP research spans neural interfaces, augmented reality, vibrotactile substitution, and hybrid sensory encoding strategies.

Finally, several **surgical interventions** aim to preserve or recreate proprioceptive pathways:

- Targeted Muscle Reinnervation (TMR) and Regenerative Peripheral Nerve Interfaces (RPNI) reroute nerves to new muscle targets, enabling clearer control signals and potential sensory feedback (Leskovar et al., 2026).
- Osseointegration can serve as a conduit for two-way neural communication, allowing users to experience stable sensory feedback (Leskovar et al., 2026).
- Agonist-Antagonist Myoneural Interfaces (AMI) surgically recreate natural muscle pairings, restoring proprioceptive signals related to joint movement (Leskovar et al., 2026).

More information about these techniques could be found in *Chapter 2.5.4*.

B.V Cineplastic prostheses



Figure 13. Cineplastic lower arm prosthesis with two rods located in lower arm for opening and closing the hand (Brückner, 2019)



Figure 14. Cineplastic lower arm prosthesis with one rod located in lower arm to close the hand (voluntary closing) (*Elektroniknet*, n.d.).



Figure 15. Cineplastic lower arm prosthesis with two rods located in lower arm for opening and closing of the hand (Klinkhammer, 2014)



Figure 16. Cineplastic upper arm prosthesis with rod located in upper arm (biceps) for controlling elbow and hand (Bell, 2014)

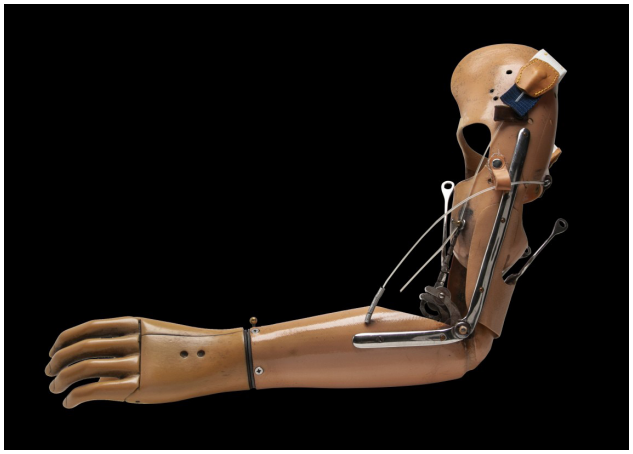

Figure 17. Cineplastic upper arm prosthesis with two rods located in upper arm (biceps-triceps) for control of the hand and a shoulder strap for controlling the elbow (Greifpunkte., n.d.)



Figure 18. Cineplastic lower arm prosthesis with one rod located in the upper arm (biceps) to close the hand (voluntary closing) (Greifpunkte., n.d.)

B.VI Lower arm vs. upper arm prosthetics

People with upper arm prosthesis are often more dissatisfied than people with lower arm prosthetics. This is related to the fact that controlling an upper arm prosthesis is more complex and less comfortable (P1, P3). This made me research the applicability of cineplasty on upper arm amputees.

Controlling a myoelectric upper arm prosthesis could be quite challenging, since the upper arm has a smaller amount of muscles to charge the electrodes, namely only the biceps and triceps. This makes a myoelectric device with multiple functions more challenging than in the lower arm (P1, P3; C2, Hoogstraat). They exist, but they are not intuitive/convenient in use (P4). Besides, the elbow is an extra element to control, which makes the whole system even more complex. Moreover, changing modes in myoelectric upper arm prosthesis is not intuitive at all, since co-contraction in the upper arm it is way less intuitive and more challenging to contract the biceps and triceps simultaneously. For those reasons, upper arm prostheses are often experienced as blunt (C2, P3).

It also depends geographically which decisions regarding are advised. In the US, specialists are more tending towards providing prosthesis users with body-powered prostheses, while Europe focuses more on myoelectric prostheses (G. Smit, personal communication, 28 November 2025). Thus, too challenging and maybe not that much more value.

The lack of possibilities in myoelectric devices for upper arm prosthetic users is clear. For this target group however, mechanical prosthetics provide a solution. A downside of the mechanical prosthetics is the need for harnassing to connect the prosthesis to the body, since often the stump is too small for a connection solely between the stump and the prosthesis (P1, P2, P4, Hoogstraat). When looking into its functioning however, mechanical prostheses function very accurately and are reliable, which makes it a valid option for upper limb amputees (Gerwin Smit, personal communication, 12 December, 2025).

For the scope of this project will be focused on lower arm amputees, since within the scope of this project, focusing on upper arm amputees will be too challenging regarding cineplasty. The concept of cineplasty is too dependent on the bicep muscle function, which is not guaranteed in upper arm amputees. Moreover, elimination of the elbow will be too great of a challenge within the timespan of the project, compared to the upsides of its value for upper arm amputees. Since upper arm amputees are less common and mechanical prostheses are a sufficient option for upper arm amputees, this project focuses on lower arm amputees for the concept of cineplasty.

B.VII Challenges in protheses supply

Insurance coverage is better arranged for military patients than for civilians (C2, C9, P1). Rehabilitation organisations receive a specific package of money for each treatment, which is not always a sufficient amount (P1, C10). Besides, insurance agencies often deny a request carefully drawn up by experts, which leads to frustrations at the side of the patients and experts, who want -and know- what is best for the patient (C1, C2, P1, P2, P3).

Weight is another challenging factor. An average myoelectric prosthesis weighs 1,5 kg, where the highest mass is located furthest away from the origin: thus a big moment arm (*How much does TrueLimb weigh?* , 2021).

Choice for the selection of a terminal device is influenced by several factors (Smit, 2020):

- Reimbursement
- Availability of other options
- Preference of the prosthetist
- Modes of actuation

Thus reimbursement remains a challenge that should be looked into further. Moreover, availability of other options is a similar influence on the selection of the prosthesis type when reintroducing cineplasty.

B.VIII Historical analysis of cineplasty

Early variations of cineplasty

The concept of cineplasty originated with Giuliano Vanghetti, who introduced the earliest invasive prosthesis linking residual muscles and tendons of the arm to generate functional motion. He continued on the early ideas of the German dentist Peter Bailiff, who in 1818 designed one of the first body-powered prostheses: an upper limb device controlled by leather straps using tension in the residual muscles and shoulder. His idea was later realised by Beaufort and Larrey in Paris in 1867. Vanghetti radically advanced Bailiff's concept. Inspired by the mutilations inflicted during the Battle of Adwa in 1896, he reasoned that prostheses should be linked directly to residual muscles and tendons to allow active control. Vanghetti published a list of 52 different ways to connect muscles and tendons with the prosthesis, the three most promising shown in Figure 19.

The first cineplastic operation on a human was performed by Antonio Ceci in 1900 in Pisa. Astley Ashhurst introduced the procedure in the United States in 1911, with excellent reported results. The procedure was executed more frequently during WWI, where Vanghetti organised and headed a centre for amputees in the Melino Mellini surgical hospital, Italy (Tropea et al., 2017).

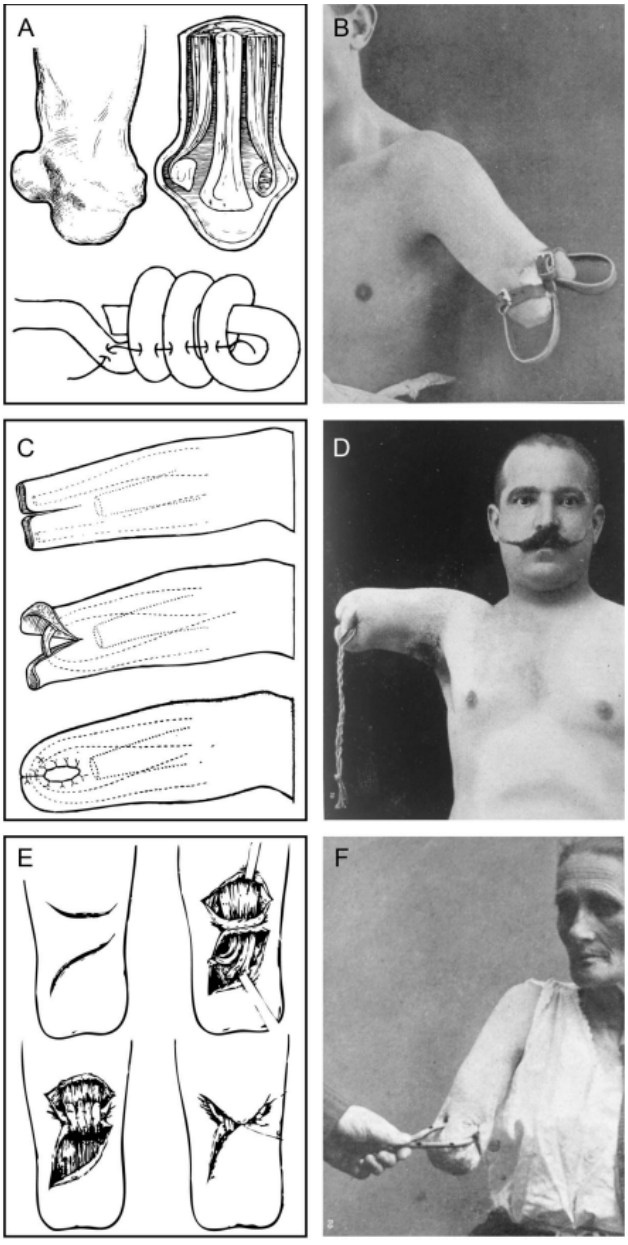

Figure 19. Most promising forms of cineplasty by Vianghetti (Tropea et al., 2017)

Krukenberg technique

Where cineplasty focuses on maintaining the human proprioception and feedback (more information about this topic could be found in *Chapter 2.4*), Hermann von Krukenberg took that principle one step further by developing his operation in 1917, converting the radius and ulna into functional prongs, with minimal complications. This preserved tactile sensation and proved especially valuable for bilateral amputees and those with visual impairments, since they could

use their own functioning tactile control without relying on visual feedback, see Figure 20 (Gillis, 1948; Kumar et al., 2025). Since prosthetics could be unaffordable, unavailable or culturally incongruent, this procedure could be a solution as an alternative for prosthetics. Kumar et al. (2025) also state that cineplasty is preferred over the Krukenberg method, when prosthetics were available and if appearance was a priority. The Krukenberg procedure remains notable for its ability to provide proprioceptive feedback unmatched by prosthetics - particularly in resource limited settings - and is as recent as 2002 successfully performed (Kumar et al., 2025; Schatz & Rosenwasser, 2002). Contemporaneously, around 1917, Vittorio Putti - Professor of Orthopaedics at Bologna - developed his own clinic at the Rizzoli Institute, where his operative technique for creating “loop” motors became the standard. In this approach, muscle contraction tightened a loop that shortened the connection with the prosthesis (Tropea et al., 2017). Pellegrini (1920) was the first and last to focos on cineplasty in the leg, where he published about detailed cineplastic procedures designed to obtain alternating motors in the leg, but the theoretical conceptions which were not realised in his life (Weir, 1995).



Figure 20. Patient with bilateral Krukenberg, bimanual dexterity in sharpening a pencil (Garst, 1991)

Later evaluations identified several shortcomings of loop and club motors, including inefficient force transfer, poor prosthetic fit, instability of the stump due to push pull motion, stretching of skin tubes, irritation from ivory components, and persistent hygiene challenges (Mazet, 1958; Weir, 1995).

Sauerbruch and the introduction of muscle tunnels

Parallel to Vanghetti’s work, cineplasty was significantly refined in Germany by Ferdinand Sauerbruch, who began experimenting with muscle tunnels in 1915 (Tropea et al., 2017). His work was initiated after Dr. Stodola, a Swiss engineer and professor of mechanics, suggested that a superior prosthetic hand could be developed if the surgical component could be solved. The Prussian War Department subsequently placed the Singen Military Hospital at Saurbruch’s disposal, enabling large scale clinical experimentation during WWI. Hundreds of cineplasties were performed by Sauerbruch and other European surgeons during this period (Weir, 1995). A key challenge of the tunnel procedure was that the scarred stumps were frequently unsuitable, and adequate tunnel size and excursion were essential for success. Besides, Sauerbruch emphasised coordinated use of agonist and antagonist muscles for precise

control, but he was cautious about the loads muscles could tolerate and stressed the need for structured rehabilitation and training (Tropea et al., 2017; Weir et al., 2001; Weir, 1995). He also advocated a collaborative approach involving surgeons, physiologists, and technicians—one of the earliest examples of interdisciplinary rehabilitation practice (Weir, 1995).
Several refinements emerged from his circle (Mazet, 1958; Weir, 1995):

- Spitzy (1917) created the first biceps tunnel in a short below elbow amputee
- Erlacher (1918) introduced a method using paired transverse skin incisions to protect suture lines from pressure
- Anschutz (1919) described releasing the distal end of the tunneled muscle to increase excursion and strength

Cineplasty activity centred around Sauerbruch in Munich (by Sauerbruch, 1916; Sauerbruch & ten Horn, 1923, from Weir, 1995), later expanding to the Charité Hospital in Berlin and to Max Lebsche in Munich (Weir, 1995).

The steps of the 'Sauerbruch-Lebsche-Vianghetti cineplasty' surgical procedure performed as recent as 1992 is documenten by Brückner (1992). The cineplastic surgery technique uses a split thickness skin graft to cover the remaining skin defect over the biceps (Brückner, 1992). The downsides of this method are that the donor site (often the thigh) takes a long time to heal and could result in a (permanent) painful area (Jones & Lister, 2021; C1, C2). Besides, there are some conditions for this technique to succeed: (1) there should be no contact with a tendon or bone and (2) the layer underneath should be smooth and vascularised, since the STSG has no independent blood supply-in contrary to the 'flaps' (vascularised skin flaps) that could be transplanted. Moreover, there is risk on ulcerations, contraction or even rejection of the transplant, resulting in skin necrosis (Brücker, 1992; Jones & Lister, 2021).

Tunnel location: forearm, pectoralis, and biceps

As cineplasty techniques evolved, surgeons experimented with different anatomical locations for constructing the muscle tunnel. By 1953, around 7000 operations had already been performed only in Berlin (Spittler & Woodard, 1953). Early attempts in the forearm frequently produced inconsistent results, largely because the available musculature often lacked the strength and excursion needed to reliably power a prosthesis. These tunnels were also more prone to complications such as irritation, hygiene difficulties, and mechanical inefficiency (Mazet, 1958). For above elbow amputees, some surgeons explored tunnels in the pectoralis major, but long term outcomes were generally less favourable. Brav et al. (1957) reported that only about one third of patients with pectoral tunnels continued to use their prostheses, and later analyses noted that limited excursion, discomfort, and challenges integrating the pectoral motor with elbow mechanisms contributed to these lower success rates (Weir, 1995). These limitations led to a gradual shift toward the biceps brachii as the preferred motor site.
Lebsche was among the first to argue that tunnels should be placed in a healthy, proximal muscle with sufficient bulk and excursion, identifying the biceps as particularly suitable for below elbow amputees (Weir, 1995). Subsequent clinical data strongly supported this view: biceps tunnels consistently produced higher success rates, greater user satisfaction, and more reliable force transmission than either forearm or pectoral tunnels. Brav et al. (1957) found that more than 70% of biceps cineplasty patients continued

to use their prostheses, compared to only 31% of those with pectoral tunnels. Later follow ups, including Brückner's work in the 1990s, further confirmed that the biceps offered the most favourable balance of strength, excursion, and long term usability (Brückner, 1992; Hueston, 1959; Kukla, 1962; Spittler & Woodard, 1953). Together, these findings established the biceps tunnel cineplasty as the most reliable and widely adopted form of the procedure, while forearm and pectoral tunnels gradually fell out of favour.

International expansion and interwar developments

Cineplasty spread internationally after WWI. Bosch Arana introduced the technique to Argentina around 1918, initially following Vanghetti but later adopting Sauerbruch's method (Weir, 1995). In the United States, Gaudiani, Rockey, and Kessler continued the procedure around 1920. Kessler alone performed approximately 400 cases (Kessler, 1947 from Weir, 1995), remaining one of the few American advocates during the interwar period.

Despite these efforts, enthusiasm waned due to limited access to adequate prostheses and the surgical challenges associated with tunnels. Reports by Purckhauer (1925) state that only 21 of 68 amputees continued using their prostheses, with many discontinuing due to infection, pain, or loss of strength (Weir, 1995). Jottkowitz (1931), cited by Kessler (1939), reported that only 37% of Sauerbruch's 729 patients continued prosthesis use (Weir, 1995).

Lebsche concluded that the best results were obtained by placing tunnels in healthy muscles proximal to the amputation, such as the biceps for below elbow amputees or the pectoralis major for above elbow amputees. He emphasised the importance of large tunnel diameters for hygiene and to reduce pressure on tissues (Weir, 1995).

Mid 20th century: refinement, evaluation, and mixed outcomes

During WWII, Kessler no longer received German prostheses, prompting American engineers to develop alternatives. Northrop Aircraft Inc. (California, USA) designed a wrist rotation arm with cineplastic control around 1945, and their voluntary opening hook -later developed by Sierra Engineering Co. (California, USA)- became widely used and served as a precursor to the APRL hook (Weir, 1995). Post WWII, some follow up studies were published, with varying results (Weir, 1995). See Figure 22 for an overview of multiple

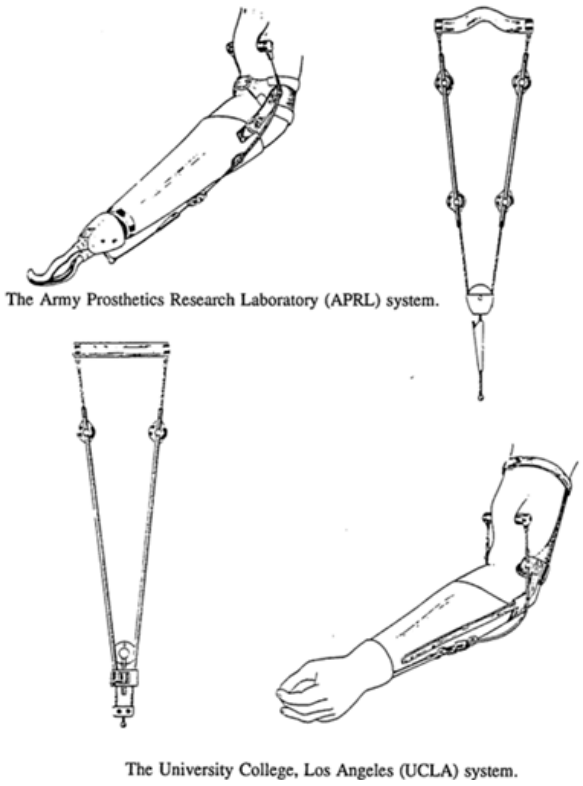

Figure 21. Wrist rotation arm with cineplastic control designed by Northrop Aircraft Inc. (California, USA) around 1945 (Weir, 1995)

study results.
Patients were able to carry out an impressive amount of functions with their prostheses, as shown in Figure 22.

According to Brückner and Thomas (1994), outcomes are strongly dependent on motivation and psychological wellbeing (Weir, 1995). Compared to conventional prostheses, cineplasty showed lower overall acceptance: 62% vs. 82% (Brav et al., 1957). The authors recommended that amputees first trial a conventional prosthesis for six months before considering cineplasty (Weir, 1995).

Patients generally reported highly positive experiences with cineplasty. They valued the sensitive, finely graded grip and the reduced need for harnessing, which contributed to a strong sense of independent arm and hand use (Spittler & Woodard, 1953). Later studies similarly noted improved prosthetic control, appreciation for the unilateral nature of the procedure, effective use in awkward positions—especially among biceps users—and enhanced perception of finger position and applied pressure, all without reliance on a shoulder harness (Brav et al., 1964).

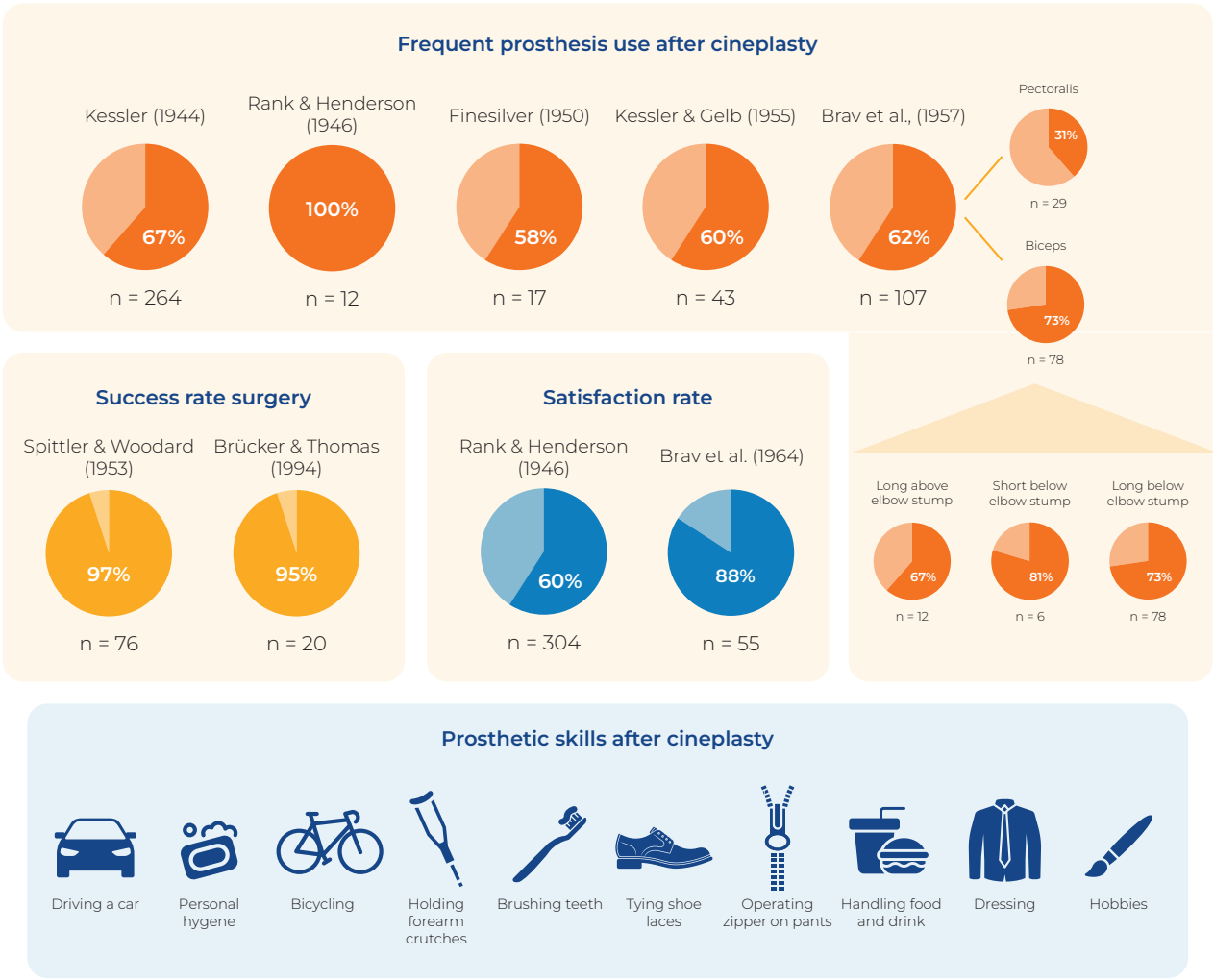

Figure 22. Results from follow up studies (Brav et al., 1964; Spittler & Woodard, 1943; Weir, 1995)

According to Brav et al. (1964), the main reasons why subjects were not wearing prostheses at follow up:

- Painful stumps
- Tunnel insufficiencies
- Stump inadequacy
- Prosthetic difficulties
- Uncomfortable harness (pectoralis)
- Prosthesis not needed

Engineering insights and prosthetic mechanisms

Parallel to surgical refinements, engineers studied mechanical requirements. Blaschke and Taylor (1953) quantified **force and excursion needs** for prosthetic hooks, noting that 15 lbs of force and 1.5 inches of excursion sufficed for most daily tasks. These insights informed voluntary opening and voluntary closing devices, which cineplasty could power with greater precision than shoulder harnesses (Hueston, 1959; Weir, 1995). In Germany, the **Hüfner hand** (1922) became a common companion device for cineplasty due to its low actuation forces and high pinch output compared to other body-powered prosthesis (Smit, 2020).

When focusing on materials, the prosthesis experienced some developments: the Northrop arm, designed in 1945, used **plastic laminates** instead of the leather and metal devices from Germany (Weir, 1995). Besides, the rods inserted into the tunnel used to be made out of ivory, which later became plastic (plexiglass) (Brückner, 1992).

The adoption of of the **Bowden cable** into prosthetics - originating from early aircraft control systems, and ultimately from bicycle engineering - was a key element in the modernisation of prosthetic technology: the goal of the Committee on Artificial Limbs during the final years of World War II (Weir, 1995). Its ability to transmit force efficiently over curved paths made it particularly suitable for body-powered prostheses. This simple mechanical interface provided a reliable and low-maintenance means of generating functional grasp, and it established a control principle that remains largely unchanged today. For cineplasty, the Bowden cable offered a practical way to translate residual muscle contractions into prosthetic motion. Its responsiveness, durability, and compatibility with curved routing made it an effective intermediary between the user's muscle-driven input and the terminal device. As a result, the Bowden cable became a foundational component in integrating direct biological control with mechanical prosthetic function (Weir,

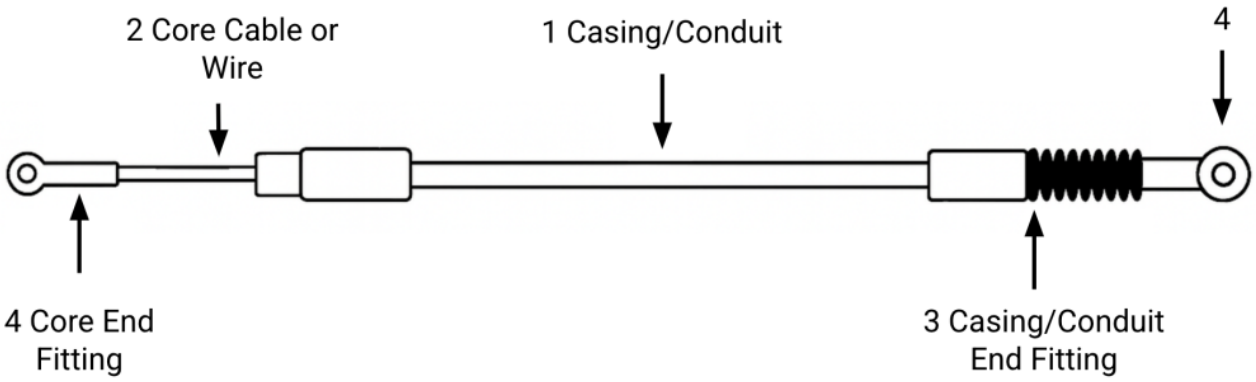

Figure 23. Bowden cable principle (Tyler Madison Inc., 2026)

1995).

Late 20th century: revival, hybrid systems, and decline

After WWII, many veterans in the USA were fitted with cineplastic limbs (Munroe & Nasca, 1975; Weir, 1995). More cineplastic operations were performed from the end of WWII until 1980s, with mixed reported results (Tropea et al., 2017). Germany saw a revival in the 1980s, with Biedermann's son improving the original design. However, just a decade later, Baumgartner and Plöger (1992) reviewed patients who had worn their prostheses for an average of 40 years, concluding that modernisation of the prosthesis was urgently needed (Weir, 1995).

Later developments explored combining cineplasty with externally powered prostheses. Filatov and Voinova's physiological studies in the 1980s demonstrated that tunnel cineplasties were reliable control sources. Murphy and Childress (1989) proposed miniature tunnel cineplasties integrated with extended physiological proprioception (EPP), highlighting the potential for natural feedback in advanced prosthetic systems (Weir, 1995).

By the early 2000s, cineplasty had largely declined in the United States. Cineplasty faded into obscurity due to a combination of technological, clinical, economic, and educational factors. The rise of myoelectric prostheses, which were less invasive and offered superior cosmetic outcomes, made cineplasty increasingly unattractive (Brückner, 1992; Weir, 1995; C1, C2, C4, C5). As the technique was only performed by a small number of surgeons, it gradually disappeared from surgical training, leading to a loss of practitioner expertise (Weir et al., 2001; C2, P1, P2). Another possiblity could be "gadget-like" character of a certain procedure (in this case the myoelectric device), like seen before in total hip replacements (C4, C5). Clinical complications such as tunnel breakdown and painful stumps further limited adoption (Brückner, 1992; C6). Moreover, early cineplastic prostheses were awkward, functionally poor, and prone to failure, contributing to declining confidence in the procedure (Weir, 1995). The lack of validated or well developed prostheses specifically designed for cineplasty hindered progress (Spittler & Woodard, 1953), and even functioning muscle tunnels could not be fully exploited due to the limited opening range of available artificial hands (Brückner, 1992). High production costs restricted access and prevented broader uptake (Zuo & Olson, 2014). Ultimately, cineplasty effectively ended in the United States mid-seventies with the retirement of its main proponents and the rise of myoelectric control (Weir et al., 2001), while the aesthetic advantages of myoelectric devices and the lack of further cineplastic innovation diminished surgeon interest (Brückner, 1992).

However, Weir et al. (2001) emphasised cineplasty's unique advantages: force and excursion amplification, freedom from harnessing, immunity to electromagnetic interference and most of al: natural sensory feedback. Modern reviews note that in bilateral amputees or resource limited settings, cineplasty remains a viable option (Kumar et al., 2025).

Conclusion

Across more than a century of development, cineplasty has undergone repeated cycles of innovation, refinement, and decline. From Vanghetti's early vision of directly linking residual muscles to prosthetic mechanisms, through Sauerbruch's transformative introduction of muscle tunnels, to the

mid-twentieth-century integration of engineering advances such as the Bowden cable, the technique consistently pushed the boundaries of biologically integrated prosthetic control. Clinical outcomes varied widely across eras, motor sites, and prosthetic designs, yet biceps cineplasty emerged as the most reliable and enduring form of the procedure. Although cineplasty ultimately declined with the rise of myoelectric prostheses, loss of surgical expertise, and persistent complications, many long-term users reported highly positive experiences and even recommended the technique to others—highlighting the unique value of natural proprioceptive feedback and intuitive control. Today, cineplasty remains historically significant not only as an early attempt at neuromuscular integration, but also as a reminder of the potential of direct biological control in contexts where simplicity, robustness, and sensory feedback are paramount.

B.IX Scoping review references

Regarding the scope of this half year project, the search was focused on the title abstract and keywords.

- Search term PubMed: ((cineplast*[Title/Abstract] OR kineplast*[Title/Abstract]) AND (arm[Title/Abstract] OR “upper limb”[Title/Abstract] OR “upper extremit*”[Title/Abstract]) AND prosthe*[Title/Abstract])

- Search term Scopus: TITLE-ABS-KEY((cineplast* OR kineplast*) AND (arm OR “upper limb” OR “upper extremit*”) AND prosthe*)

- Search term Web of Science:Title((cineplast* OR kineplast*) AND (arm OR “upper limb” OR “upper extremit*”) AND prosthe*) or Abstract((cineplast* OR kineplast*) AND (arm OR “upper limb” OR “upper extremit*”) AND prosthe*) or keyword Plus ((cineplast* OR kineplast*) AND (arm OR “upper limb” OR “upper extremit*”) AND prosthe*)

Which resulted in the following articles that were read and included or excluded showed in Figure 24. Unfortunately, a high number of articles were not accessible, probably due to the fact that the articles were published a long time ago. See Figure 25 for the analysis of the eventually included article.

#	Database	Want to include?	Full text available?	Title
1	Scopus, PubMed			The Krukenberg Procedure: A Scoping Review
2	Scopus			A biomechatronics-based EPP topology for upper-limb prosthesis control: Modeling & benchtop prototype
3	Scopus			Mechanical evaluation of the "hüfner hand" prosthesis
4	Scopus, PubMed, Web of Science			Giuliano Vanghetti and the innovation of "cineplastic operations"
5	Scopus			Extrapolation of Emerging Technologies and Their Long-Term Implications for Myoelectric versus Body-Powered Prostheses: An Engineering Perspective
6	Scopus, Web of Science			A biomechatronic Extended Physiological Proprioception (EPP) controller for upper-limb prostheses
7	Scopus, PubMed, Web of Science			Advantages of externally powered prosthesis with feedback system using pseudo-cineplasty
8	Scopus, PubMed			Augusto Pellegrini (1877–1958): Contributions to surgery and prosthetic orthopaedics
9	Scopus, PubMed			Krukenberg kineplasty: A case study
10	Scopus, PubMed, Web of Science			Cineplasty as a control input for externally powered prosthetic components
11	Scopus			Advances in upper extremity prosthetics in the United States during World War II and early post-World War II era
12	Scopus			Sauerbruch-lebsche-vanghetti cineplasty: The surgical procedure
13	Scopus			Report of experience about the initiation of the operation to Sauerbruch-Lebsche (Kineplasty to Sauerbruch) ERFAHRUNGSBERICHT UBER DIE WIEDEREINFUHRUNG DER OPERATION NACH SAUERBRUCH-LEBSCHE (SAUERBRUCH-KINEPLASTIK)
14	Scopus			Renaissance of kineplasty according to Sauerbruch? GIBT ES EINE RENAISSANCE DER KINEPLASTIK NACH SAUERBRUCH?
15	Scopus			VA/USMC electric hand with below-elbow cineplasty
16	Scopus			Kineplastic reconstruction after upperlimb amputation La cinéplastie après l'amputation des extrémités supérieu-res Kineplastik nach der amputation der oberen extremitäten Reconstrucción cineplástica tras la amputación de miembro superior
17	Scopus			Cineplastic operations in the system of rehabilitation of invalids after upper-extremity amputations
18	Scopus			Zur Bedeutung der Kineplastik des Biceps brachii nach Sauerbruch-Vanghetti bei der fortschrittlichen prothetischen Versorgung des Unterarmamputierten (mit Film)
19	Scopus	Not available		DOUBLE-TUNNEL PECTORAL CINEPLASTY.
20	Scopus, PubMed			FOLLOW-UP NOTES ON ARTICLES PREVIOUSLY PUBLISHED IN THE JOURNAL. CINEPLASTY--TEN YEARS LATER.
21	Scopus, PubMed	Not available		A COSMETIC ARM PROSTHESIS FOLLOWING KINEPLASTIC AMPUTATION IN WOMEN. PROTEZA KOSMETYCZNA RAMIENIA PO AMPUTACJI KINEPLASTYCZNEJ U KOBIET.
22	Scopus			Plea for cineplasty of the biceps following amputation of the forearm.
23	Scopus			MUSCLE TRAINING FOR PECTORAL CINEPLASTY
24	Scopus			BICEPS CINEPLASTY FOR FOREARM AMPUTEES
25	Scopus			MUSCLE TRAINING FOR BICEPS CINEPLASTY
26	Scopus	Not available		Motor muscle cineplasty for prostheses of the upper extremity. Sobre motores musculares cineplásticos para prótesis de miembro superior.
27	Scopus	Not available		Kineplasty and fore-arm prosthesis. La cinéplastie et les prothèses d'avant-bras.
28	Scopus	Not available		Pectoral cineplasty
29	Scopus, PubMed	Not available		Prosthetic training for the upper extremity amputee with cineplasty.
30	Scopus			Cineplasty for arm amputees.
31	Scopus			The mechanical design of muscle-operated arm prostheses
32	Scopus	Not available		New cineplastic prosthesis.
33	Scopus, PubMed, Web of Science			Cineplastic muscle motors for prostheses of arm amputees.
34	Scopus			A utility attachment for cineplastic artificial arms.
35	PubMed			Operations in upper extremity amputees.
36	PubMed, Web of Science			Recent advances in the treatment of arm amputations, kineplastic surgery and arm prostheses.
37	PubMed	Not available		[Is there a renaissance of the Sauerbruch kineplasty?].
38	PubMed	Not available		[Experience with the reintroduction of the Sauerbruch-Lebsche operation (Sauerbruch's kineplasty)].
39	PubMed	Not available		[Motor muscle cineplasty for prostheses of the upper extremity].

Figure 24. Complete literature results, which to include and availability of literature

	RQ: What types of evidence exist regarding evolution of cineplasty in upper limb prosthetic care?										
	Database	Title	Authors	Year	Level of evider	Country	Study design	Patients	Time	Included?	Full text availa
1	Scopus, PubMed	The Krukenberg Procedure: A Scoping Review	Kumar, J. A., Be	2025	3	Australia	Scoping review/ descriptive survey	166	1937-2024		
3	Scopus	Mechanical evaluation of the "hüfner hand" prosthesis	Smit, G.	2020	5	The Netherlanc	/ **analytic** experimental	-	1920-1960		
4	Scopus, PubMed, Web of Science	Giuliano Vanghetti and the innovation of "cineplastic operations"	Tropea, P., Maz	2017	5	Italia	Historical review/ descriptive qualitati	-	1900-1980		
7	Scopus, PubMed, Web of Science	Advantages of externally powered prosthesis with feedback system using pseudo-cineplasty	Nambu, S., Ike	2014	5	Japan	Descriptive qualitative	1	2014		
10	Scopus, PubMed, Web of Science	Cineplasty as a control input for externally powered prosthetic components	Weir, R. F., Hecl	2001	5	United States	**Analytic**, experimental	3	2001		
12	Scopus	Sauerbruch-lebsche-vanghetti cineplasty: The surgical procedure	Brückner	1992	5	Germany	observational **analytic** (case series)	14	~1980-90		
18	Scopus	Zur Bedeutung der Kineplastik des Biceps brachii nach Sauerbruch-Vanghetti bei der fortschrittlichen prothetischen Versorgung des Unterarmamputierten (mit Film)	Kukla, D	1964	4	Germany	Observational **analytic**	-	1960		
20	Scopus, PubMed	FOLLOW-UP NOTES ON ARTICLES PREVIOUSLY PUBLISHED IN THE JOURNAL. CINEPLASTY--TEN YEARS LATER.	Brav, E. A., Ma	1964	3	United States	**analytic** cohort study	55	1964		
24	Scopus	BICEPS CINEPLASTY FOR FOREARM AMPUTEES	Hueston, J. T.	1959	4	Australia	Observational **Analytic**, Case series	7 tunnels	~1950-1960		
30	Scopus	Cineplasty for arm amputees	Spittler, A. W.,	1953	4	United States	observational **analytic** (case series)	76 tunnels	1953		
31	Scopus	The mechanical design of muscle-operated arm prostheses	Blaschke, A. C	1953	5	United States	descriptive quantitative / engineering	5	1953		
35	PubMed	Operations in upper extremity amputees.	Mazet, R., Jr.	1961	5	United States	Observational **analytic** / case series	-	1961		
36	PubMed, Web of Science	Recent advances in the treatment of arm amputations, kineplastic surgery and arm prostheses.	Gillis, L.	1948	5	United Kingdo	descriptive qualitive	-	~1948		
33	Scopus, PubMed, Web of Science	Cineplastic muscle motors for prostheses of arm amputees.		1951							
34	Scopus	A utility attachment for cineplastic artificial arms.		1948							
21	Scopus, PubMed	A COSMETIC ARM PROSTHESIS FOLLOWING KINEPLASTIC AMPUTATION IN WOMEN. PROTEZA KOSMETYCZNA RAMIENIA PO AMPUTACJI KINEPLASTYCZNEJ U KOBIET.		1963							
11	Scopus	Advances in upper extremity prosthetics in the United States during World War II and early post-World War II era		1998							
13	Scopus	Report of experience about the initiation of the operation to Sauerbruch-Lebsche (Kineplasty to Sauerbruch)		1990							
14	Scopus	Renaissance of kineplasty according to Sauerbruch?		1988							
15	Scopus	VA/USMC electric hand with below-elbow cineplasty		1981							
16	Scopus	Kineplastic reconstruction after upperlimb amputation		1981							
17	Scopus	Cineplastic operations in the system of rehabilitation of invalids after upper-extremity amputations		1978							
38	PubMed	[Is there a renaissance of the Sauerbruch kineplasty?].		1988							
40	PubMed	[Experience with the reintroduction of the Sauerbruch-Lebsche operation (Sauerbruch's kineplasty)].		1990							
41	PubMed	[Motor muscle cineplasty for prostheses of the upper extremity].		1956							
37	PubMed	[Kineplasty and fore-arm prosthesis].		1956						Not available	
22	Scopus	Plea for cineplasty of the biceps following amputation of the forearm.		1962						Not available	
26	Scopus	Motor muscle cineplasty for prostheses of the upper extremity. Sobre motores musculares cineplásticos para prótesis de miembro superior.		1956						Not available	
28	Scopus	Pectoral cineplasty		1954						Not available	
32	Scopus	New cineplastic prosthesis.		1951						Not available	

Figure 25. Analysis of the included articles

B.X Consent forms

Prosthesis users



Users

Toestemmingsformulier interview Cineplasty TU Delft

Prothesegebruikers

U wordt uitgenodigd om deel te nemen aan een onderzoek genaamd *"De potentie van een volledig mechanische onderarmprothese met behulp van cineplastiek in de 21e eeuw"*. Dit onderzoek wordt uitgevoerd door Nynke Heeringa van de TU Delft, in opdracht van het Reinier Haga Orthopedisch Centrum.

Het doel van dit interview is kennis vergaren over het gebruik van met een armprothese en zal ongeveer 30 minuten in beslag nemen. De data zal gebruikt worden voor het afstudeerverslag van Nynke Heeringa. U wordt gevraagd om een aantal vragen te beantwoorden over uw ervaring met arm protheses en de potentiële rol van cineplasty hierin (later volgt meer uitleg hierover).

Zoals bij elke online activiteit is het risico van een databreuk aanwezig. Wij doen ons best om uw antwoorden vertrouwelijk te houden. We minimaliseren de risico's door data anoniem te verzamelen en niet op openbare platformen op te slaan.

Uw deelname aan dit onderzoek is volledig vrijwillig, en u kunt zich elk moment terugtrekken zonder reden op te geven. U bent vrij om vragen niet te beantwoorden.

Contactgegevens:

Nynke Heeringa
n.heeringa@student.tudelft.nl

Figure 26. Consent form U (p.1)

VINK DE JUISTE VAKJES AAN	Yes	No
A: ALGEMENE OVEREENKOMST – ONDERZOEKSDOELEN, TAKEN VAN DE DEELNEMERS EN VRIJWILLIGE DEELNAME		
1. Ik heb de informatie over het onderzoek gedateerd [*dd/mm/yyyy*] gelezen en begrepen, of deze is aan mij voorgelezen. Ik heb de mogelijkheid gehad om vragen te stellen over het onderzoek en mijn vragen zijn naar tevredenheid beantwoord.	☐	☐
2. Ik doe vrijwillig mee aan dit onderzoek, en ik begrijp dat ik kan weigeren vragen te beantwoorden en mij op elk moment kan terugtrekken uit de studie, zonder een reden op te hoeven geven.	☐	☐
3. Ik begrijp dat mijn deelname aan het onderzoek betekent dat data anoniem wordt verzameld en niet op openbare platformen wordt opgeslagen, tijdens het gesprek worden notities meegeschreven.	☐	☐
4. Ik begrijp dat mijn deelname aan het onderzoek niet wordt gecompenseerd.	☐	☐
5. Ik begrijp dat de studie eindigt na afronding van het afstudeerproject in april 2026.	☐	☐
B: MOGELIJKE RISICO'S VAN DEELNAME (INCLUSIEF GEGEVENSBESCHERMING)		
6. Ik begrijp dat mijn deelname de volgende risico's met zich meebrengt: het gesprek kan meer tijd innemen dan u had verwacht en er kunnen vragen gesteld worden die u liever niet wil beantwoorden. Ik begrijp dat deze risico's worden geminimaliseerd door elk moment aan te kunnen geven dat ik wil dat het gesprek eindigt.	☐	☐
7. Ik begrijp dat mijn deelname betekent dat er persoonlijke identificeerbare informatie en onderzoeksdata worden verzameld (beroep, ervaring en werkplek), met het risico dat ik hieruit geïdentificeerd kan worden.	☐	☐
8. Ik begrijp dat de volgende stappen worden ondernomen om het risico van een databreuk te minimaliseren, en dat mijn identiteit wordt beschermd in het geval van een databreuk door data anoniem te verzamelen, en niet op te slaan op openbare platformen	☐	☐
9. Ik begrijp dat de persoonlijke informatie die over mij verzameld wordt en mij kan identificeren, zoals functie ervaring en werkplek, niet gedeeld worden buiten het studieteam.	☐	☐
10. Ik begrijp dat de persoonlijke data die over mij verzameld wordt, vernietigd wordt op 1 mei 2026	☐	☐

Figure 27. Consent form U (p.2)

C: ONDERZOEKSPUBLICATIE, VERSPREIDING EN TOEPASSING		
11. Ik begrijp dat na het onderzoek de geanonimiseerde informatie gebruikt zal worden voor onderbouwing in ontwerpkeuzes en voor het eindverslag van de afstudeeropdracht van Nynke Heeringa.	☐	☐
12. Ik geef toestemming voor het maken van foto's, die geanonimiseerd in het afstudeerverslag gebruikt kunnen worden.	☐	☐
13. Ik geef toestemming om mijn antwoorden, ideeën of andere bijdrages anoniem te quoten in resulterende producten.	☐	☐
14. Ik geef toestemming om mijn naam te gebruiken voor quotes in resulterende producten.	☐	☐
D: (LANGDURIGE) GEGEVENSOPSLAG, TOEGANG EN HERGEBRUIK		
15. Ik geef toestemming om de geanonimiseerde data van dit interview die over mij verzameld worden niet gearchiveerd worden.	☐	☐
16. Ik begrijp dat de toegang tot de tijdelijke repository (tot vernietiging in mei 2026) beperkt is tot Nynke Heeringa en haar onderzoeksbegeleiders Richard Goossens, Gerald Kraan en Gerwin Smit.	☐	☐

Figure 28. Consent form U (p.3)

Signatures

Naam deelnemer	Handtekening	Datum

Ik, **de onderzoeker**, verklaar dat ik de informatie en het instemmingsformulier correct aan de potentiële deelnemer heb voorgelezen en, naar het beste van mijn vermogen, heb verzekerd dat de deelnemer begrijpt waar hij/zij vrijwillig mee instemt.

Naam onderzoeker	Handtekening	Datum

Contactgegevens van de onderzoeker voor verdere informatie: Nynke Heeringa, n.heeringa@student.tudelft.nl, +

Figure 29. Consent form U (p.4)

Clinical experts

Toestemmingsformulier interview Cineplasty TU Delft

Artsen

U wordt uitgenodigd om deel te nemen aan een onderzoek genaamd "*De potentie van een volledig mechanische onderarmprothese met behulp van cineplastiek in de 21e eeuw*". Dit onderzoek wordt uitgevoerd door Nynke Heeringa van de TU Delft, in opdracht van het Reinier Haga Orthopedisch Centrum.

Het doel van dit interview is kennis vergaren over de potentie van de cineplastische operatie toen en nu en zal ongeveer 20 minuten in beslag nemen. De data zal gebruikt worden voor het afstudeerverslag van Nynke Heeringa. U wordt gevraagd om een aantal vragen te beantwoorden over de cineplastische operatie techniek en de potentiële verbetering hiervan.

Zoals bij elke online activiteit is het risico van een databreuk aanwezig. Wij doen ons best om uw antwoorden vertrouwelijk te houden. We minimaliseren de risico's door data anoniem te verzamelen en niet op openbare platformen op te slaan.

Uw deelname aan dit onderzoek is volledig vrijwillig, en u kunt zich elk moment terugtrekken zonder reden op te geven. U bent vrij om vragen niet te beantwoorden.

Contactgegevens:

Nynke Heeringa
n.heeringa@student.tudelft.nl

Figure 30. Consent form C (p.1)

VINK DE JUISTE VAKJES AAN	Yes	No
A: ALGEMENE OVEREENKOMST – ONDERZOEKSDOELEN, TAKEN VAN DE DEELNEMERS EN VRIJWILLIGE DEELNAME		
1. Ik heb de informatie over het onderzoek gedateerd [*dd/mm/yyyy*] gelezen en begrepen, of deze is aan mij voorgelezen. Ik heb de mogelijkheid gehad om vragen te stellen over het onderzoek en mijn vragen zijn naar tevredenheid beantwoord.	☐	☐
2. Ik doe vrijwillig mee aan dit onderzoek, en ik begrijp dat ik kan weigeren vragen te beantwoorden en mij op elk moment kan terugtrekken uit de studie, zonder een reden op te hoeven geven.	☐	☐
3. Ik begrijp dat mijn deelname aan het onderzoek betekent dat data anoniem wordt verzameld en niet op openbare platformen wordt opgeslagen, tijdens het gesprek worden notities meegeschreven.	☐	☐
4. Ik begrijp dat mijn deelname aan het onderzoek niet wordt gecompenseerd.	☐	☐
5. Ik begrijp dat de studie eindigt na afronding van het afstudeerproject in april 2026.	☐	☐
B: MOGELIJKE RISICO'S VAN DEELNAME (INCLUSIEF GEGEVENSBESCHERMING)		
6. Ik begrijp dat mijn deelname de volgende risico's met zich meebrengt: het gesprek kan meer tijd innemen dan u had verwacht en er kunnen vragen gesteld worden die u liever niet wil beantwoorden. Ik begrijp dat deze risico's worden geminimaliseerd door elk moment aan te kunnen geven dat ik wil dat het gesprek eindigt.	☐	☐
7. Ik begrijp dat mijn deelname betekent dat er persoonlijke identificeerbare informatie en onderzoeksdata worden verzameld (beroep, ervaring en werkplek), met het risico dat ik hieruit geïdentificeerd kan worden.	☐	☐
8. Ik begrijp dat de volgende stappen worden ondernomen om het risico van een databreuk te minimaliseren, en dat mijn identiteit wordt beschermd in het geval van een databreuk door data anoniem te verzamelen, en niet op te slaan op openbare platformen	☐	☐
9. Ik begrijp dat de persoonlijke informatie die over mij verzameld wordt en mij kan identificeren, zoals functie ervaring en werkplek, niet gedeeld worden buiten het studieteam.	☐	☐
10. Ik begrijp dat de persoonlijke data die over mij verzameld wordt, vernietigd wordt op 1 mei 2026	☐	☐

Figure 31. Consent form C (p.2)

C: ONDERZOEKSPUBLICATIE, VERSPREIDING EN TOEPASSING		
11. Ik begrijp dat na het onderzoek de geanonimiseerde informatie gebruikt zal worden voor onderbouwing in ontwerpkeuzes en voor het eindverslag van de afstudeeropdracht van Nynke Heeringa.	☐	☐
12. Ik geef toestemming voor het maken van foto's, die geanonimiseerd in het afstudeerverslag gebruikt kunnen worden.	☐	☐
13. Ik geef toestemming om mijn antwoorden, ideeën of andere bijdrages anoniem te quoten in resulterende producten.	☐	☐
14. Ik geef toestemming om mijn naam te gebruiken voor quotes in resulterende producten.	☐	☐
D: (LANGDURIGE) GEGEVENSOPSLAG, TOEGANG EN HERGEBRUIK		
15. Ik geef toestemming om de geanonimiseerde data van dit interview die over mij verzameld worden niet gearchiveerd worden.	☐	☐
16. Ik begrijp dat de toegang tot de tijdelijke repository (tot vernietiging in mei 2026) beperkt is tot Nynke Heeringa en haar onderzoeksbegeleiders Richard Goossens, Gerald Kraan en Gerwin Smit.	☐	☐

Figure 32. Consent form C (p.3)

Signatures

_____	_____	_____
Naam deelnemer	Handtekening	Datum

Ik, **de onderzoeker**, verklaar dat ik de informatie en het instemmingsformulier correct aan de potentiële deelnemer heb voorgelezen en, naar het beste van mijn vermogen, heb verzekerd dat de deelnemer begrijpt waar hij/zij vrijwillig mee instemt.

_____	_____	_____
Naam onderzoeker	Handtekening	Datum

Contactgegevens van de onderzoeker voor verdere informatie: Nynke Heeringa, n.heeringa@student.tudelft.nl

Figure 33. Consent form C (p.4)

Prosthetists

Toestemmingsformulier interview Cineplasty TU Delft

Orthopedisch instrumentenmakers

U wordt uitgenodigd om deel te nemen aan een onderzoek genaamd *"De potentie van een volledig mechanische onderarmprothese met behulp van cineplastiek in de 21e eeuw"*. Dit onderzoek wordt uitgevoerd door Nynke Heeringa van de TU Delft, in opdracht van het Reinier Haga Orthopedisch Centrum.

Het doel van dit interview is kennis vergaren over de rol van cineplasty binnen het ontwerpen en produceren van armprotheses en zal ongeveer 30 minuten in beslag nemen. De data zal gebruikt worden voor het afstudeerverslag van Nynke Heeringa. U wordt gevraagd om een aantal vragen te beantwoorden over de productie van protheses en de potentiële rol van cineplasty hierin.

Zoals bij elke online activiteit is het risico van een databreuk aanwezig. Wij doen ons best om uw antwoorden vertrouwelijk te houden. We minimaliseren de risico's door data anoniem te verzamelen en niet op openbare platformen op te slaan.

Uw deelname aan dit onderzoek is volledig vrijwillig, en u kunt zich elk moment terugtrekken zonder reden op te geven. U bent vrij om vragen niet te beantwoorden.

Contactgegevens:

Nynke Heeringa
n.heeringa@student.tudelft.nl

Figure 34. Consent form P (p.1)

VINK DE JUISTE VAKJES AAN	Yes	No
A: ALGEMENE OVEREENKOMST – ONDERZOEKSDOELEN, TAKEN VAN DE DEELNEMERS EN VRIJWILLIGE DEELNAME		
1. Ik heb de informatie over het onderzoek gedateerd [*dd/mm/yyyy*] gelezen en begrepen, of deze is aan mij voorgelezen. Ik heb de mogelijkheid gehad om vragen te stellen over het onderzoek en mijn vragen zijn naar tevredenheid beantwoord.	☐	☐
2. Ik doe vrijwillig mee aan dit onderzoek, en ik begrijp dat ik kan weigeren vragen te beantwoorden en mij op elk moment kan terugtrekken uit de studie, zonder een reden op te hoeven geven.	☐	☐
3. Ik begrijp dat mijn deelname aan het onderzoek betekent dat data anoniem wordt verzameld en niet op openbare platformen wordt opgeslagen, tijdens het gesprek worden notities meegeschreven.	☐	☐
4. Ik begrijp dat mijn deelname aan het onderzoek niet wordt gecompenseerd.	☐	☐
5. Ik begrijp dat de studie eindigt na afronding van het afstudeerproject in april 2026.	☐	☐
B: MOGELIJKE RISICO'S VAN DEELNAME (INCLUSIEF GEGEVENSBESCHERMING)		
6. Ik begrijp dat mijn deelname de volgende risico's met zich meebrengt: het gesprek kan meer tijd innemen dan u had verwacht en er kunnen vragen gesteld worden die u liever niet wil beantwoorden. Ik begrijp dat deze risico's worden geminimaliseerd door elk moment aan te kunnen geven dat ik wil dat het gesprek eindigt.	☐	☐
7. Ik begrijp dat mijn deelname betekent dat er persoonlijke identificeerbare informatie en onderzoeksdata worden verzameld (beroep, ervaring en werkplek), met het risico dat ik hieruit geïdentificeerd kan worden.	☐	☐
8. Ik begrijp dat de volgende stappen worden ondernomen om het risico van een databreuk te minimaliseren, en dat mijn identiteit wordt beschermd in het geval van een databreuk door data anoniem te verzamelen, en niet op te slaan op openbare platformen	☐	☐
9. Ik begrijp dat de persoonlijke informatie die over mij verzameld wordt en mij kan identificeren, zoals functie ervaring en werkplek, niet gedeeld worden buiten het studieteam.	☐	☐
10. Ik begrijp dat de persoonlijke data die over mij verzameld wordt, vernietigd wordt op 1 mei 2026	☐	☐

Figure 35. Consent form P (p.2)

C: ONDERZOEKSPUBLICATIE, VERSPREIDING EN TOEPASSING		
11. Ik begrijp dat na het onderzoek de geanonimiseerde informatie gebruikt zal worden voor onderbouwing in ontwerpkeuzes en voor het eindverslag van de afstudeeropdracht van Nynke Heeringa.	☐	☐
12. Ik geef toestemming voor het maken van foto's, die geanonimiseerd in het afstudeerverslag gebruikt kunnen worden.	☐	☐
13. Ik geef toestemming om mijn antwoorden, ideeën of andere bijdrages anoniem te quoten in resulterende producten.	☐	☐
14. Ik geef toestemming om mijn naam te gebruiken voor quotes in resulterende producten.	☐	☐
D: (LANGDURIGE) GEGEVENSOPSLAG, TOEGANG EN HERGEBRUIK		
15. Ik geef toestemming om de geanonimiseerde data van dit interview die over mij verzameld worden niet gearchiveerd worden.	☐	☐
16. Ik begrijp dat de toegang tot de tijdelijke repository (tot vernietiging in mei 2026) beperkt is tot Nynke Heeringa en haar onderzoeksbegeleiders Richard Goossens, Gerald Kraan en Gerwin Smit.	☐	☐

Figure 36. Consent form P (p.3)

Handtekeningen

_____	_____	_____
Naam deelnemer	Handtekening	Datum

Ik, **de onderzoeker**, verklaar dat ik de informatie en het instemmingsformulier correct aan de potentiële deelnemer heb voorgelezen en, naar het beste van mijn vermogen, heb verzekerd dat de deelnemer begrijpt waar hij/zij vrijwillig mee instemt.

_____	_____	_____
Naam onderzoeker	Handtekening	Datum

Contactgegevens van de onderzoeker voor verdere informatie: Nynke Heeringa, n.heeringa@student.tudelft.nl, +3

Figure 37. Consent form P (p.4)

B.XI Interviews experts ‘context analysis’

Prosthesis users



Users

Achtergrond informatie	U1	U2	U3
Q. Gender	v	v	v
Q. Leeftijdsrange	30	80	80
Q. Woonplaats	oost nederland	brabant	hillegom
Q. Wat is de oorzaak van uw verkorte arm?	Geboren	Geboren	Verkeersongeluk
SQ. Wat is de hoogte van uw prothese (onderarm/bovenarm)?	Onderarm	Onderarm	Bovenarm
SQ. Hoe lang heeft u al een prothese?	Hele leven	Sinds 16e, want arts aanbevolen zo best te ontwikkelen.	Rond 61, 62. 21, 22 jaar. Deze nu 4 jaar, nieuwe ligt boven.
SQ. Wat waren uw overwegingen om een prothese te nemen?	Nodig	Toen starten aan nieuwe opleiding. Uiterlijk.	Dit was toen de enige optie zeiden ze.
Q. Kunt u mee meenemen door de ervaring van het leren gebruiken van de prothese?	Zo jong, weet niet anders. Heel intuitief.	Cosmetisch dus niet ingewikkeld.	Best logisch hoe dat werkt, ging wel of ging niet. Dacht er niet zo bewust over na.
Q. Wat voor protheses heeft u al gehad?	Koker om mee te kruipen, vaste hand, vanaf basisschool myo elektrische prothese. Later uitgebreid met polsdraaifunctie.	5 cosmetische protheses. Soms huid wat geirriteerd, nieuwe	Eerst hulpstokken. Tunneltje pas later gemaakt. Geopereerd door dokter Bosserds in SMK Nijmegen.
SQ. Welke prothese die u heeft gebruikt vond u het prettigst en waarom? Welke vond u het onprettigst en waarom?	Alles fijn, meeste herinneringen aan myo. Heel fijn.	Siliconen prothese met afdruk van rechter hand, heel realistisch heel mooi. Klachten aan de stomp door prothese. Sindsdien altijd dezelfde pvc protheses met riempje. Heel vervelend, omdat die wel opvalt. Voelt als een blok aan mijn lijf. Heel standaard.	Was de enige optie zeiden ze.
Prothese ervaring			
Q. Hoe vaak gebruikt u uw prothese? Hoe veel uur per dag is dat ongeveer?	Volgens prothesebouwers een van de weinigen die hem zo vaak gebruikt. Draagt hem vaak de hele dag, alleen als ze savonds niks meer hoeft te doen kan die af.	Sochtends aan en savonds af. Hele dag. Altijd als ik naar buiten ga.	Eigenlijk altijd, sochtends bij opstaan aandoen en savonds voor slapen gaan uit.
SQ. Bij welke handelingen gebruikt u uw prothese vooral?	Met bijna alles. Als ze naar buiten gaat zeker.	Fietsen (want duim om stuur). Kleding naaien. Strikken (ook met 1 hand). Breien.	Doe bijna alles met gezonde hand, wanneer nodig klemmen erg handig.
SQ. Bij welke activiteiten gebruikt u uw prothese liever niet?	In de zomer minder, want dan is het erg warm. Afwas drogen makkelijker zonder dan met. Niet met water in contact komen, alleen schoonmaken met water.	Bij kou wordt prothese ook erg koud, arm dus ook. Gebruikt handwarmer.	Gebruikt hem niet bij fietsen, dat doet ze met één hand. En douchen doet ze zonder. Wanneer ze buiten loopt geen korte mouwen, want geen zin in bekijk of vragen. Bij zwemmen ook zonder.
SQ. Wat vindt u beperkend aan het gebruik van uw prothese?	Warmte en water. Andere hand die alle grepen kon met alle vingers, maar ik wil graag dat het cosmetisch zo min mogelijk opvalt. Huidskleurige handschoen zou functie wel verliezen. Belangrijk dat zo min mogelijk opvalt.	Kou en niet mooi	Prima, doet het alleen niet altijd.
SQ. Wat is iets dat u fijn vindt aan de prothsese?	Heel fijn. Alles lukt beter met dan zonder. Waardevol. Belangrijk dat die zo min mogelijk opvalt.	Handschoen over prothese, esthetisch karakter.	Hebben van een arm ziet er ‘gewoon’ uit als je anders een arm mist.
Q. Wat vindt u het belangrijkste aspect aan een prothese?	Uiterlijk en comfort over functie.	Realistisch uitzien	Dat het lijkt alsof je een arm hebt
SQ. Wat vindt u belangrijk in het uiterlijk van een prothese?	Min mogelijk opvalt.	Realistisch uitzien	Realistisch
SQ. Kunt u de volgende aspecten op volgorde van belang zetten?	Uiterlijk - aansturing - duurzaam - bewegingen	Uiterlijk - duurzaam - aansturing/beweging	Uiterlijk- duurzaam- aansturen- beweging
Comfort			
Q. Kunt u mij meenemen door het proces om een prothese aan en uit te doen?	Sort van kous achtig ding. Vacuum trekken in de koker. Zonder kan ook maar dan niet zo stevig vast. Sochtends een keer aan voor hele dag. Misschien aantrekzak.	Nu met het riempje om en af doen. Met een riempje	Prothese aan, staafje in het tunneltje, knoopjes aan drukken en klaar.
SQ. Wat is hierbij uitdagend en wat vindt u dat goed werkt?	Ik vind het wel prima want die kous is gewoon stof. Aantrekzak van plastic niet prettig.	Gaat prima	Werkt prima. Zit goed vast. Sluitingkje soms met jas aan los, verder niet. Doet het niet altijd. Als het heel zwaar is zakt ie wel eens door. Dan schiet het er doorheen. Ondersteun gauw met andere hand om te voorkomen dat het valt.

Q. In het gebruik van uw prothese, wat vindt u comfortabel? Wat vindt u niet comfortabel?	Zo recht mogelijk is wel makkelijk zodat die niet in een bepaalde bocht hoeft te zitten bijvoorbeeld bocht van fiets stuur. Daar krijg je op den duur last van. Dingen pakken die achter me staan kosten meer moeite.	Gaat prima	Prima, werkt niet altijd, dat is soms onhandig. Bij warmte zit hij soms niet zo lekker.
Aansturing			
Q. Heeft u voorkeur voor een statische of bewegende prothese? Waarom?	Bewegend. Echt nodig, ook omdat ik er nu aan gewend ben.		Bewegend: ellenboog op slot.
Bij statisch:			
SQ. Mist u de optie om de prothese te kunnen laten bewegen?		Ja: potjes openmaken, want weinig kracht in rechterhand. Draad in de naald krijgen 2 handen voor nodig.	Nee, mis geen grijpfunctie, niet nodig
SQ. Welke bewegingen zou u het belangrijkst vinden om weer te kunnen?	-	Grijpfunctie	-
Bij bewegend:			
SQ. Welke bewegingen vindt u het belangrijkst om te kunnen?	Draaien en grijpen. Draaien wel ook nodig. Grijpen belangrijkst.	-	Vastzetten van een houding van de ellenboog. Grijpen niet nodig. Ellenboog flexie meest interessant.
SQ. Waar ziet u ruimte voor verbetering voor bewegende protheses?		-	-
SQ. Hoe heeft u het leertraject ervaren om de prothese aan te sturen?	Ook op latere leeftijd, 4 jaar geleden nog ergotherapie gehad. Aangesloten op computer programma met auto over muur, hardheid van duwen hoogte van springen. Gaat heel snel	-	Prima, ging goed. Even wennen maar intuitief.
SQ. Heeft u wel eens last van het gebrek aan feedback bij het oppakken van dingen? Laat u wel eens iets vallen of knijpt u iets kapot?	Pak niet zo vaak dingen op, als het breekbare dingen zijn liever met gewonen hand omdat ik niet zo goed weet hoe hard ik moet of kan knijpen.	-	-
Cineplasty			
Q. Wat is uw eerste reactie over cineplasty ik dit zo vertel?	Plaatje ziet er beetje luguber uit met zo'n pin door je arm. Voor de tijd wel vooruitstrevend. Aansturing lijkt me wel een stuk intuitiver, zeker als je 2 handen mist. Of bijv door amputatie dat je wel gewend bent geweest aan feedback uit 2 handen. Deze methode geeft misschien meer feedback.	Veel minder duur. Wat als problemen met spieren. Mijn linkerarm is ook wat minder goed ontwikkeld dan de rechter, hij is wat dunner. Dus vraag mij wel af of bij aangeboren sterk genoeg is. Ik dacht daarnet ook het kan best pijnlijk zijn. Vreemd element in je arm, lijkt mij pijnlijk. Alles bedekt met huid, zou dan niet pijnlijk zijn	Het werkt.
Q. Stel dat u de arm zelfstandig kan strekken en buigen (waarbij een deel van de onderarm nog aanwezig is), wat zou u vinden van een protheses die alleen de hand kan openen en sluiten?	Belangrijkste beweging.	Zeker proberen. Je gebruikt je hand heel vaak om iets te grijpen. Als aansluiting van spieren goed gaat. Als het pijnlijk is dan doe je het niet.	Geen behoefte aan grijpfunctie.
Q. Wat zou u vinden van een standaard gat (soort piercing) in de arm waar een staafje doorheen kan voor de aansturing?	In het begin kan dat pijnlijk zijn zijn en misschien gek idee dat die pin erdoorheen moet. Later zal het gewoon wennen. Dat het net zo normaal wordt als bij myo.	Niet pijnlijk en gaat verder goed, dan neem ik aan dat dat vreemde element in je lijf niet erg is, ik heb nu ook een vreemde arm aan mijn lichaam hangen. Zou ik geen probleem vinden.	Prima, valt niet op. Zwem ermee en niemand ziet het.
Q. Wat zou u vinden van het idee om de prothese aan te sturen met behulp van het staafje?	Zie bovenstaand.	Dat maakt niet uit, kan me niet schelen. Zelf uit kunnen doen, belangrijk.	Voelt logisch. Ben eraan gewend.
SQ. Hoe verwacht u dat de aansturing van de prothese op deze manier voelt?	Zie bovenstaand.	Moeilijk voor te stellen, denk wel logisch	Voelt logisch. Ben eraan gewend.
Q. Als u cineplasty vergelijkt met bestaande alternatieven, wat zijn dan in uw ogen de voor- en nadelen van cineplasty?	Voordeel myo geen operatie, cineplasty meer feedback en intuitiever.	Heb geen ervaringen daarmee, maar denk zeker dat die daartussen zou passen. Juist vanwege het praktische. Als ik jong was zou ik ervoor kiezen. Lukt het niet of zit het vervelend, dan kan je altijd nog terug naar een cosmetische.	Je doet het met wat je hebt.
Q. Ziet u waarde in de techniek van cineplasty?	Misschien nuttiger bij mensen die hebben geweten hoe hand heeft gevoeld dus amputaties. Daarnaast is er al in gesneden dus is dat idee minder naar en wellicht kan het misschien in 1 x.	ja	Ja, het werkt prima voor mij.

Clinical experts (C1-C4)



Clinical experts

	C1	C2	C3	C4
1. Achtergrond informatie				
Wat is uw specialisme?	revalidatie arts	revalidatie arts	revalidatie arts	orthopedisch chirurg
Wat is uw specialisatie?	bovenste extremiteit	bovenste extremiteit	hand/pols, ellenboog/schouder (bovenste extremiteit)	hand en pols
Wat is uw leeftijdscategorie?	35-45	35-45	>55	45-55
Wat is uw gender?	v	v	v	m
In wat voor ziekenhuis practiseert u?	academisch	academisch + perifeer	Academisch	academisch en perifeer
Bent u opleider van aios?	ja	nee	Ja	ja
Wanneer van toepassing: wanneer bent u begonnen met uw eigen praktijk?	-	-	-	-
2. Originele techniek				
Q. Was u al bekend met deze techniek?	Ja, alleen uit geschiedenisboeken	Nee	Ja, filmpje van Gerwin gezien en les over gegeven	Ja
Q. Wat is uw eerste reactie op de techniek van tunnel cineplasty?	Grote belasting op patient, maar wel erg betrouwbaar en functionele techniek.	Atrofie van de biceps? Krachtverlies door flexiemoment brachialis en brachioradialis.	Obsuleet. Heel erg onder de indruk van wat zij konden op het fimpje. Nog nooit zulke goed werkende protheses gezien.	Echt super". Concept van proprioceptie (pijn,tast, prop, tempj kunnen we niet tegenop met techniek. Mooie techniek
SQ. Op het gebied van cosmethiek, haalbaarheid en techniek?	Prothesegebruikers vaak blij dat stomp dicht is, vaak huiverig over opnieuw openen. Cosmetisch niet mooiste techniek, zeker hoe operatie toen werd gedaan. Cosmetisch niet heel mooi natuurlijk. Er is zeker modernisatie nodig voordat het geaccepteerd zal worden. Maar myo zwaar > balansverschuiving in bovenlijf, stompverandering > elektroden verplaatsen. Lichaamsbekrachtigd en passief beperkt in ROM.	Ik zou het toch een mutilerende operatie noemen.	Haalbaar zeker, niet zo mooi cosmetisch. Nu misschien wel sneller geaccepteerd dan vroeger doordat iedereen tattoeages en piercings heeft	Cosmetisch nog niet daar, zeker haalbaar en relatief eenvoudige techniek
Q. Het is niet volledig bekend waarom deze operatie niet meer wordt gedaan, heeft u een idee wat hier de oorzaak van kan zijn op basis van uw medische expertise?	Enorm invasief. Myo lijkt dan natuurlijk veel aantrekkelijker.	Niche	Cosmetisch niet mooi en iedereen wil het gaafste robotische dat er is.	Cosmetische component. Hype. Myo groot innovatief karakter. 'Gadget'. Net als voorste benadering van de heup prothese en duimprothese.
3. Risico's				
Q. Wat verwacht u dat de grootste risico's zijn van deze operatie techniek? Zowel tijdens operatie als bij revalidatie.	Ontsteking, atrofie en dichtgroeien	Infectie. Donorhuid afstoting. Atrofie van de biceps. Complicaties na amputaties. Donorsite voor huidtransplantatie. Met schaafmachine. Grote brandwond. Litteken. Geen gevoel meer.		Spierscheuring kleine kans, atrofie: als spier niet belast wordt verdwijnt die.
SQ. Kunt u ideeën bedenken hoe de mogelijke risicos verlaagd kunnen worden?		Vistel bij osseo integratie (opening van buiten naar binnen). Verhoogd risico op infectie. Pin permanent in de arm.		
4. Level van uitdaging				
Q. Hoe zou u de learning curve van deze operatie omschrijven?	-			Goed aan te leren
SQ. Hoe gradeert u de cineplastische operatie?	Eenvoudig	Ingewikkeld, wordt ook niet vaak gedaan		Gemiddeld
SQ. Hoe lang verwacht u dat het uitvoeren van zo'n operatie duurt?	1 uur	Net als osseointegratie: 3 a 4 uur		1,5 uur
5. Verbeteringen				
Q. Met uw kennis en de huidige operatie technieken, hoe zou u een cineplastische operatie uitvoeren?	Degelijker, minder lomp. Ga vragen aan plastisch chirurgen, die pakken het al veel nauwkeuriger aan dat orthopeden. Kijk vooral naar verschil van aanpak, interessant			Probleem is dat binnenkant van tunnel bij piercing zelf laagje huid vormt, bij arm niet.
Q. Met behulp van welke bij u bekende technieken/tools/materialen kan de cineplastische operatie tegenwoordig minder belastend zijn voor de patient dan in de jaren '50? Is er een minimaal invasieve optie? Zonder de huid dermate open te snijden?	Vooral veel nieuwe materialen gebruikt in operaties.			Implantaten in bot werkt prima (markers), in pees ook regelmatig gedaan. Spier weet ik niet zo.
Q. Als u alle tools en materialen tot uw beschikking zou hebben, wat zou dan de optimale manier zijn om een soortgelijke operatie uit te voeren?	Er zijn steeds meer materialen die goed kunnen met spier/pees/zenuw.	Hout/ivoor > titanium		Eigenlijk wil je niet zoveel littekenweefsel creeren, dus zonder huid te openen, wel lastig.
Q. Heeft u andere ideeën hoe men de prothese intuitief kan aansturen (zonder een tunnel door de spier te creeëren)?	TMR + klikprothese. TMR/TSR combinatie (4 uur) zorgen voor pijnverlichting, aansturing en sensorishe informatieverwerking. Wordt gecombineerd nog niet zo vaak gedaan, en heeft ook nog niet zulke geweldige resultaten.	Feedback kan door trilling in de botten, net als bij oortjes op mastoid.		
Q. Ziet u in de cineplastische methode ruimte als oplossing voor andere aandoeningen?	Bij uitval aansturing van een handschoen, wordt dan een orthese ipv prothese.	Plexus brachialis letsel		
Q. Ziet u waarde in deze techniek?	Ja, zeker in betrouwbaarheid heeft het veel meer waarde dan de huidige myo elektrisch aangestuurde protheses. Daarnaast is vormverandering van de stomp een veelvoorkomende issue bij emg protheses en dat zou bij cineplasty geen invloed hebben. Feedback ook super belangrijk. Zodra dat met TMR en TSR nog niet helemaal lukt, cineplasty zeker goede optie.	Ja		
SQ. Zo ja, alleen in verbeterde versie of ook in de originele techniek? Voor welke toepassingen?		Ontwikkelingslanden. Leren welke bewegingen inzetten.		
SQ. Zo nee, waarom niet?				

Clinical experts (C5-C8)

	C5	C6	C7	C8
1. Achtergrond informatie				
Wat is uw specialisme?	Orthopedisch chirurg	Plastisch chirurg	plastisch chirurg	plastisch chirurg
Wat is uw specialisatie?	hand en pols	Hand-pols en ellenboog	hand/pols	hand en pols
Wat is uw leeftijdscategorie?	35-45	35-45	>55?	35-46
Wat is uw gender?	v	m	m	v
In wat voor ziekenhuis practiseert u?	Perifeer en kliniek	perifeer	Academisch	academisch + perifeer
Bent u opleider van aios?	ja	nee	Ja?	nee
Wanneer van toepassing: wanneer bent u begonnen met uw eigen praktijk?	-	-	Ja?	-
2. Originele techniek				
Q. Was u al bekend met deze techniek?	Nee	Nee	Nee	Nee, best wel heftige wond op vervelende plek als je daar ook protshese overheen draagt. Inmiddels betere alternatieven beschikbaar. Beter alsin minder morbiditeit.
Q. Wat is uw eerste reactie op de techniek van tunnel cineplasty?	Best wel ontsierend'. Maar lijkt me erg makkelijk aan te leren.	Low budget	Unilaterale, een functie die je kan teruggeven. Individuele hand en duim niet haalbaar. Powergrip en sleutel greep. Voor iets wat voelt als een hele ouderwetse techniek. Krukenberg ongelooflijk ouderwets en ongelooflijk lelijk. Kan eigenlijk niet, maar heel functioneel. Enige indicatie is blind. Kleine populatie. Voelt alsof je terug gaat in de tijd. En die heeft ook wel echt zijn waarde. Tripod. Bij afwezigheid van myo elektrisch. Technisch niet zo moeilijk	
SQ. Op het gebied van cosmethiek, haalbaarheid en techniek?	Je bent natuurlijk al gemutileerd, en je krijgt er wel een hand mee.	Cosmetisch niet de mooiste optie, wel haalbaar, maar ook complicatiegevoelig.	Zie bovenstaande.	Je krijgt best wel een lelijke biefstuk die op je arm ligt met een huidtransplantaat eroverheen.
Q. Het is niet volledig bekend waarom deze operatie niet meer wordt gedaan, heeft u een idee wat hier de oorzaak van kan zijn op basis van uw medische expertise?	Als er esthetisch mooiere alternatieven ontstaan, hypes in de gezondheidszorg kan ook (duimbase), geld: als de een goedkoper is dan de ander, gebrek aan post operatieve begeleiding.	Hoge complicatiekans, moet best specifiek deel van je onderarm hebben wil het kunnen passen. Lengte en kwaliteit. Mechanisch, grote moment arm.	Kan van alles zijn, maar myo elektrisch natuurlijk veel mooier. Lijkt mij moeilijk om te leren qua bicep. Biceps worden voor triceps functie gebruik bij dwarsleasie. Motivatie. Intuitief. Bain plasticity. Ellenboog flexie idee voor hand sluiten. Peestranspositities voelen	Veel betere alternatieven, elektroden op de huid, bovenop een spier. Dus niet invasief. Vreselijk lelijk groete wond met een holte die slecht verzorgbaar is, waar huidcellen worden aangemaakt. Goed schoon houden iedere keer. Wond ook nog eens op plek van koker ish. Hygiene.
3. Risico's				
Q. Wat verwacht u dat de grootste risico's zijn van deze operatie techniek? Zowel tijdens operatie als bij revalidatie.	Infectie & falen van de flap. Gevoelsstoornis of pijn? Contraheren van de tunnel	Zenuwletsel tijdens operatie, post operatief: vistel moet mooi ontstaan, niet contraheren, en behouden blijven, willen wel eens dichtgroeien. Op lange termijn kans op soort doorligplek van vistel. Buiten drukpunten van prothese zelf.	Wondinfectie. Schakelt biceps uit, levert wat kracht in. Ondertussen wel zware prothese.	Tijdens operatie niet zo heel veel spannende dingen, infectie/bloeding/zenuwletstel kans lijkt me niet heel groot.
SQ. Kunt u ideeën bedenken hoe de mogelijke risicos verlaagd kunnen worden?		Electronisch aangestuurde prothese. Zie geen andere opties bij deze techniek.	-	Postoperatieve huidtranspantatie niet goed ingroeit, necrose van huidlap die je eropheen vouwt. Contractie van het tunneltje, te nauw om het staafje in te brengen. Normaal distale biceps pees ruptuur, bicep spier gaat proximaliseren, trekt samen. Mischien kans daarop. Bij aanspannen van bicep dat die heel veel beweegt, problemen met de wond.
4. Level van uitdaging				
Q. Hoe zou u de learning curve van deze operatie omschrijven?	Voor mij gemiddeld maar voor plastisch eenvoudig	Goed te leren	Goed aan te leren	Eenvoudig aan te leren
SQ. Hoe gradeert u de cineplastische operatie?	Eenvoudig	Eenvoudig	Eenvoudig	Eenvoudig
SQ. Hoe lang verwacht u dat het uitvoeren van zo'n operatie duurt?	45 min/uur	Half uurtje	Snel, 40 min?	Uurtje. Ziet er niet uit als een complexe ingreep.
5. Verbeteringen				
Q. Met uw kennis en de huidige operatie technieken, hoe zou u een cineplastische operatie uitvoeren?	Kunstmaterialen. Lichaam snel geneigd om littekenweefsel aan te maken	Staafje door de biceps krijgen hoef je niet heel veel voor te doen. Dat systeem integreren in een wat modernere prothese fit. Ellenboog wil je niet beperken, dat komt je grijpfunctie ten goede.	Volgens de originele stappen.	Patient onder narcose/plexus blokkade. Meeste operatie bloedleegte band, ind it geval te proximaal om erbij te kunnen. Huidlap ontwikkelen, naar diepte opzoek naar biceps, distaal doornemen. Op subcutis leggen (bed waar stukje huid vandaan gehaald is zeg maar), biceps distaal vasthechten anders trekt terug naar proximaal, huidlap tunneltje maken. Gat in biceps, huid in tunneltje doorheen en aan eind vasthechten, huidtransplantaatje van been inhechten. Verband of spons eropheчten, tijdelijk niet schuiven of bewegen. Goed aangedrukt en niet schuiven (5-7 dagen) tie over.

Q. Met behulp van welke bij u bekende technieken/tools/materialen kan de cineplastische operatie tegenwoordig minder belastend zijn voor de patient dan in de jaren '50? Is er een minimaal invasieve optie? Zonder de huid dermate open te snijden?	Ankertje	Denk het niet, want gaat mechanisch doen. Biceps los en gat in. Blijft vastzitten in de schouder en loszitten in de arm.	Primair sluiten.	Nee niet per se andere. Nu elektrisch apparaatje om huidtransplantaatje te openen (dermatoom).
Q. Als u alle tools en materialen tot uw beschikking zou hebben, wat zou dan de optimale manier zijn om een soortgelijke operatie uit te voeren?		Ziet het niet per se als invasieve operatie. Kan wel net als piercing schieten, groeit ooit wel dicht, maar duurt erg lang.	Piercing idee te lange afstand, blijft altijd wond. Pen osseointegratie blijft een stoma. Blijft lekken en irritant. Zeker in vombi met spier die aangetrokken. Aparte incisie doorsnijden biceps.	Piercing idee: distaal spier losmaken, daar heb je toch een incisie voor nodig. Zou al een stuk mooier zijn als je die spier kan laten zitten waar die zit, en niet losmaakt en oppervlakkig brengt. Ene kant biceps, andere kant klein gaatje maken iets doorheen schieten en iets waardoor er allemaal huidcellen groeien. Risico dat dat allemaal gaat samenvallen. Altijd risico waar buisstructuren worden gereconstrueerd. Penis reconstructie, urinebuis, huid omheen clappen, grootste risico is dat je contractuur kan krijgen, smanetrekken en verlittekenen. Groot risico dat het helemaal gaat samentrekken en erniks mee rin krijgt. Helemaal als je de binnenbekleding van de tunnel met iets anders gaat doen dan wat de dikte van de huid heeft. Misschien wel gat in die spier, maar wanden in de tunnel moeten goed bekleed zijn. Vast in spier veel logsicher, electrode in spier, of misschien net distaal biceps pees doorsnijden met kleine incisie. Kleine electrode. Zo iets maar ingewikkelder voor sensibiliteit (TMR/TSR). Uitdagingen van prothesiologie lastig om feedback te krijgen.
Q. Heeft u andere ideeën hoe men de prothese intuitief kan aansturen (zonder een tunnel door de spier te creeëren)?	Maak gebruik van pees in plaats van spier. Met anker systeempje > maar 1 uitgang	Feedback creeeren met een trilling, hoe dicht de hand zit. Cineplasty is wel heel directe feedback.	Nee	Meest intuitief als je op een of andere manier die sensibiliteit kan nabootsen.
Q. Ziet u in de cineplastische methode ruimte als oplossing voor andere aandoeningen?	Zenuwletsel of verlamming.	Om je boodschappentas aan te hangen. Ik zie nu niet meteen een idee.	Techniek niet meoten willen veranderen, eerst uit de kast halen en checken. En patienten vinden. Zelf kunnen aantrekken.	Wat ik bijv vaak doe is pees of zenuw transfers die functieuitval hebben van bepaalde spiergroepen. Nu verplaats ik ene zenuwtakje naar andere zenuwtakje voor spier die is uitgevallen. Niet helemaal overmaken, maar staafje inschieten om andere aan te sturen. Staafje in ene spier die nog werkt, staafje in andere spier die niet werkt.
Q. Ziet u waarde in deze techniek?		Ja ik denk wel in de low budget vorm. Denk dat de technieken steeds beter en beter worden, zitten nu in een soort groei voor de elektrische protheses. In low budget landen kunnen mensen er erg gebaat bij kunnen zijn. Zou wel soort universele fit moeten zijn, waarbij one proshtesis fit all oplossing. Ellenboog functie behouden. In NL slecht verkocht. Mainstream patienten willen vaak meest technologisch geavanceerde opties.	Voelt als heel ouderwets, net als Krukenberg ook zeker zijn waarde. Ik krijg ze niet op de poli, blijven allemaal bij revalidatie artsen hangen. Nieuwe techniek invoeren revalidatieland bespelen. Functionerende ellenboog zien ze nooit terug met de wens. Krukenberg in 12 jaar.	Als je dit zou willen toepassen denk ik dat dit wel een optie is, maar ik vraag me af hoe zinvol het is. Ik kan me niet voorstellen dat ik gauw deze operatie zou doen. Geen goede indicatie voor zou kunnen bedenken. Goed alternatief met externe sensoren.
SQ. Zo ja, alleen in verbeterde versie of ook in de originele techniek? Voor welke toepassingen?	Ontwikkelingslanden	Nah het is niet zo mooi, medium. Zou niet zeggen ziet er zo lelijk uit ik zou het niet doen. Zal best een leuke attractie zijn en ziet er niet afzichtelijk zijn als je een gat in de biveps hebt zitten, maar na amp sws al niet zo fraai.	Wordt lastig. Hoe het nu cosmetisch eruit ziet niet aantrekkelijk voor de patient.	Maar als het minder invasief kan, met ergens een staafje in een spiertje schieten wat klein is, dan is het misschien een ander verhaal.
SQ. Zo nee, waarom niet?				Niet hoe die in de voorbeeldjes getekend is, betere alternatieven zijn. Minder risico en minder ellende opeleveren met die wond.

Prosthetists



Prosthetists

	P2 + P3	P4	P5
1. Toepassing en indicatie			
Hoe vaak hebben jullie patiënten met tunnel cineplasty door de biceps gezien?	Vrouw in Leiden in bicep, verder nog 1 onderarm 1 pin en 1 onderarm 2 pinnen.	Nooit gezien. Eerste reactie 'Lijkt me niet prettig'. Niet per se met huidige alternatieven in het achterhoofd maar uberhaupt.	Het werkte wel heel goed vond ik, 2 van de bovenarm. Ellenboog mee los maken. Kunststof buisje door arm. Afgedraaid naar soort druk knop op net als jas. Y verbinding van leer ging naar. Patient in Limburg (man). Twee mannen. Gaat hij achteraan man uit Limburg. Andere patient uit Rotterdam. De heer Tans. Peter van Vliet. Ellenboog vaststelling voor lifting van de bovenarm. Stype ellenboog. Onderaan hendel die je omhoog kon trekken en die aangesloten. Grijpfunctie niet logisch met bovenarm. Ligt eraan hoe sterk je ermee bent, en uitslag moet voldoende zijn. 5-7 cm geloof ik niet. Eerder 3 cm bij de klanten. Bedienen van ellenboog 1 cm genoeg. Als je biceps pakt altijd midden voor. Zit die eigenlijk al in het midden. Naar beneden werken via een kabel begeleid en naar de hand toe. Sluiting zit vaak aan mediale of laterale kant. Rekening houden welk type hand gebruikt gaat worden. Verlies door wrijving. Binnen en buitenkabel zorgt voor veel weerstand. Eerst veer aatnrekken, loopt door die kabel heen en veel weerstand. Waterdruk (hydraulisch), maar dan nog wrijving van cylinders. Risico op lekkages. Misschien ook geen optie. Toch zien in kabel met eventueel vast draaipunt in de ellenboog.
Is er een indicatie voor wanneer cineplasty wordt toegepast of wanneer juist niet?	Spieren/spierbuik. Vroeger actief, meer vrijheid dan bandage. Myo in opmars. Tegenwoordig cosmetisch aspect. De Boer nieuw leven inblazen in oude technieken. Cosmetisch aspect groter dan vroeger. Osteointegratie vergelijking. In NL nog niet vaak gedaan voor armen alleen benen. Doelen te hoog, verwachtingen niet gehaald. TMR en osteo. Daarna mechanisch. HERO arm geen kabeltjes.	-	Nooit gehoord dat het pijnlijk was. Helemaal geen last van. Elke dag gebruikt, geen last. Heel groot gat in koker en daar buisje in. Laatste prothese die voor hem is gemaakt niet meer nodig want boerenbedrijf niet meer. Ze zijn gruwelijk sterk daarmee. Konden zeker een kilo of 8 omhoog houden. Meer kracht leveren dan lb. Makkelijker via biceps.
Patiënten die met cineplasty een onderarmprothese aansturen kunnen alleen de hand openen en sluiten. Is dit voldoende voor een patiënt? Of zijn er verlangens naar het uitvoeren van meer verschillende bewegingen?	Operatie kosten niet grootste tegenhouder. Handen jaren 40-50-60 metaal (alu) katrollen en veren. VO/VC. Hand of haak. Cosmetisch of functie. Per kabel vinger aansturen. Seml multiarticulaire hand. Vingers over balletje heen sluiten. Printen voor prototype prima maar niet heel duurzaam. SLS beter, carbon fiber beter.	Lengte compenseren in combinatie met kunnen grijpen.	Meestal grijpen belangrijkste functie, voor bovenarm ellenboog ook belangrijk.
2. Ontwerp en techniek			
Hebben jullie wel eens protheses voor patiënten met tunnel cineplasty ontworpen/gemaakt? Hoe verloopt dit traject?	Geen fitting nodig qua ophanging door kabels. Bvenarm kap met kables, meer opengewerkte prothses dan gesloten koker. Flexoren extensoren lijkt makkelijker dan bicep want afstand overbruggen. Pronatie supinatie in onderarm. Voor fitting zorgen. Mhand. Eerder technisch oplossen dan naar bovenarm gaan. Arm vast kunnen zetten scheelt in kracht. Bandage nodig. Veel kracht om los te krijgen.	Niet alleen meer door instrumentmaker maar ook chirurg, dus kan voorstellen dat het traject langer gaat duren. PPP protocol om te kijken of juiste voorziening uit hulpvraag komt. Dan nog iemand geopereerd worden. Ten aanzien van huidig proces vertraagt enorm.	Zelfde als altijd, alleen nu aan pin bevestigen ipv bandage
Welke connectiemethode wordt gebruikt voor de prothese aan de stomp?	Liner/om botten ellenboog (condyle fit)/posl ex/ vacuum	-	Drukknoopjes aan pin, verder condiele fit logisch of bandages voor bovenarm.
Zijn er dingen waar je op moet letten die anders zijn dan bij andere body-powered protheses, of EMG-aangestuurde protheses?		Body powered zo optimaal mogelijk afstellen, hoe beter je dat afstelt hoe directer de aansturing is. Als je dat niet goed afstelt zit er vertraging in. Zo strak mogelijk, geen speling. Kan me voorstellen hoe die vicep is en als die atrofeert bij minder gebruik.	Kabel exact op draaipunt. Of anders mee laten helpen aan de flexie.
Cineplasty is natuurlijk een oude techniek, waarbij vooral oude protheses passen. Zijn er verbeterpunten aan de protheses die voor cineplasty beschikbaar zijn?	Veel afstand overbruggen, kan dat wel met spier? Kracht vs uitslag. Pees veel uitslag. Deel van spier stuk maken ten koste van kracht.	Intuitief? Leeftijd, en ligt heel erg aan persoon zelf. Zie nu ook met myo heel verschillend pp. Ligt ook heel erg aan hoe lang arm niet meer ingezet voor amputatie.	
3. Gebruik en ervaring			
Hoe verloopt donnen en doffen? Wordt dit ervaren als eenvoudig of ingewikkeld (vergeleken met andere protheses)?	Druk knoopjes aan zijkant van staafje.T stukje leer, riempje, prothese. Klik ellenboog vast. Klik (trek) ellenboog los). Veer ellenboog		Kabels met drukknoopjes aan pinnetje vast. Verder prothese aan en uitdoen als normaal.
Hoe zou een revalidatietraject eruitzien voor een patiënt die een cineplasty-prothese krijgt? En hoe verschilt dit met een EMG prothese?	Gaat heel makkelijk, direct. 2 lektroden herkenning helemaal leren, ook door combinaties van spieren. Heel onnatuurlijk. Patroonherkenning leert de computer wat jij wil. Cineplasty zit er dan tussenin. 50 tot 100 duizend eu. Mechanisch geprint verwacht: ligt aan naam . Moveable vanuit TU erg duur. Verzekering categoriën mechanisch/my vaste bedragen.		Kan ik niks over zeggen.
Hoe werkt het 'leren gebruiken' van een cineplasty-prothese vergeleken met EMG-protheses? Verloopt het traject sneller/minder snel? Is het te verleren?	Allebei makkelijk, even wennen en dan automatisch.		Leek wel intuitief.
Hebben gebruikers wel eens iets genoemd over de directe feedback die zij voelen in hun biceps? Helpt het hen in gebruik van de prothese?	Oekrainers gaan toch voor hoogste snufjes. Lijken niet open te staan voor cineplasty. Voordelen niet kapot en water. Hulpvraag van die gasten weer op de been en doorvechten, dan prima.	Goeie feedback alleen maar prettig, met huidige handen feedback natuurlijk nogsteeds beperkt. Direct voelen is er gewoon niet. Vind ik een lastige eerlijk gezegd/ Kan mee voorstellen dat er behoefte naar is.	Niet dat ik weet.
Waren gebruikers over het algemeen tevreden met de techniek? Wat waren positieve punten en waar waren de patiënten kritisch op?	Ja, werkte goed.		Ja werkte goed. Geen kritiek.
Was de prothese ervaren als comfortabel in gebruik?	Niemand horen klagen.		Denk het, weet het niet.
Wat vonden patiënten van het staafje? Vonden ze het idee van dat er iets door de arm gaat storend of het erin en eruit halen gedoe? Of geen last van? Hoe hard werd er door het staafje aan de huid getrokken?	Weet ik niet.		Je doet het ook met wat je hebt, heb er geen klachten over gehoord.
Maken patiënten met cineplasty meer of minder gebruik van hun prothese vergeleken met andere protheses (passief/actief)?	Weet ik niet.		Geen idee. Lastig te zeggen.
Hoe zou je de fysieke belasting van cineplasty vergelijken met die van traditionele body-powered protheses?	Denk vergelijkbaar.	Lichaamsbekrachtgd vaak bandage, gevoelig voor overbelasting. Kan me voorstellen dat dat bij deze methode niet erger hoeft te zijn. Mensen die wij hebben zijn bestnog wel actieve mensen. Aardappelen en uien boer gebruikt het als een stuk gereedschap. Hele bandage met zomer enzo minder prettig. Boer neemt het voor waar. Oncomfortabel kan je niet omheen. Hoe losser die is hoe minder directe aansturing. Siliconen oksel beschermers er is van alles maar hoort gewoon niet en zal niet prettig voelen.	Wel iets beter.
4. Reflectie en toekomst			

Kunt u een inschatting maken wat de voor- en nadelen zijn van cineplasty vergeleken met de huidige alternatieven?	Operatie, cosmetiek, functiediversiteit.	Alleen dat myo geen optie is. Lastig te antwoorden want ik ken het niet.	Als mensen het hebben is het een voordeel. Hygiene maakt ook niet uit want is weer helemaal dicht, soort oorbel. Tegenwoordig heel veel met liners gedaan, dat kan na de operatie niet meer. Bovenarm moet dan altijd met schouderkap.Pin alleen voor bediening, niet om prothese op te hangen. Als shouder vrij houden nogsteeds bandage nodig. Toch wel nadeel snijden en wringen.
Waarde van minder bandages?	Plus		Goed
Waarde van proprioceptie behoud?	Uniek		Heel goed
Waarde van duurzaamheid?	Plus vergeleken met myo maar niet per se met body powered		Goed
Waarde van lage kosten prothese?	Beter dan myo		Goed
Zien jullie cineplasty eerder als optie voor de boven- of onderarm? Waarom?	Staafje in onderarm werkte goed. Bij ontbreken ellenboog extra uitdaging.	Bovenarm scheelt wel met bandages. Hand kan bij bovenarm en onderarm. Alleen gebruik en aansturing, in gebruik dat je je ellenboog mist.	Hoe ze vroeger deden, ja. Maar nooit gezien bij onderarm. Geen ervaring mee.
Stel dat cineplasty weer een gangbare techniek zou worden, wat zijn dan de overwegingen voor de keuze tussen cineplasty, lichaamsbekrachtigd of EMG bij een onderarmprothese?	Past het bij behoeften patient.	Bovenarm myo gestuurd is er ook zeker wel. Ligt er aan welke spieren er nog zijn. Kan ook nog met 1 signaal. Kan ook allebei, maar moet dan schakelen, maakt het soms omslachtig. Omslachtige methode.	Praktisch, wat werkt het makkelijkst: myo of body powered. Cosmetiek, wat is mooier. Ligt aan behoften patient.
Wat zou er nodig zijn om cineplasty opnieuw op te nemen in het standaard aanbod van protheseboww?	Andere verwachtingen van patienten.		Overtuiging
Weten jullie andere technieken waarmee een prothese mechanisch aangestuurd kan worden (body-powered) in het geval van een onderarm?	Nee	Elleboog flexie. Voorkeur van aansturingsplek, ligt aan onder en bovenarm. Onder ellenboog boven andere schouder.	-
Zien jullie er waarde in om cineplasty te combineren met andere aansturingstechnieken, zoals EMG of sensoren, voor hybride controle?	Ukrainse multiacticulaire hand Esper hand. Goeie marketing. Concreet voorbeeld nodig. Servo uitrekken translinear reducer. In spier implanteren, In bovenarm manchet. Misschien niet helemaal waard. Wordt nu gebruikt in bandages. Geen Waarde. Is al iets van feedback met myo. Geluid/gevoel van de motor van myo geeft ook feedback. Japanse handschoen met druksensoren. Bi bionic, i limb eerste bionische armen (15 jr terug). Vingers uit elkaar kan nog niet met multi articulare hand.Steeds meer lijken op echte hand.	Moeilijke om voor me te zien.	Waardevol voor praktisch met armen werken, agrariërs, bouw, houtbewerking. Myo bezwijkt. Kan meer halen uit cineplasty dan mechanisch. Echte actieve gebruikers.Alle 3 klanten bovenarm.
Wat denken jullie dat cineplasty kan betekenen voor patienten in de huidige maatschappij?	Voorziening meerwaarde. Veel haken, aantal handen beperkt. Site van TRS. Fillhouwer.Voor elke sport of hobby bepaald hulpstuk, veel passief en actief. Systeem met kabel in binnenkant. Open source hand.PETG hand met TPU tussenstukjes.	In dagelijkse patienten tot nu toe niet. Komt ook omdat ik er geen ervaring mee heb en wat eventuele voorkeuren kunnen zijn. Veteranen zijn vaak jonge mensen, dus juist niet aangezien zij aansturen van elektrische prothese snel onder de knie. Misschien iets voor kunnen stellen bij ontwikkelingslanden. Simpel en effectief, niet veel techniek, niet stuk kan gaan of gerepareerd kan worden. Alleen vragen over operatie. Hufterproof.	Kan zeker, maar moet wel kunnen overtuigen want operatie wel drempel.

B.XII Shadowing days

Hand Wrist Centre The Hague

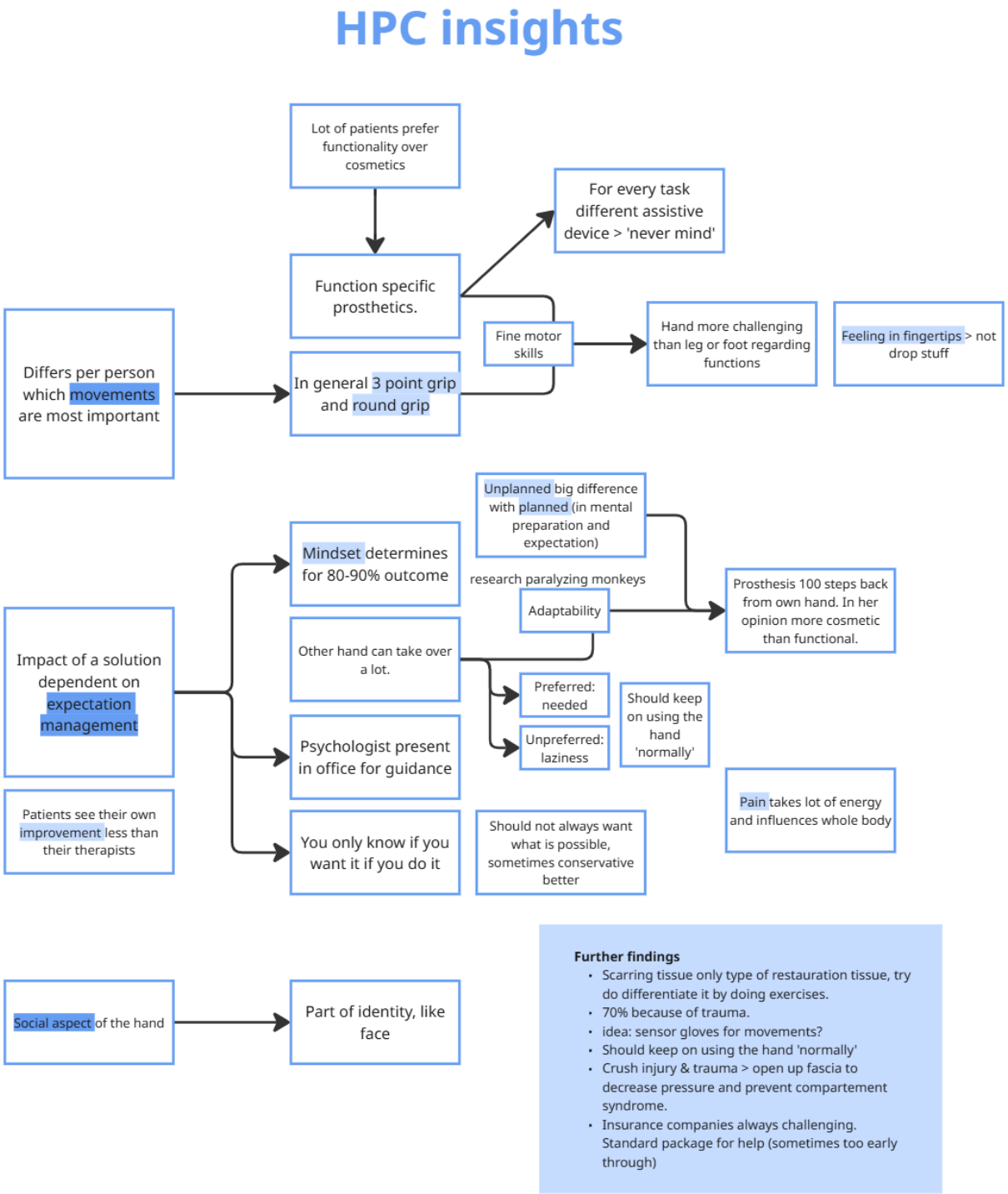

Figure 38. Experience and findings after a shadowing day at the Hand and Wrist Centre The Hague

De Hoogstraat Orthopedietechniek

Cosmetic prostheses

The main function of a cosmetic prosthesis seems to be improving the patient's appearance. However, a cosmetic prosthetic could also be quite functional, since the extension of the arm provides the possibility of pushing on the same length as the healthy arm (P4; Hoogstraat). When focusing on the cosmetic aspect, prostheses could look very realistic nowadays. There are standard arms (often PVC), but it is also possible to create a personal prosthesis by making a 3D scan of healthy side, mirroring this scan and then creating the perfect shape by 3D printing or silicone molding, which could be done by the prosthesist or by an artist specialised in prosthetics. Even colouring of the prosthesis is a whole science, where all small spots of colour change are analysed and included on the prosthesis (P3; Rijndam, Hoogstraat).

Body-powered prostheses

When a patient prefers the moving function of a prosthesis, a mechanical prosthesis could be an option. With a mechanical prosthesis, the prosthesis is connected to a moving joint in the human body, often with help of straps. Cineplastic prosthetics are thus a form of mechanical body-powered prosthesis, where the main difference is the direct connection to a muscle or tendon (internal) or connected to the outside of the human body. The position of the connection can differ per patient. The shoulder of the healthy side is often chosen as the optimal placement, but it is also possible to control the prosthetic with elbow flexion (C2, P1, P3, P4).

In general, mechanical prostheses are lighter in weight and more precise than myoelectric prostheses (C2, P3). This was confirmed during the Cybathlon 2016 competition in Zürich (could be

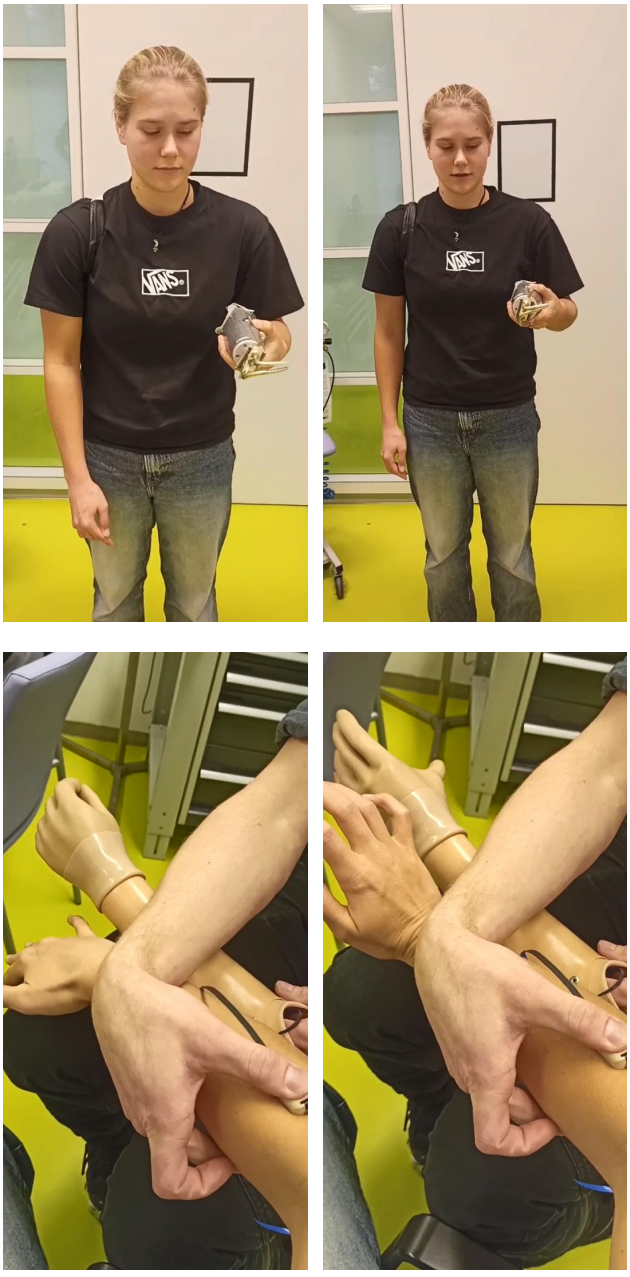

Figure 39. Trying out a body-powered (up) and myoelectric prosthesis (down) in 'de Hoogstraat Orthopedietechniek'

seen as the bionic Olympics), where the body-powered TRS Grip Prehensor outperformed advanced myoelectric prosthetic hands (Smit, 2020). Another huge advantage of mechanical prosthesis in general, is the consistency and reliability of the device, in contrast to myoelectric devices (Gerwin Smit, personal communication, 12 December 2025; C1, C3).

Yet, the acceptance rates of body-powered hands are low: approximately 20%. The fact that 'current body-powered hands require actuation forces that are uncomfortably high and provide low pinch forces in return' could be a contributing factor. The higher acceptance rate of 70% (n=300) in 1966 in combination with the far more efficient Hüfner hand at that time could stress the importance of low actuation forces (Smit, 2020).

Another downside of body-powered prostheses is that the physical load comes down to the other joint, which means that the healthy side of a patient experiences twice the physical demand. Prone for physical overtraining (Hoogstraat, C2).

Myoelectric prostheses

Approximately half of the patients in the Netherlands uses a myoelectric prosthesis (P3). Myoelectric prosthetics pick up the electrical signals within the muscles. There are some levels of advancements, where the basics lie in the number of electrodes. The simplest prosthesis, the two electrode prostheses could be used to open or close the hand with signals from the flexor or extensor in the lower arm. The amount of electrodes could go up to 8 (placed in a ring around the lower arm inside of the socket), where 8 different signals from 8 different muscles can be identified, and thus a lot of movements can be performed.

Besides the method that every electrode identifies a signal from a specific muscle and thus executes the matching movement, it is also possible to install pattern recognition in the device. This means that specific combinations of muscle signals could be coupled to different motions than in first glance would make sense. This type of control is very intuitive, since the patient can choose which muscle contractions feel like certain motions (P1, P2, P3, P4).

The major downside of myoelectric prosthetics is the weight of the prosthesis. Since all electronics is integrated in the prosthesis, mass accumulates, which could lead to straining joints (P1;P3). Another disadvantage of myoelectric devices is the dependence on maintenance, since they are quite frequently (multiple times in 3 years) in need of repair (P3).
Frequent and heavy physical work is a contraindication for myoelectric prosthesis (P3).

C. Define

C.I Mechanical expert consultation (teacher at IDE)

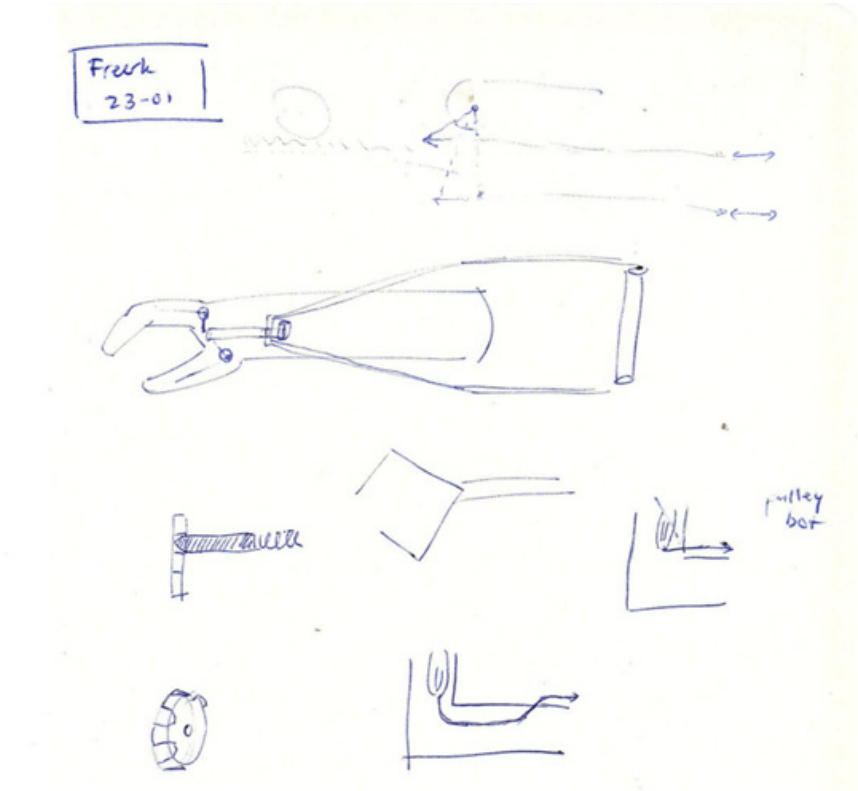

Figure 40.Notes of the meeting to analyse the prosthesis mechanically

Find out which force is needed and calculate where the optimum is in force – hand opening, and what is possible with the maximum excursion
Make overview of all places where energy gets lost (foremost elbow)
Bowden cable vs. pulley
Ask Gerwin whether there are already improved hands/prosthetics on the market and use those.

Think of ideas to reduce friction
- Bearings
- Cables
- Geometry
- Materials

C.II List of Requirements & Criteria

	REQUIREMENTS	Information derived from
1	**Functionalities**	
1.1	The prosthetic must provide the user with the ability to create a grasping motion.	2.1 What is cineplasty
1.2	The prosthetic must be able to generate sufficient pinch force (>15N) to accomplish a broad range of daily tasks at a comfortable activation force level (Smit, 2020).	2.6.1 A Deep dive into cineplasty
1.3	The prosthetic must be able to generate sufficient opening range (>70 mm) comparable to average hands on the market (Smit, 2020; Blaschke & Taylor, 1953; Kumar et al., 2025).	2.6.1 A Deep dive into cineplasty
1.4	The prosthetic, in combination with the tunnel, must be able to withstand 1.4 kg of weight (Blaschke & Taylor, 1953).	2.6.1 A Deep dive into cineplasty
1.5	The prosthetic must function accordingly with an excursion in the biceps muscle of 40 mm (Hueston, 1959; Blaschke & Taylor, 1953).	2.6.1 A Deep dive into cineplasty
1.6	The prosthetic must be able to stay connected to the user for 8 hours consequently.	2.5.3 Findings from experts
1.7	The prosthetic must provide the user with the ability to continue 80% of their ADL activities.	2.5.3 Findings from experts
2	**Weight & measurements**	
2.1	The prosthetic must weigh less than 300 g (Belter & Dollar)	2.5.2 Current prosthetics
2.2	The prosthetic must be in a continuous line with the arm (PO#3).	2.5.2 Current prosthetics
2.3	The prosthetic must be of similar length as the other arm (PO#3).	2.5.2 Current prosthetics
3	**Material**	
3.1	The prosthetic's material may not interact with sweat of the stump leading to discomfort in the user (PO#3).	2.5.3 Findings from experts
3.2	The prosthetic's materials that are in contact with the skin may not lead to irritation or redness of the skin (Hoogstraat).	2.5.3 Findings from experts
3.3	The prosthetic's materials must be able to withstand water repeatedly for a period of xx years without damaging the prosthetic.	2.5.3 Findings from experts
4	**Ease of use**	
4.1	The prosthetic should beable to be donned and doffed in less than 30 seconds (Rijndam/Hoogstraat).	2.5.3 Findings from experts
4.2	The prosthetic's fitting may not lead to any discomfort	2.5.3 Findings from experts
4.3	The grasping may not should not lead to any discomfort	Own ideas
4.4	Repeating activation forces should preferably be at a fatigue-free level, which is estimated to be below 66N for males and below 38N for females (Smit, 2020)	2.6.1 A Deep dive into cineplasty
5	**Durability**	
5.1	The prosthetic must have a minimum lifetime of 5 years (PO#3)	2.5.3 Findings from experts
5.2	The prosthetic must be water resistant according to IP68 standards (Hoogstraat) (Clarion Security Systems., n.d.)	2.5.3 Findings from experts
5.3	The prosthetic must have a maximum repair frequency of once per year (PO#1)	2.5.3 Findings from experts
5.4	The prosthetic must be able to withstand a droptest from 1.20 m	Own ideas
6	**Appearance**	
6.1	The prosthetic must be available in skin color	2.5.3 Findings from experts
7	**Costs**	
7.1	The prosthetic may cost no more than xx	2.5.2 Current prosthetics
	CRITERIA	Information derived from
1	**Functionalities**	
1.1	The prosthetic should should allow for higher pinch forces (>30 N) (Smit, 2020).	2.6.1 A Deep dive into cineplasty
1.2	The prosthetic should provide the user the ability to perform tasks with ultimate precision.	2.6.1 A Deep dive into cineplasty
1.3	The prosthetic should create similar or less discomfort than average prosthesis	2.5.3 Findings from experts
1.4	The prosthetic should not harm the user in any way	Own ideas
1.5	The prosthetic's connection to the user's muscle should be as natural as possible, where the selected muscle is preferred to be a muscle with the same function (agonist) (Tropea et al., 2017)	2.6.1 A Deep dive into cineplasty
2	**Weight & measurements**	
2.1	The prosthetic should be as light as possible.	2.5.3 Findings from experts
3	**Material & production**	
3.1	The prosthetic should not conduct temperature, leading to too warm or too cold stumps (ET).	2.5.3 Findings from experts
3.2	There should be no room for play in the cable length, leading to optimal control of the hand (PO#4)	2.5.3 Findings from experts
3.3	The prosthetic's production should be able to be done in-house of orthopedic centres.	Own ideas
4	**Ease of use**	
4.1	The prosthetic's control is experienced as intuitive.	2.5.3 Findings from experts
4.2	The prosthetic's feedback is experienced as intuitive.	2.5.3 Findings from experts
4.3	The prosthetic's control and feedback ask an as small cognitive load as possible.	2.5.3 Findings from experts
4.4	The prosthetic's control and feedback ask an as small physical load as possible.	2.5.3 Findings from experts
4.5	The prosthetic's fits should be experienced as ergonomic.	Own ideas
4.6	The prosthetic's controlling system should be experienced as ergonomic.	Own ideas
4.7	The prosthetic must be clear in use after explanation from the prothetist.	Own ideas
5	**Durability**	
5.1	The prosthetic's lifetime should be as long as possible.	2.5.3 Findings from experts
5.1	The prosthetic's materials should be recyclable at its end of life.	Own ideas
5.1	The prosthetic's repair should be able to be done in-house of orthopedic centres.	Own ideas
6	**Appearance**	
	The prosthetic should look as natural as possible (LC,ET)	2.5.3 Findings from experts
	The prosthetic should be not noticeable underneath clothing (ET).	2.5.3 Findings from experts
6.1	The prosthetic should be aesthetically pleasing by the target group.	2.5.3 Findings from experts
6.2	The prosthetic should be available in the same skin tone as the user.	2.5.3 Findings from experts
6.3	The prosthetic should hide the result of the cineplastic surgery.	Own ideas
	The surgery site should look as natural as possible with limited scarring.	
7	**Costs**	

C.III Design tips

Design tips

General:
Cooperation between surgeon, therapist and prosthetist is of great value (Weir, 1995).

“Think of wearing comfort (weight and temperature), functionality, ease of use, provide sensory feedback” (Smit, 2013)

When designing the system, three parameters should be prioritised: length, angle, and rotation. Each of these directly shapes how users position their bodies and interact with the device, meaning that careful tuning is essential for both comfort and performance. Because optimal values cannot always be predetermined, the design process should allow users to explore different configurations to identify what feels most natural.

- Length should be treated as both user-specific and task-dependent.
- Two angular considerations are particularly important: the hinge angle at the end of the residual limb and the rotational angle around the forearm axis.
- Rotation around this axis also influences how effectively users can operate various tools, especially in dynamic tasks (Hofmann et al., 2016).

Shape:

- In prosthetic design, it is important to create length by extending the arm. With this length patients can push and somewhat feel elements in their surroundings. It is also important that the prosthesis is in a continuous line with the arm. Try to prevent rust, especially in springs. Keep sweating of the stump into account for the material choice (P3).
- Keep it open, so no water that goes in gets stuck on the inside (visiting Hoogstraat).
- Make sure there is no play in the cables (P4)
- Take length of stump into account for moving rod connected to cables in hand (P5).

Material

- Materials on the skin, fabric more comfortable than plastic (U1)
- Some patients suffer from silicone allergy, which is most often the coloring of the silicone (meelopen Hoogstraat).
- Material choice: with braces, metal is less sweat inducing than plastics (meelopen RHOC).

Appearance

- Age could have an influence on the execution of the patient’s treatment, for example a young patient could find a brace ‘cool’ so wants to continue using it. This important to keep in mind for the use strategy of the cineplastic prosthesis (visiting RHOC)

D. Develop

D.I WWWWH method

General prosthetics

	Problem statement: Current prostheses have no proprioceptive feedback	**Problem statement:** Cineplasty is not widely adopted
Who	• Upper/ lower arm prosthetic users • Bilateral • Impaired vision/blind • Old	• Military people • Critics (doctors/technicians) • Little offer of good prosthetics (Biedermann)
What (for)	• Fine motor skills tasks more challenging • Vision always needed • Vibration/sound of motors/TSR	• Military people • Critics (doctors/technicians) • Little offer of good prosthetics (Biedermann)
Where	• Demographically widespread • Fine motor skills • Research into vibration/sound/TSR	• Germany • US • Military environments
When	• All ages • Rise of myo: contrast of movement diversity vs feedback • Lots of amputation due to wars • ADL more challenging: limiting in certain tasks + takes more time (mental load)	• Upcoming of myo around 1960 • Solved as soon as possible
Why	• Compared to proprioceptive qualities real hand big challenge	• Lack of proprioceptive feedback • Current version not cosmetic and invasive
How	• Rise of myo: contrast of movement diversity vs feedback • Lots of amputation due to wars • Vibration/sound of motors/TSR	• New method, thus old method to background • Maybe also too underdeveloped to continue • Not enough 'teachers' > obscurity

Cineplasty related

	Problem statement: Cineplasty is not appealing cosmeticaly	**Problem statement:** Cineplasty needs (invasive) surgery	**Problem statement:** Alternatives function well
Who	• Women • Citizens • Surgeons (technique) • Rehabilitation specialists • Prosthesists: little maintenance	• Amputees • Surgeons • Rehabilitation experts	• Amputees • Rehabilitation specialists • Insurance (?)
What (for)	• Mutilating • Deformation of the bicep • Skin transplantation • Scarring • Focus on military/quickly satisfied people	• Often second surgery needed, patients reluctant • Not all surgeries were successful • Myo is a solution that is not invasive	• When there are good alternatives, the need for this technique is less • Nothing is done to solve it > obscurity
Where	• Upper arm • Germany and US	• Often second surgery needed, patients reluctant • Not all surgeries were successful • Myo is a solution that is not invasive	• Alternatives are very good, since invested and innovated in these options • Solution: everywhere, mindset. Pros and cons
When	• 1950's • Introducing a 'better looking' cineplasty (surgery/prosthesis?) asap	• 1950's • Asap	• 1950's • Asap
Why	• If it's going to be used, it needs to look better than before • Cosmesis is a big aspect nowadays, people have high standards nowadays, unless you focus on the ones with lower standards	• Patients more reluctant to choose the technique when a surgery is needed • Longer traject > prosthesists will not advise the technique	• Other options function well, cineplasty only competes on the field of proprioception and reliability.
How	• Cosmetics of alternatives better • Solution: improve surgical procedure • Or improve prosthesis in such a way that hole and pin don't stand out	• Myo no need for surgery: more attractive	• Alternatives came up and developed further > cineplasty in obscurity

Figure 41. Results of the WWWWH method

D.II C-Boxes

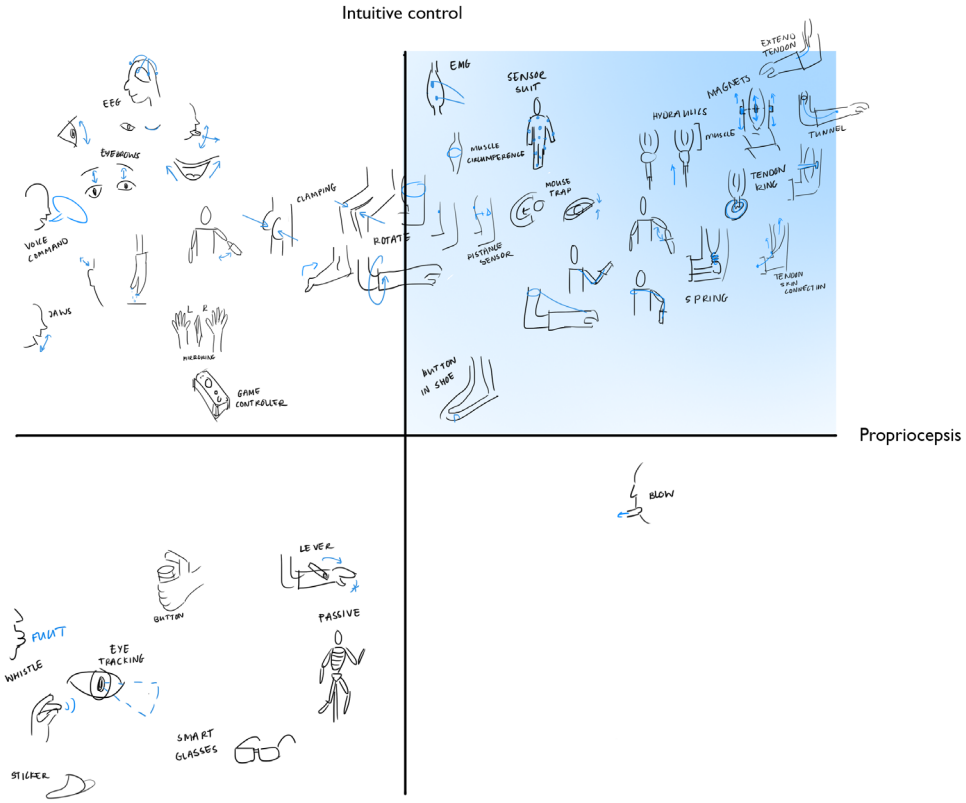

Figure 42. C-Box intuitive control vs. proprioception

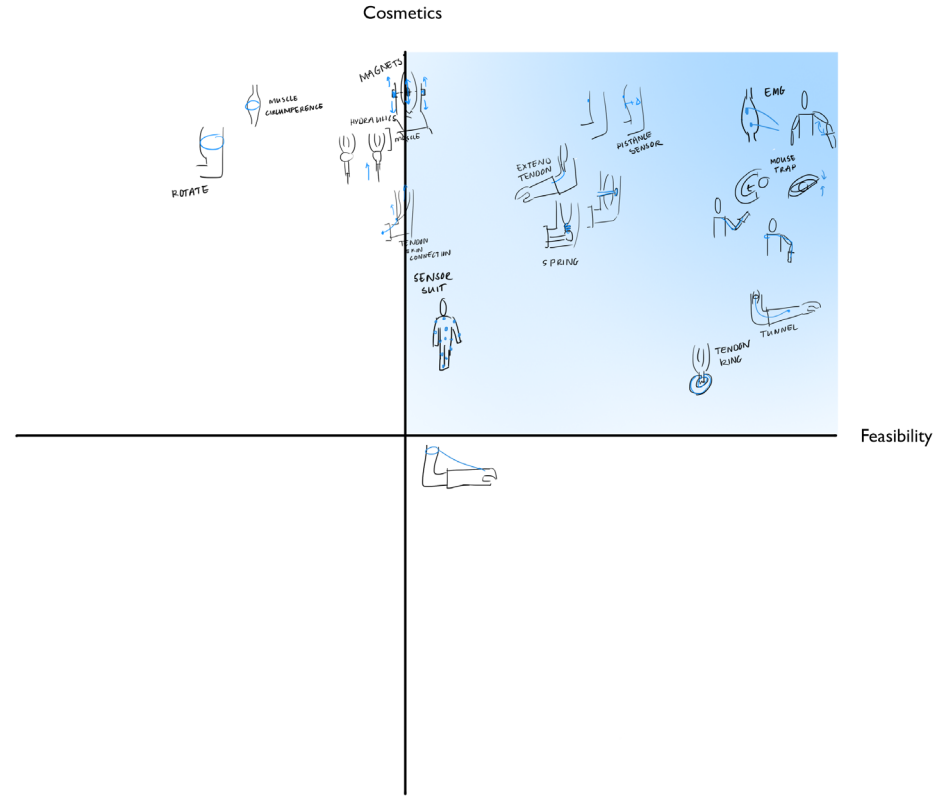

Figure 43. C-Box cosmetics vs. Feasibility

D.III Interviews experts ‘concept feedback’

A. Cineplasty 2.0
Q. Wat is uw eerste reactie op het concept?
Q. Hoe schat u de haalbaarheid invan deze techniek? (feasibility)
Q Verwacht u dat prothesegebruikers hiervoor open staan? (desirability)
Q. Hoe verwacht u dat dit concept ligt qua prijs? (viability)
Q. Ziet u bepaalde nadlen (bijv. risico’s) bij deze techniek? (limitations)
Q. Ziet u bepaalde voordelen bij deze techniek? (opportunities)
Q. Hoe verwacht u dat deze techniek scoort op het gebied van proprioceptie?
Q. Wat vindt u van de cosmetiek van dit concept?

B. SKINtegration
Q. Wat is uw eerste reactie op het concept?
Q. Hoe schat u de haalbaarheid invan deze techniek? (feasibility)
Q Verwacht u dat prothesegebruikers hiervoor open staan? (desirability)
Q. Hoe verwacht u dat dit concept ligt qua prijs? (viability)
Q. Ziet u bepaalde nadlen (bijv. risico’s) bij deze techniek? (limitations)
Q. Ziet u bepaalde voordelen bij deze techniek? (opportunities)
Q. Hoe verwacht u dat deze techniek scoort op het gebied van proprioceptie?
Q. Wat vindt u van de cosmetiek van dit concept?

C. Active Control
Q. Wat is uw eerste reactie op het concept?
Q. Hoe schat u de haalbaarheid invan deze techniek? (feasibility)
Q Verwacht u dat prothesegebruikers hiervoor open staan? (desirability)
Q. Hoe verwacht u dat dit concept ligt qua prijs? (viability)
Q. Ziet u bepaalde nadlen (bijv. risico’s) bij deze techniek? (limitations)
Q. Ziet u bepaalde voordelen bij deze techniek? (opportunities)
Q. Hoe verwacht u dat deze techniek scoort op het gebied van proprioceptie?
Q. Wat vindt u van de cosmetiek van dit concept?

Vergelijking
Q. Welke optie heeft uw voorkeur?
SQ. Waarom?
Q. Welke optie verwacht u dat prothesegebruikers zouden kiezen?
SQ. Waarom?

Verdere opmerkingen

E. Deliver

E.I Aesthetics test

A small test (could be seen as a 'light version') to identify the concept with the highest aesthetics score was conducted. The participants exisited of 10 students of the Delft University of Technology. Three drawings, shown in Figures 44, 45 and 46, were showed to them simultaniously. Then the main question was asked: "Which of the following designs do you think is most aesthetically pleasing?" The results of this question are shown below by the number of votes: B is experienced as the most aesthetically pleasing design.

A

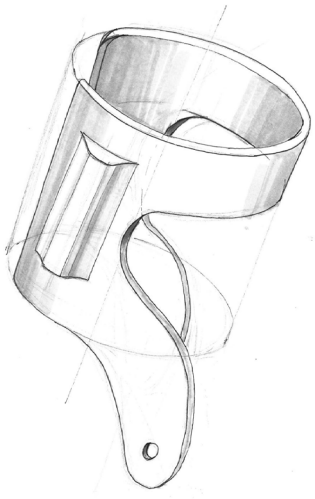

Figure 44. Cover Concept A

2

B

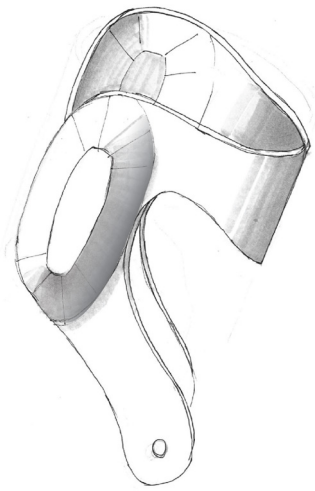

Figure 45. Cover Concept B

7

C

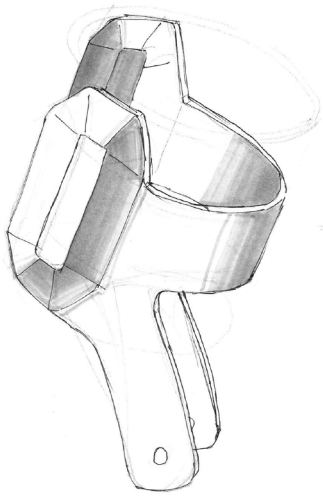

Figure 46. Cover Concept C

1

E.II Prototype visibility validation test

As shown in the Figures below (where the Cover is worn around the left arm), the Cover is not visible underneath clothing.



Figure 47. Discreet Cover design not visible underneatch clothing

E.III Interviews experts ‘validation’ - set up

Eight interviews were conducted to investigate the potential of the modernised version of cineplasty. First, the expert was thanked for their time, then the content of the interview was introduced: first I reminded them on the concluding findings, then I explained the new surgery technique and finally I showed the renders of the Cover. The slide show can be found in Figure 48.

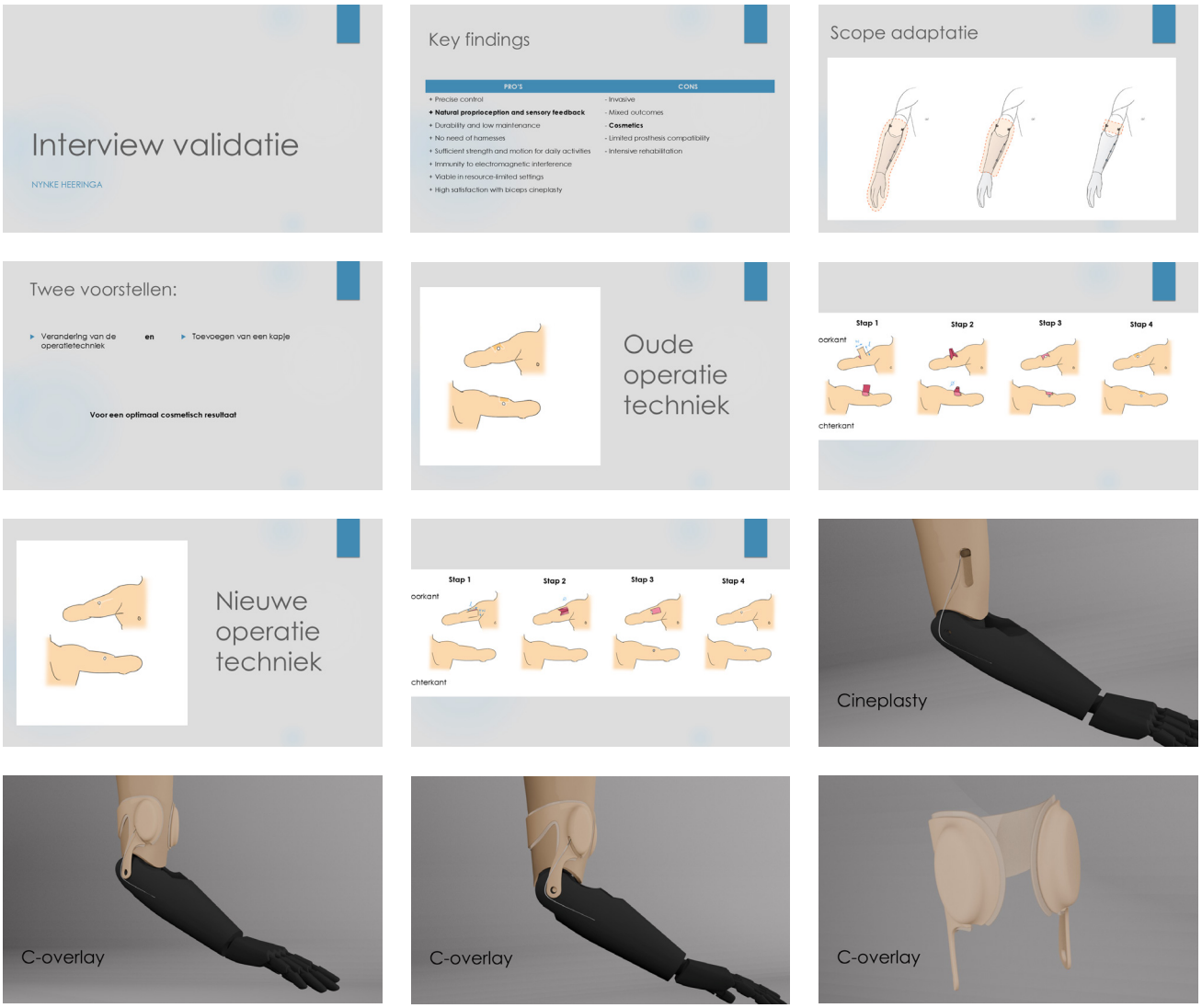

Figure 48. Interview ‘validation’ slides

In the case of live interviews, the prototype was shown during the part of Cover renders, to broader explain how the Cover works in use. With online interviews, the prototype was shown via Microsoft Teams, during the same slide.

See Figure 49 for the interview setting with C2.



Figure 49. Interview ‘validation’ set-up

E.IV Interviews expert 'validation' - questions

Questions product focused

Questions to validate the Cover were based on literature questionnaires to validate the product. The D-Quest focuses on the satisfaction rate of medical devices, whereas the TAPES specifically focuses on the satisfaction rate of prostheses.

Literature questionnaire
Questions were drawn up with different assessment strategies at the back of the mind:

- The fourth set of the **TAPES** assesses the extent to which respondents are satisfied/ dissatisfied with their artificial limb (Gallagher & Maclachlan, 2000), these questions were used to analyse the satisfaction rate.
- The **D-Quest** analysis the satisfaction of a patient with a medical devices/ medical equipment (Wessels, de Witte, Knops)
- Questions are focused on the main outcomes of the research: rating **functionality, cosmetics and comfort**, already included in questionnaires
- A scale of 0-7 is used, based on the form of the TAPES (Gallagher & Maclachlan, 2000).

Basis of questions
Own questions

- What do you think of the cosmetics of the product?
- What do you think of the cosmetics of the operation?
- What do you think of the functionality of the product?
- What do you think of the comfort of the product?
- Can you rank cosmetics, functionality, and comfort by level of importance?

Satisfaction rate (TAPES)
(0 very dissatisfied, 5 very satisfied)

- How satisfied are you with the color of the product?
- How satisfied are you with the shape of the product?
- How satisfied are you with the sound of the product?
- How satisfied are you with the overall appearance of the product?
- How satisfied are you with the weight of the product?
- How satisfied are you with the usability of the product?
- How satisfied are you with the reliability of the product?
- How satisfied are you with the fit of the product?
- How satisfied are you with the comfort of the product?
- What is your overall opinion of the product?

Satisfaction rate (D-Quest)
(0 very dissatisfied, 5 very satisfied)

- How satisfied are you with the dimensions of your assistive device? (size, height, length, width)

- How satisfied are you with the weight of your assistive device?
- How satisfied are you with the adjustability of your assistive device?
- How satisfied are you with the safety of your assistive device?
- How satisfied are you with the durability of your assistive device? (durability, wear resistance)
- How satisfied are you with the ease with which you can use your assistive device?
- How satisfied are you with the comfort of your assistive device?
- How satisfied are you with the effectiveness of your assistive device? (The extent to which the assistive device does what it is intended for)
- All things considered, how satisfied are you with your assistive device?

Eliminating questions
Interviewees could not really have a say about sound, mass, or comfort, since it is not possible to try on the prototype.
The Cover's itting could not be tested, and would be similar to products that use scanning techniques to create an anatomical fit.
The Cover has no options for adjustment.
Usability and functionality challenging to test, since the product can't be tried on.

Final questions (English)
(0 heel ontevreden - 5 heel tevreden)
- How satisfied are you with the color of the product?
- How satisfied are you with the shape of the product?
- How satisfied are you with the sound of the product?
- How satisfied are you with the overall appearance of the product?
- How satisfied are you with the weight of the product?
- How satisfied are you with the usability of the product?
- How satisfied are you with the reliability of the product?
- How satisfied are you with the fit of the product?
- How satisfied are you with the comfort of the product?
- How satisfied are you with the dimensions of your assistive device? (size, height, length, width)
- How satisfied are you with the adjustment options of your assistive device?
- How satisfied are you with the safety of your assistive device?
- How satisfied are you with the durability of your assistive device? (resistance, wear resistance)
- How satisfied are you with the ease with which you can use your assistive device?
- How satisfied are you with the effectiveness of your assistive device? (The extent to which the assistive device does what it is intended for)
- What is your overall opinion of the product? Can you rank cosmetic functionality and comfort by level of importance?
- What do you think of the cosmetics of the surgery?

Final questions (Dutch)
(0 heel ontevreden - 5 heel tevreden)

- Hoe tevreden bent u met de kleur van het product?
- Hoe tevreden bent u met vorm van het product?
- Hoe tevreden bent u met het geluid van het product?
- Hoe tevreden bent u met het gehele uiterlijk van het product?
- Hoe tevreden bent u met het gewicht van het product?
- Hoe tevreden bent u met de bruikbaarheid van het product?
- Hoe tevreden bent u met de betrouwbaarheid van het product?
- Hoe tevreden bent u met de passing van het product?
- Hoe tevreden bent u met het comfort van het product?
- Hoe tevreden bent u over de afmetingen van uw hulpmiddel? (maat, hoogte, lengte, breedte)
- Hoe tevreden bent u over de verstel-mogelijkheden van uw hulpmiddel?
- Hoe tevreden bent u over de veiligheid van uw hulpmiddel?
- Hoe tevreden bent u over de duurzaamheid van uw hulpmiddel? (bestendigheid, slijtvastheid)
- Hoe tevreden bent u over het gemak waarmee u uw hulpmiddel kunt gebruiken?
- Hoe tevreden bent u over de effectiviteit van uw hulpmiddel? (De mate waarin het hulpmiddel doet waarvoor het bedoeld is)

- Wat is uw algehele mening van het product?
- Kunt u cosmetiek-functionaliteit en comfort ordenen op niveau van belangrijkheid?
- Wat vindt u van de cosmetiek van de operatie?

E.V Interviews expert ‘validation’ - answers

Prosthesis users



Users

1. Nieuwe concept
Q. Wat is uw eerste reactie van het nieuwe concept?
SQ. Doorvragen naar cosmethiek, haalbaarheid en techniek
Q. Wat vindt u van de cosmetiek van de operatie?
Q. Wat vindt u van de Cover?

Productgefocuste vragen
- Verwacht u dat patienten het product willen gebruiken qua kleur?
- Verwacht u dat patienten het product willen gebruiken qua vorm?
- Hoe tevreden bent u met het gehele uiterlijk van het product?
- Hoe tevreden bent u over de afmetingen van uw hulpmiddel? (maat, hoogte, lengte, breedte)
- Hoe tevreden bent u over de veiligheid van uw hulpmiddel?
- Hoe tevreden bent u over de duurzaamheid van uw hulpmiddel? (bestendigheid, slijtvastheid)
- Hoe tevreden bent u over het gemak waarmee u uw hulpmiddel kunt gebruiken?

Q. Kunt u cosmetiek, functionaliteit en comfort ordenen op niveau van belangrijkheid?
Q. Denkt u dat het nieuwe concept geimplementeerd kan worden in de huidige prothesiologie?

2. Vergelijking oud – nieuw
Q. Wat zou u vinden van een standaard gat (soort piercing) in de arm waar een staafje doorheen kan voor de aansturing?
Q. Wat zou u vinden van het idee om de prothese aan te sturen met behulp van het staafje?
SQ. Hoe verwacht u dat de aansturing van de prothese op deze manier voelt? Natuurlijk/intuitief/oncomfortabel/vermoeiend.
Q. Als u cineplasty vergelijkt met bestaande alternatieven, wat zijn dan in uw ogen de voor- en nadelen van cineplasty?

Q. Ziet u waarde in de techniek van cineplasty?

3. Verbeteringen
Q. Suggesties/optimalisatie huidige en nieuwe operatie technieken,
Q. Heeft u het idee dat nieuwe techniek minder belastend is voor de gebruiker, waarom?
Q. Toepasbaarheid op prothesegebruikers (0-5)

Q. Op een procentuele schaal, hoe vergelijkt u myo elektrisch met mechanisch op het gebied van:
SQ. Feedback
SQ. Cosmetiek

Q. Heeft u suggesties voor vervolg onderzoek?
Q. Wilt u betrokken blijven bij toekomstig onderzoek over cineplasty?

Clinical experts



Clinical experts

1. Nieuwe concept
Q. Wat is uw eerste reactie van het nieuwe concept?
SQ. Doorvragen naar cosmethiek, haalbaarheid en techniek
Q. Wat vindt u van de cosmetiek van de operatie?
Q. Wat vindt u van de Cover?

Productgefocuste vragen
- Verwacht u dat patienten het product willen gebruiken qua kleur?
- Verwacht u dat patienten het product willen gebruiken qua vorm?
- Hoe tevreden bent u met het gehele uiterlijk van het product?
- Hoe tevreden bent u over de afmetingen van uw hulpmiddel? (maat, hoogte, lengte, breedte)
- Hoe tevreden bent u over de veiligheid van uw hulpmiddel?
- Hoe tevreden bent u over de duurzaamheid van uw hulpmiddel? (bestendigheid, slijtvastheid)
- Hoe tevreden bent u over het gemak waarmee u uw hulpmiddel kunt gebruiken?

Q. Kunt u cosmetiek, functionaliteit en comfort ordenen op niveau van belangrijkheid?
Q. Denkt u dat het nieuwe concept geimplementeerd kan worden in de huidige prothesiologie?

2. Vergelijking oud – nieuw
Q. Wat is uw eerste reactie op de vernieuwde techniek van tunnel cineplasty?
SQ. Doorvragen naar cosmethiek, haalbaarheid en techniek
Q. Wat verwacht u dat de grootste risico's zijn van de vernieuwde operatie techniek? Zowel tijdens operatie als bij revalidatie.
SQ. Kunt u ideeën bedenken hoe de mogelijke risicos verlaagd kunnen worden?
Q. Hoe zou u de learning curve van deze operatie omschrijven? Welke vaardigheden zijn het lastigst om te beheersen, en hoeveel tijd kost het doorgaans om deze operatie zelfstandig en veilig uit te voeren?
SQ. Hoe gradeert u de cineplastische operatie: eenvoudig/ gemiddeld/ uitdagend?
SQ. Hoe lang verwacht u dat het uitvoeren van zo'n operatie duurt?
Q. Heeft u he tidee dat nieuwe techniek minder belastend, waarom?

Q. Ziet u waarde in de techniek van cineplasty?

3. Verbeteringen
Q. Suggesties/optimalisatie huidige en nieuwe operatie technieken,
Q. Heeft u het idee dat nieuwe techniek minder belastend is voor de gebruiker, waarom?
Q. Toepasbaarheid op prothesegebruikers (0-5)

Q. Op een procentuele schaal, hoe vergelijkt u myo elektrisch met mechanisch op het gebied van:
SQ. Feedback
SQ. Cosmetiek

Q. Heeft u suggesties voor vervolg onderzoek?
Q. Wilt u betrokken blijven bij toekomstig onderzoek over cineplasty?



Prosthetists

Prosthetists

1. Nieuwe concept

Q. Wat is uw eerste reactie van het nieuwe concept?
SQ. Doorvragen naar cosmethiek, haalbaarheid en techniek
Q. Wat vindt u van de cosmetiek van de operatie?
Q. Wat vindt u van de Cover?

Productgefocuste vragen

- Verwacht u dat patienten het product willen gebruiken qua kleur?
- Verwacht u dat patienten het product willen gebruiken qua vorm?
- Hoe tevreden bent u met het gehele uiterlijk van het product?
- Hoe tevreden bent u over de afmetingen van uw hulpmiddel? (maat, hoogte, lengte, breedte)
- Hoe tevreden bent u over de veiligheid van uw hulpmiddel?
- Hoe tevreden bent u over de duurzaamheid van uw hulpmiddel? (bestendigheid, slijtvastheid)
- Hoe tevreden bent u over het gemak waarmee u uw hulpmiddel kunt gebruiken?

Q. Kunt u cosmetiek, functionaliteit en comfort ordenen op niveau van belangrijkheid?
Q. Denkt u dat het nieuwe concept geimplementeerd kan worden in de huidige prothesiologie?

2. Vergelijking oud – nieuw

Q. Kunt u een inschatting maken wat de voor- en nadelen zijn van cineplasty vergeleken met de huidige alternatieven?
Q. Wat denkt u dat cineplasty kan betekenen voor patienten in de huidige maatschappij?
Q. Verwacht u dat patienten open zouden staan voor deze vorm van cineplasty?
SQ. Eerder dan vorige versie?

Q. Ziet u waarde in de techniek van cineplasty?

3. Verbeteringen

Q. Suggesties/optimalisatie huidige en nieuwe operatie technieken,
Q. Heeft u het idee dat nieuwe techniek minder belastend is voor de gebruiker, waarom?
Q. Toepasbaarheid op prothesegebruikers (0-5)

Q. Op een procentuele schaal, hoe vergelijkt u myo elektrisch met mechanisch op het gebied van:
SQ. Feedback
SQ. Cosmetiek

Q. Heeft u suggesties voor vervolg onderzoek?
Q. Wilt u betrokken blijven bij toekomstig onderzoek over cineplasty?

Prosthesis users



Users

	U1	U2
Nieuwe concept		
Q. Wat is uw eerste reactie van het nieuwe concept?	Zon kapje goed idee want ziet minder at er iets door die arm heen zit. Persoonlijk tegenhouden dat er staaf in arm zit. Hele mooie manier om het af te dekken, lijkt alsof er niks in de arm zit. Protheses waar achterkant open is, lijkt het op. Mooi ontwerp. Open fitting.	Nieuwe beter, esthetisch gezien veel beter. Dit lijkt mij goed. Zou het niet storend vinden als het om arm zou zitten. Binnenkant ook mooier, valt minder op. Vind het heel mooi uitzien.
SQ. Doorvragen naar cosmethiek, haalbaarheid en techniek		Lijkt me een kleine ingreep. Lijkt me niet hinderlijk. Mooie oplossing.
SQ. Wat vindt u van de cosmetiek van de operatie?	Operatietechniek zou me niet super veel uitmaken als kapje erbij zou zitten. Hoe minder littekens hoe beter. Nieuwe techniek voorkeur.	Ziet er niet zo gek uit.
SQ. Wat vindt u van het kapje (C-overlay)?	Hele mooie manier om het af te dekken, lijkt alsof er niks in de arm zit. Protheses waar achterkant open is, lijkt het op. Mooi ontwerp. Open fitting.	Je hebt er altijd kleding overheen. Driekwart mouw. Kapje misschien niet nodig. Ik betwijfel of het het per se mooier maakt. Weet niet of ik het op zou doen. Zonder kapje minder opvallend. Verewacht niet dat het gaat schuren. Zo klein, niet schuren of last met t-shirt. Valt meer op dan zonder kapje. Ik zou echt zonder kapje doen.
Productgefocuste vragen		
Q. Verwacht u dat patienten het product willen gebruiken qua kleur?	6	7. Goed, maar maakt niet uit dat het onder je mouw zit.
Q. Verwacht u dat patienten het product willen gebruiken qua vorm?	6	6. Valt meer op bij strakkere mouwen.
Q. Hoe tevreden bent u met het gehele uiterlijk van het product?	6	6. Gewoon goed. Zo klein mogelijk gehouden.
Q. Hoe tevreden bent u over de afmetingen van uw hulpmiddel? (maat, hoogte, lengte, breedte)	6	6. Vind het groot vergeleken met alleen staafje. In wezen onder de mouw maakt het niet uit.
Q. Hoe tevreden bent u over de veiligheid van uw hulpmiddel?	5, blijven hangen of eronder	7. Lijkt me niet, mooi rond afgewerkt. V
Q. Hoe tevreden bent u over de duurzaamheid van uw hulpmiddel? (bestendigheid, slijtvastheid)	6	7. Gaat vast heel lang mee, net als prothesehandschoenen.
Q. Hoe tevreden bent u over het gemak waarmee u uw hulpmiddel kunt gebruiken?	6	7. Lijkt mij geen enkel probleem
Q. Kunt u cosmetiek, functionaliteit en comfort ordenen op niveau van belangrijkheid?	Comfort - cosmetiek - functionaliteit	Cosmetiek-comfort-functionaliteit
Q. Denkt u dat het nieuwe concept geimplementeerd kan worden in huidige prothesiologie?	Ik denk dat het wel een toevoeging zou kunnen zijn. Mensen zouden hier wel voor open kunnen staan en zouden dit kunnen willen.	Ja
Vergelijking oud-nieuw		
Q. Wat zou u vinden van een standaard gat (soort piercing) in de arm waar een staafje doorheen kan voor de aansturing?	Minder het gevoel van ai dat wil ik niet. Zou nogsteeds denken er zit een gat in mn arm, maar andere reconstructie net iets minder erg. Geen verkleuring.	Lijkt mij geen probleem, zolang er geen infecties kunnen komen. Alleen maar gemakkelijker.
Q. Wat zou u vinden van het idee om de prothese aan te sturen met behulp van het staafje?	In mijn geval zou ik echt even moeten wennen aan staafje door gat, en waar je hem ook nog mee moet bedienen. Misschien wel overeenkomsten in aansturen als nu. Weet niet of staafje erg aanweizg is of voelt zitten. Drempel na gewennig.	Kwestie van oefenen, niet iets onprettigs. Geen enkel probleem.
Q. Als u cineplasty vergelijkt met bestaande alternatieven, wat zijn dan in uw ogen de voor- en nadelen van cineplasty?	Weet ik niet.	Ja denk echt dat het een hele goede optie is. Vooral omdat het zo klein en eenvoudig is. Heel goedkoop. Verder geen nadelen.
Q. Ziet u waarde in de techniek van cineplasty?	Mensen zouden hier wel voor open kunnen staan en zouden dit kunnen willen. Vooral na amputatie.	Ja zeker.
Q. Zou u zelf openstaan voor deze techniek?	Ik hou niet zo van verandering, werkt nu goed zoals het werkt.	Als ik jonger was geweest wel ja.
Verbeteringen		
Q. Suggesties/optimalisatie huidige concept?	Heel goed uitgedacht, perfect aansluitend kapje. Verder geen idee.	Kousje los van prothese ipv kapje.
Q. Heeft u het idee dat nieuwe techniek minder belastend is voor de gebruiker, waarom?	Nieuwe techniek minder belastend, want geen transplantatie. Eigen huid aan elkaar komt over als minder belastend.	-
Q. Toepasbaarheid op prothesegebruikers (0-5)	3	4/5
Q. Vergeleken met myo elektrisch vs. mechanisch (%):		
SQ. Feedback	80	90
SQ. Cosmetisch	50	90
Q. Suggestie voor vervolg onderzoek?		-
Q. Betrokken blijven?	Betrokken blijven, net of het uitkomt.	Nee
		Kan je er ook mee zwemmen?
		Kousje eroverheen trekken zodat het niet opvalt.
		Denk dat het heel goed werken kan, met of zonder kapje. Denk echt dat dat gaat werken. Makkelijke oplossing, operatief snel gebeurd. Even wennen, maar geen last.
		Verrast me hoe mooi het eruit kan zien en hoe functioneel het kan zijn.

Clinical experts

1. Achtergrond informatie	C2	C5	C6	C7
Wat is uw specialisme?	revalidatie arts	Orthopedisch chirurg	Plastisch chirurg	plastisch chirurg
Wat is uw specialisatie?	bovenste extremiteit	hand en pols	Hand-pols en ellenboog	hand/pols
Wat is uw leeftijdscategorie?	35-45	35-45	35-45	>55?
Wat is uw gender?	v	v	m	m
In wat voor ziekenhuis practiseert u?	academisch + perifeer	Perifeer en kliniek	perifeer	Academisch
Bent u opleider van aios?	nee	ja	nee	Ja?
Wanneer van toepassing: wanneer bent u begonnen met uw eigen praktijk?	-	-	-	-
Nieuwe concept				
Q. Wat is uw eerste reactie op het nieuwe concept?	De vorige versie was meer afschrikkend terwijl het er nu meer fancy uit ziet. Meer van deze tijd. Nieuwe operatie techniek zorgt voor meer sensibiliteitsbehoud omdat er geen huidtransplantatie wordt gebruikt. Een kleiner gat zal waarschijnlijk ook de sensibiliteit verhogen door een directere verbinding met de beweging.	Hele grote vooruitgang op oude model. Grootste voordeel op verhoogde funcionaliteit hand. Kapje mooi en slim want modulair Keuze om te verbergen of niet.	Ziet er mooier uit. Kapje misschien niet nodig. Is ook warmer. Men heeft vingerprotheses ook vaak niet om, want al gewend om zonder vinger te leven. Kan hetzelfde zijn bij patienten. Perspectief. Functionaliteit toevoegen vaak reden om te gebruiken.	Cosmetische aanpassing, maar nog steeds gat in de arm. Zonder splitjes/huidtransplantati e 10.000 x fijner en mooier voor de patient. Achter zit ook nog horizontaal littekentje voor vastmaken huid daar.
SQ. Doorvragen naar cosmethiek, haalbaarheid en techniek	Ook fijn dat tunneltje/staafje beschermd is tegen blijven hangen en oa. stoffige omgevingen.	Hygiene kan behouden blijven. Minder lelijkheid en optie voor verhullen. Siliconen op huid aangenaam.	Zeker haalbaar.	Sowieso cosmetisch beter. Technische haalbaarheid blijft hetzelfde. Misschien nu iets moeilijker.
SQ. Wat vindt u van de cosmetiek van de operatie?	Geen transplantatie is natuurlijk mooier en veel fijner voor de patient want geen donor site en sensibiliteitsbehoud.	Duidelijk mooier dan eerdere versie. Beter cosmetisch resultaat	Mooier.	Zie bovenstaande.
SQ. Wat vindt u van het kapje (C-overlay)?	Kan helpen om het er minder gruwelijk uit te laten zien.	Goeie toevoeging voor als men dat nodig heeft/wil.	Mooi, maar misschien niet nodig.	Aesthetisch fraai. Maar hoeveel mensen zijn zo gefocust op esthetiek.
Productgefocuste vragen				
Q. Verwacht u dat patienten het product willen gebruiken qua kleur?	5	6, want aanpasbaar op huidskleur	4, geen voorkeur	7
Q. Verwacht u dat patienten het product willen gebruiken qua vorm?	5, organisch	4-5/5	6, prima	7, ergonomisch, geen drukplekken. Makkelijk
Q. Hoe tevreden bent u met het gehele uiterlijk van het product?	5	5	6, prima	7, is mooi.
Q. Hoe tevreden bent u over de afmetingen van uw hulpmiddel? (maat, hoogte, lengte, breedte)	4, liever exacte vorm van arm	5	5	Geen bezwaar.
Q. Hoe tevreden bent u over de veiligheid van uw hulpmiddel?	5, geen nadelen alleen schoon houden	6. Enige risico hygiene, huidproblemen. Normale cognitie en normaal gedrag (side note).	4, geen risico's	Geen risico
Q. Hoe tevreden bent u over de duurzaamheid van uw hulpmiddel? (bestendigheid, slijtvastheid)	4	6, slijtvast. siliconen laagje gaan misschien 2/3 jaar mee. Wisselen.	4, gaat waarschijnlijk lang mee, geen grote krachten.	Prima.
Q. Hoe tevreden bent u over het gemak waarmee u uw hulpmiddel kunt gebruiken?	5	7	4, gebruiksgemak. Lijkt nu simpel, maar wordt op een gegeven moment te veel gedoe.	klinkt gemakkelijk.
Q. Kunt u cosmetiek, functionaliteit en comfort ordenen op niveau van belangrijkheid?	?	Comfort- Functionaliteit-cosmetiek. Bij pijn niet gebruikt. Cosm, kleding	Functionaliteit / comfort-esthetiek	Functionaliteit-comfort-esthetiek
Q. Denkt u dat het nieuwe concept geimplementeerd kan worden in huidige prothesiologie?	Deze zeker eerder dan vorige versie, maar nog steeds lastig omdat patienten hier komen met de hoogste verwachtingen, eigenlijk altijd myo.	Dat denk ik wel.	Ik denk wel dat het op het gebied van feedback waarde toevoegt, maar het wordt lastig mensen te overtuigen van een gat in de arm.	Lastig te zeggen. Wel degelijk voordelen van de patient, maar er zit wel gewoon een gat in je arm wat vrij eng is voor de patient
Vergelijking oud-nieuw				
Q. Hoe zou u de learning curve van deze operatie omschrijven?	Zelfde	Zelfde	Zelfde	Iets ingewikkelder
Q. Wat verwacht u dat de grootste risico's zijn van de vernieuwde operatie techniek? Zowel tijdens operatie als bij revalidatie.	Geen huidtransplantaat dus geen risico's daarvan en geen pijn bij donor site.	Bij spanningsloos hechten kans op moeizame genezing lager dan bij huid tranplantaat. Hand eye cather	Minder risico, want primair sluiten dus geen transplantatie nodig. Verkleinde tunnel kan zorgen voor groter risico op drukplekken, afhankelijk van welke kracht erop staat. Geen constante kracht, dus waarschijnlijk minder erg.	Lap dood/ tunnel faalt. Subcutane zenuwen beschadigen. Risico even groot als eerst.
SQ. Kunt u ideeën bedenken hoe de mogelijke risicos verlaagd kunnen worden?			Nee	Nee
SQ. Hoe gradeert u de cineplastische operatie: eenvoudig/ gemiddeld/ uitdagend?	Zelfde	Gering makkelijker, want geen transplantatie (eenv-gem.)	Eenvoudig, zelfde	Eenvoudig
SQ. Hoe lang verwacht u dat het uitvoeren van zo'n operatie duurt?	Zelfde	Uurtje	Zelfde	Zelfde
Q. Suggesties/optimalisatie huidige en nieuwe operatie technieken,	-	Nee ook afhankelijk van weefselgenezing etc.	Nee	Nee

Verbeteringen		-		
Q. Suggesties/optimalisatie huidige concept?	Ipv het kapje kan je kijken naar een schuim opvulling gebaseerd op de vorm van de andere arm, behoud van symmetrie	Sierlaagje huid realistisch	Kabel door staafje laten glijden voor supinatie pronatie mogelijkheid.	-
Q. Heeft u het idee dat nieuwe techniek minder belastend is voor de gebruiker, waarom?	Ja, geen donor site.	Bij primair sluiten wondgenezing minder spannend en dus minder belastend.	Zeker minder belastend, want geen huidtransplantaat	Ja, minder belastend, want geen donor site (split skin graft)
Q. Hoe schat u de toepasbaarheid op prothesegebruikers? (0-5)	1	3.5 Denk dat er zeker mensen zijn die zeggen hup klik dt ding erop.	Moeilijk te zeggen, gaat lastig worden om te verkopen aan patienten, qua uitvoering makkelijk	Praktisch (4) esth (2), gemiddeld (3)
Q. Vergeleken met myo elektrisch vs. mechanisch (%):				
SQ. Feedback	80	Elektrische na wennen in NL logisch. 70% Verwachting biceps kan leren/trainen.	60	100
SQ. Cosmetisch	20	50	20	20
Q. Suggestie voor vervolg onderzoek?	Kan zeker nuttig zijn voor landen waar onderhoud minder bereikbaar is.		Draaipunt kan ook bijdragen aan flexie.	-
Q. Betrokken blijven?	Ja	Ja	Ja	Ja

Prosthetists



Prosthetists

	P2	P5
Nieuwe concept		
Q. Wat is uw eerste reactie van het nieuwe concept?	Er zijn heel veel alternatieven die goed werken en geen operatie nodig hebben.	Ziet er mooi uit.
SQ. Doorvragen naar cosmethiek, haalbaarheid en techniek		Cosmethiek beter dan eerst, maar klanten die hij kenden hadden er geen last van dat pin zichtbaar was.
SQ. Wat vindt u van de cosmetiek van de operatie?	Ja vast iets beter maar nog steeds gat en pin in je arm.	Mooier.
SQ. Wat vindt u van het kapje (C-overlay)?	Niet per se beter. Kan net zo goed bovenarm machette zijn, wat normaal voor onderarm protheses niet nodig is en liever niet hoeft.	Mooi, maar denk dat het niet nodig is.
Productgefocuste vragen		
Q. Verwacht u dat patienten het product willen gebruiken qua kleur?	-	Persoonsgebonden. Tegenwoordig ook vaak met mooie printjes. Gieten heeft veel opties. Hoeft tegenwoordig niet meer huidskleur.
Q. Verwacht u dat patienten het product willen gebruiken qua vorm?	-	Ziet er goed uit. De achterkant zou gewoon recht kunnen. Het kapje moet wel heel stijf/star/stevig zijn.
Q. Hoe tevreden bent u met het gehele uiterlijk van het product?	-	Goed. Ziet er mooi uit.
Q. Hoe tevreden bent u over de afmetingen van uw hulpmiddel? (maat, hoogte, lengte, breedte)	-	Prima. Lengte heb je nodig.
Q. Hoe tevreden bent u over de veiligheid van uw hulpmiddel?	-	Zie geen risico's.
Q. Hoe tevreden bent u over de duurzaamheid van uw hulpmiddel? (bestendigheid, slijtvastheid)	-	Ligt aan het materiaal. Gieten en carbon is hartstikke sterk, dus dat gaat dan wel lang mee.
Q. Hoe tevreden bent u over het gemak waarmee u uw hulpmiddel kunt gebruiken?	-	Eenvoudig in gebruik, maar stijfheid moet goed naar gekeken worden of sluiting aan voorkant nodig is.
Q. Kunt u cosmetiek, functionaliteit en comfort ordenen op niveau van belangrijkheid?	-	Functionaliteit-comfort-cosmethiek
Q. Denkt u dat het nieuwe concept geimplementeerd kan worden in huidige prothesiologie?	Kan natuurlijk altijd, maar denk niet dat patienten het willen als myo ook een optie is.	"Ik zeg van wel".
Vergelijking oud-nieuw		
Q. Kan je een inschatting maken wat de voor- en nadelen zijn van cineplasty vergeleken met de huidige alternatieven?	Voordelen natuurlijk wel feedback, duurzaam, hoeveelheid kracht bepalen, betrouwbaar. Lage knijpkracht. Niet veranderd. Bovenarm machette.	Geen veranderingen. Voordeel: geen vocht, elektrische storingen, is direct, laag gewicht, geen bandage, hufter proof.
Q. Wat denkt u dat cineplasty kan betekenen voor patienten in de huidige maatschappij?	Zie bovenstaand.	Feedback heel waardevol. Mooie techniek.
Q. Verwacht u dat patienten open zouden staan voor deze vorm van cineplasty?	Nee dat denk ik niet, myo hoeft geen operatie en werkt heel goed. Per persoon heel verschillend.	Heel lastig te zeggen, is persoonsgebonden. Zou het heel goed moeten uitleggen.
SQ. Eerder dan vorige versie?	Dat denk ik wel, maar nog steeds betwijfel ik of men het wil. Hard je best moeten doen om te overtuigen.	Ja
Verbeteringen		
Q. Suggesties/optimalisatie huidige concept?	Kijk naar onderarm, dat werkte bij die patient heel goed en direct geintegreerd in de prothese. Kabels maken te scherpe hoeken, dus toch terug naar leertje en kabels via midden, hoewel het dan misschien invloed heeft op de flexie. Aansturen vanuit de triceps? Staalkabel zou zorgen voor minder frictie.	Heffing van de onderarm ondersteunen door geen buitenkabel te gebruiken en kabel voor draaipunt (distaal) te bevestigen. Vooal handig bij hele korte onderarm. Gieten (hars) heeft veel opties voor het uiterlijk. Versterken met carbon. Elastische sluiting aan voorkant toevoegen. Moet blijven zitten na vervormen spierbal. En nog steeds makkelijk aan en uit kunnen.
Q. Heeft u het idee dat nieuwe techniek minder belastend is voor de gebruiker, waarom?	Vast wel, kan ik niet zo veel over zeggen.	Ja.
Q. Toepasbaarheid op prothesegebruikers (1-5)	1	3
Q. Vergeleken met myo elektrisch vs. mechanisch (%):		
SQ. Feedback	70	7
SQ. Cosmetisch	20	5
Q. Suggestie voor vervolg onderzoek?	Vernieuwde functionerende prothese.	Gesprek in voortraject waarin opties duidelijk uitgelegd kunnen worden. Praten met artsen die de operatie hebben uitgevoerd.
Q. Betrokken blijven?	Ja	Ja