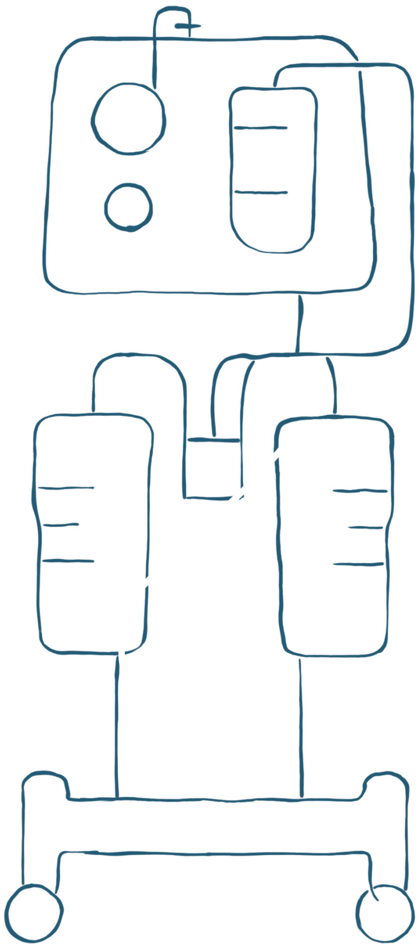
Improving the Use of Surgical Suction Pumps in Sierra Leone



APPENDIX

by
Asja Mucha

Integrated Product Design
Delft University of Technology

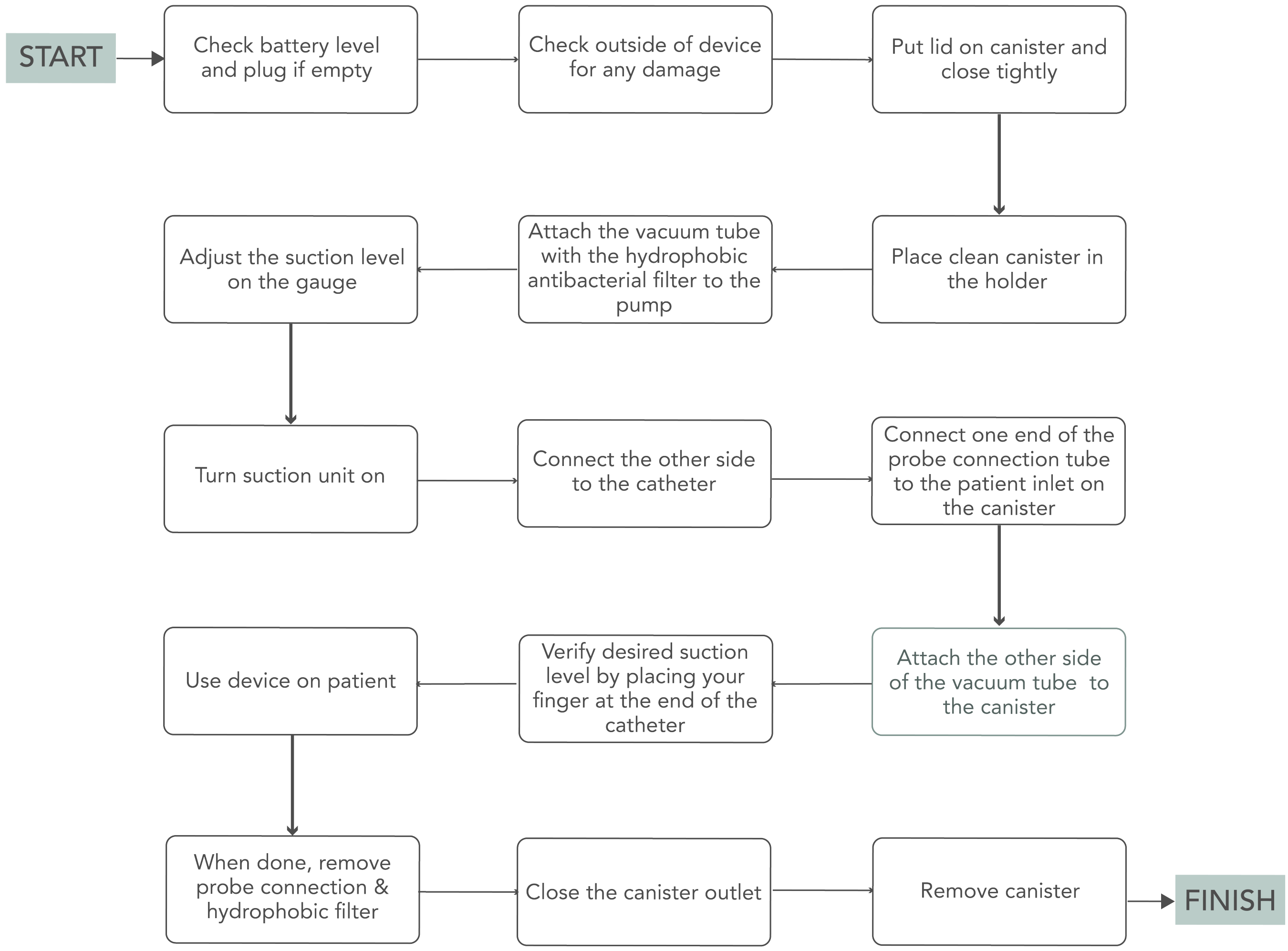
November 2020

Table of Contents

Appendix 1

SUCTION FLOW CHART

Procedure in high-end hospital

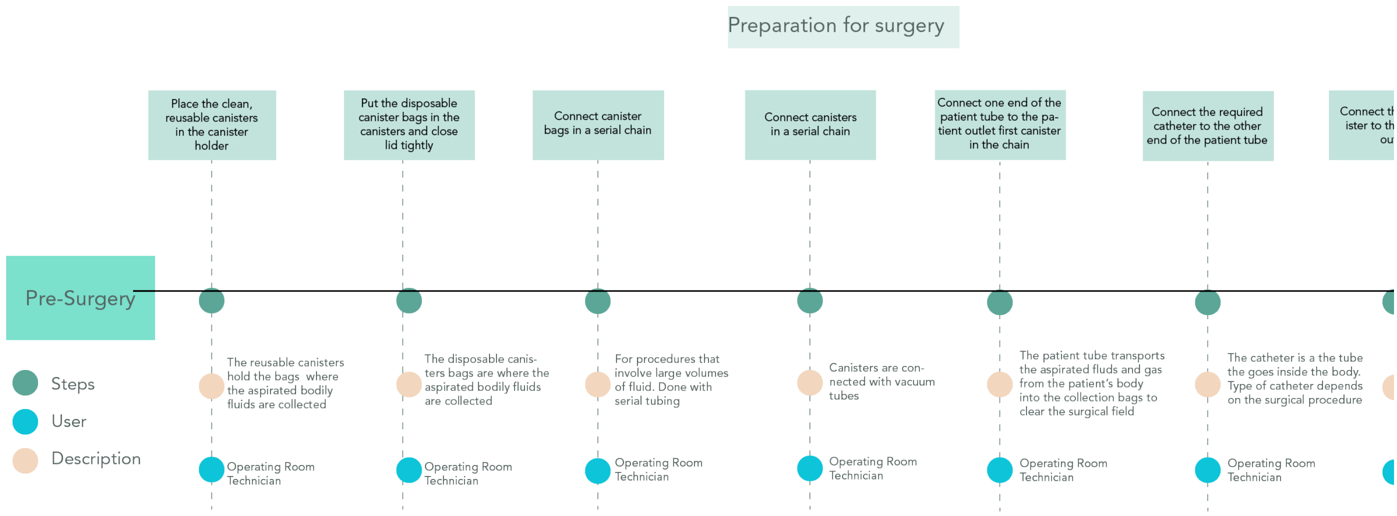


Appendix 2

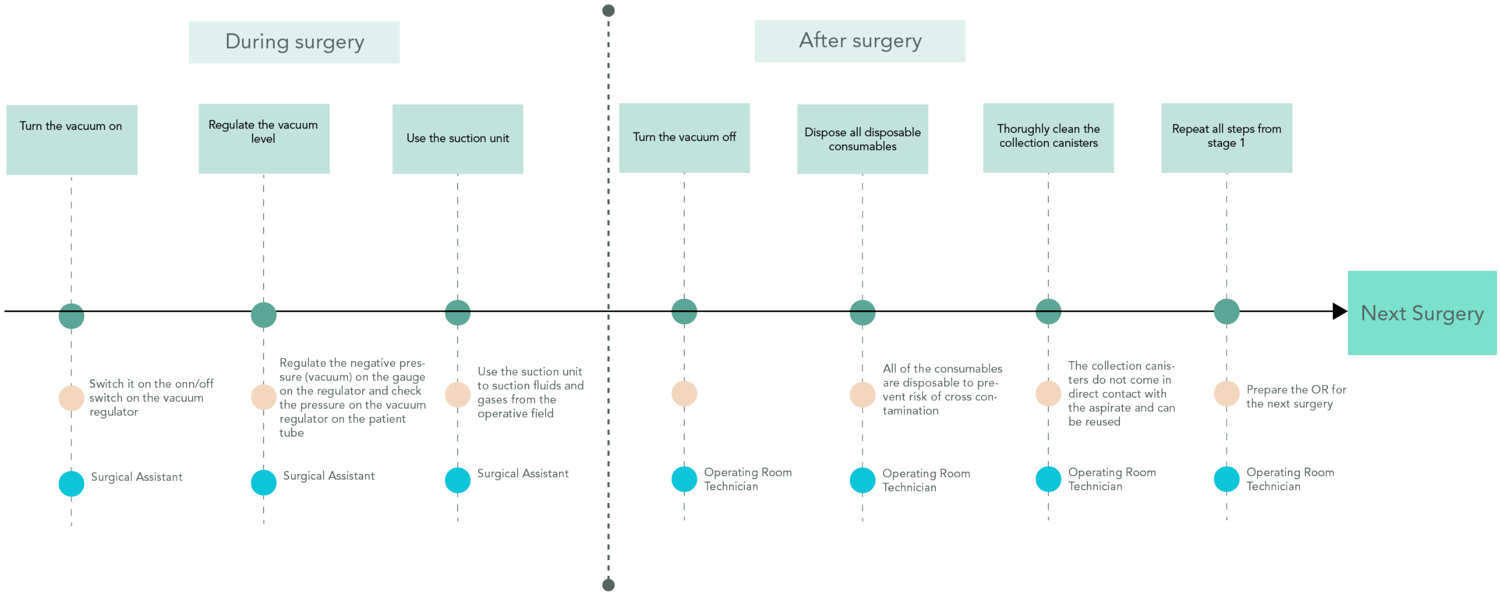
JOURNEY MAP LUMC

Manufacturers of consumables:
Disposable canister bags and canisters: Serres
Catheters: Medicoplast
Suction tubing: Medisize

Journey Map of the Use of Surgical Suction Pumps in a High-End Hospital (example: LUMC)

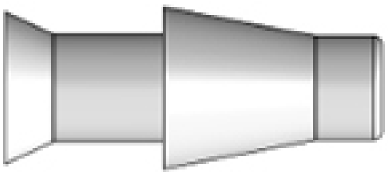


*The journey map does not take into account the use of other devices and equipment in the OR

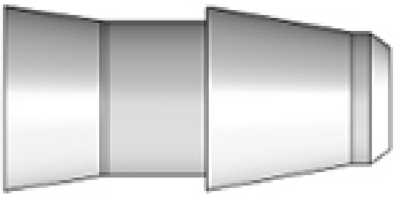

During surgery
After surgery
Turn the vacuum on
Regulate the vacuum level
Use the suction unit
Turn the vacuum off
Dispose all disposable consumables
Thorughly clean the collection canisters
Repeat all steps from stage 1
Next Surgery
Switch it on the onn/off switch on the vacuum regulator
Regulate the negative pressure (vacuum) on the gauge on the regulator and check the pressure on the vacuum regulator on the patient tube
Use the suction unit to suction fluids and gases from the operative field
All of the consumables are disposable to prevent risk of cross contamination
The collection canisters do not come in direct contact with the aspirate and can be reused
Prepare the OR for the next surgery
Surgical Assistant
Surgical Assistant
Surgical Assistant
Operating Room Technician
Operating Room Technician
Operating Room Technician
Operating Room Technician

Appendix 3

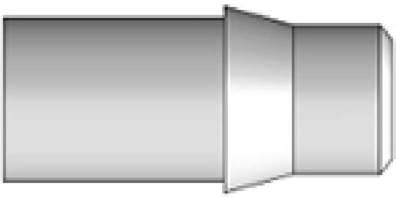
DIFFERENT CONNECTORS



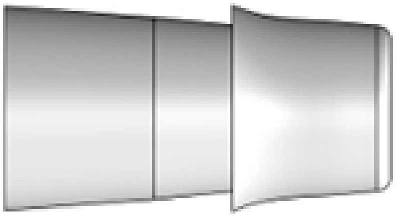
Standard



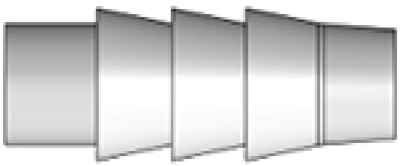
High Pressure



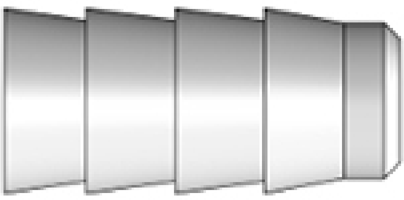
Easy Assembly



Full Range



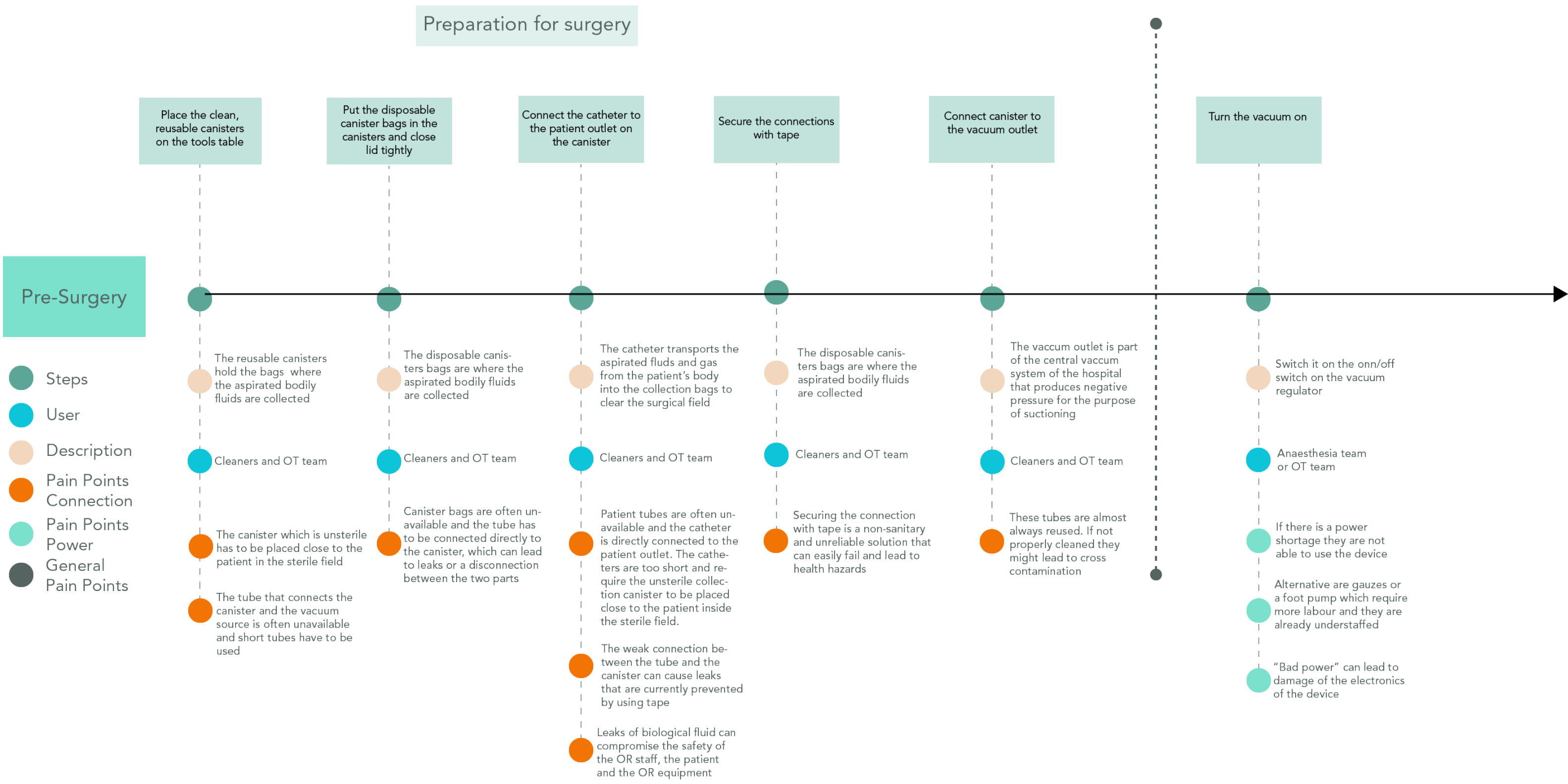
Large Multi-Barb

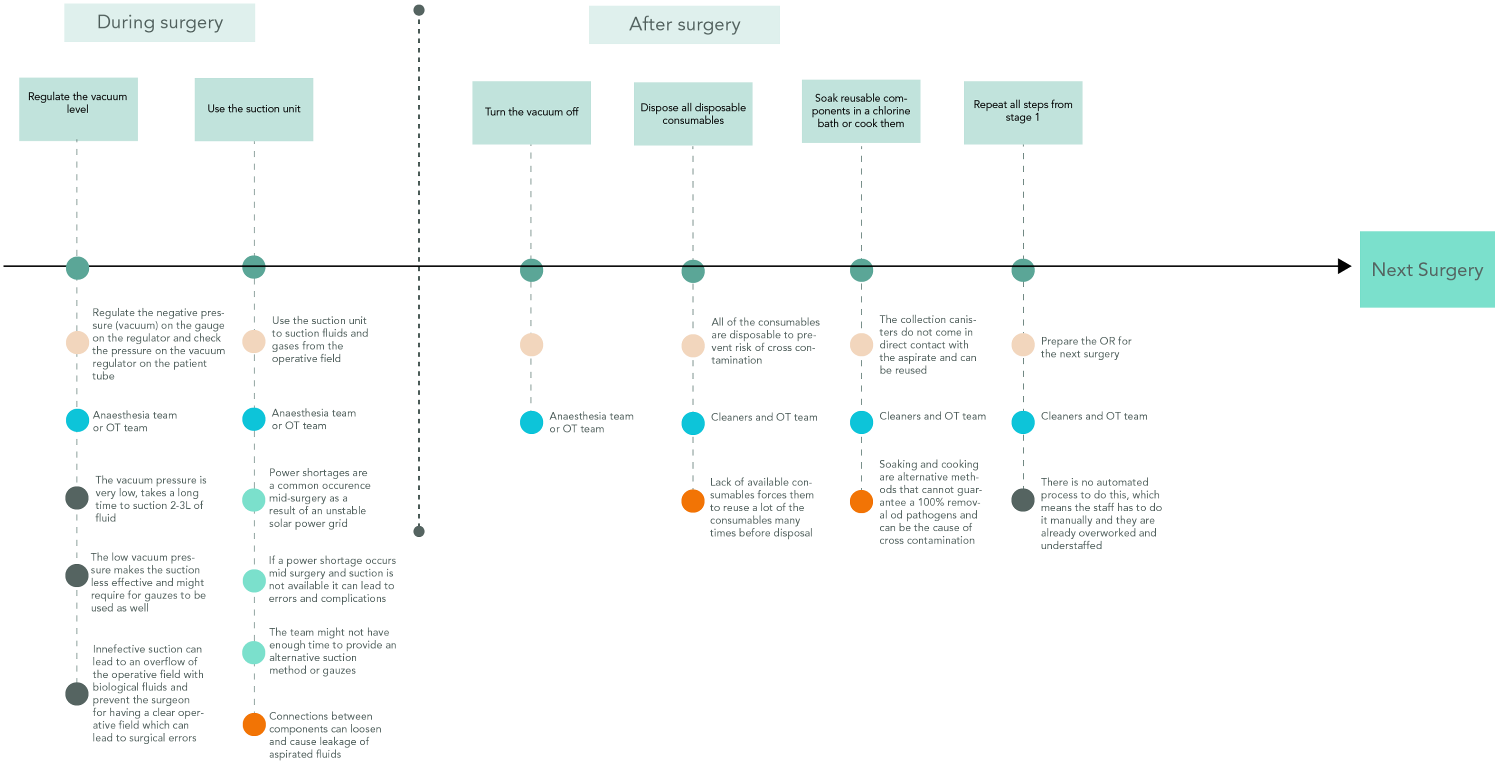


Small Multi-Barb

Appendix 4

SUCTION AT MASAGNA


Preparation for surgery
Pre-Surgery
Steps
User
Description
Pain Points Connection
Pain Points Power
General Pain Points
Place the clean, reusable canisters on the tools table
The reusable canisters hold the bags where the aspirated bodily fluids are collected
Cleaners and OT team
The canister which is unsterile has to be placed close to the patient in the sterile field
The tube that connects the canister and the vacuum source is often unavailable and short tubes have to be used
Put the disposable canister bags in the canisters and close lid tightly
The disposable canisters bags are where the aspirated bodily fluids are collected
Cleaners and OT team
Canister bags are often unavailable and the tube has to be connected directly to the canister, which can lead to leaks or a disconnection between the two parts
Connect the catheter to the patient outlet on the canister
The catheter transports the aspirated fluds and gas from the patient's body into the collection bags to clear the surgical field
Cleaners and OT team
Patient tubes are often unavailable and the catheter is directly connected to the patient outlet. The catheters are too short and require the unsterile collection canister to be placed close to the patient inside the sterile field.
The weak connection between the tube and the canister can cause leaks that are currently prevented by using tape
Leaks of biological fluid can compromise the safety of the OR staff, the patient and the OR equipment
Secure the connections with tape
The disposable canisters bags are where the aspirated bodily fluids are collected
Cleaners and OT team
Securing the connection with tape is a non-sanitary and unreliable solution that can easily fail and lead to health hazards
Connect canister to the vacuum outlet
The vaccum outlet is part of the central vaccum system of the hospital that produces negative pressure for the purpose of suctioning
Cleaners and OT team
These tubes are almost always reused. If not properly cleaned they might lead to cross contamination
Turn the vacuum on
Switch it on the onn/off switch on the vacuum regulator
Anaesthesia team or OT team
If there is a power shortage they are not able to use the device
Alternative are gauzes or a foot pump which require more labour and they are already understaffed
"Bad power" can lead to damage of the electronics of the device


During surgery
After surgery
Regulate the vacuum level
Use the suction unit
Turn the vacuum off
Dispose all disposable consumables
Soak reusable components in a chlorine bath or cook them
Repeat all steps from stage 1
Next Surgery
Regulate the negative pressure (vacuum) on the gauge on the regulator and check the pressure on the vacuum regulator on the patient tube
Anaesthesia team or OT team
The vacuum pressure is very low, takes a long time to suction 2-3L of fluid
The low vacuum pressure makes the suction less effective and might require for gauzes to be used as well
Innefective suction can lead to an overflow of the operative field with biological fluids and prevent the surgeon for having a clear operative field which can lead to surgical errors
Use the suction unit to suction fluids and gases from the operative field
Anaesthesia team or OT team
Power shortages are a common occurence mid-surgery as a result of an unstable solar power grid
If a power shortage occurs mid surgery and suction is not available it can lead to errors and complications
The team might not have enough time to provide an alternative suction method or gauzes
Connections between components can loosen and cause leakage of aspirated fluids
Anaesthesia team or OT team
All of the consumables are disposable to prevent risk of cross contamination
Cleaners and OT team
Lack of available consumables forces them to reuse a lot of the consumables many times before disposal
The collection canisters do not come in direct contact with the aspirate and can be reused
Cleaners and OT team
Soaking and cooking are alternative methods that cannot guarantee a 100% removal od pathogens and can be the cause of cross contamination
Prepare the OR for the next surgery
Cleaners and OT team
There is no automated process to do this, which means the staff has to do it manually and they are already overworked and understaffed

Appendix 5

MANUFACTURING SCENARIOS

Manufacturing Scenarios

The decision to further develop custom-designed connectors demanded looking at possible scenarios for the manufacturing of the connectors. At an earlier stage of the project, four possible manufacturing scenarios were created (Table 1).

Scenario	Locally product reusable part	Locally produced disposable parts	Outsourced reusable parts	Outsourced disposable parts
Pros	Not relying on external supply chain	Better control over repository	Not relying on local manufacturing	Not relying on local manufacturing
	Easier access to manufacturer if more are needed	Personal supply chain	Doctor or volunteer can bring them in luggage	Doctor or volunteer can bring them in luggage
Cons	Availability of manufacturing facilities	Lack of filament and silicone	Possibility of running out of spares	Lack of filament and silicone
	Transport to Masanga	Lack of expertise	Transport to Masanga	Lack of expertise
		Requires more work		Requires more work

Table 1: Manufacturing scenarios for tubing connectors for Masanga Hospital

The scenarios were the initial point towards the ideation of the first concepts for the connectors, including manufacturing the form metal or designing a mold for flexible connectors. The scenarios and concepts were evaluated against the contextual factors, which lead to several conclusions:

- Outsourced manufacturing would have the same outcome as what the situation is now: If consumables become unavailable, it could take a while before a new shipment arrives, which would again leave Masanga at square 1
- Sierra Leone does not have a medical device industry
- If the dimensions of the consumables in use change, Masanga would once again have to order them from a manufacturer and wait for a while
- Producing steel connectors was also looked into, but apart from local carpenters, there was no detected availability of a manufacturer who could produce them. Metals are also highly corrosive, so a specific grade of medical steel would be necessary, which might not be available.

In a conversation with Jan Henk, he brought back the topic of 3D printing the connectors at their 3D printing lab. The hospital has been trying to start a practice of 3D printing spare parts in the past years. 3D printing was already looked into as an option for manufacturing. The availability of filament was considered a downside, but the hospital is always stocked up with filament for their prosthesis printing project. Filament is delivered from the Netherlands, usually by a staff member when they travel between the Netherlands and Sierra Leone.

Jan Henk also expressed that they would ideally like to reuse the connectors. Reusing consumables, as mentioned earlier, is a common practice at Masanga and LRS hospitals in general and is part of the hospital's behaviour. 3D printing of medical consumables is a broad field that is still researched and not many examples of 3D printed, reusable devices exist. The biggest risk of reusing 3D printed consumables comes from the layered structure of 3D printed designs, as dirt or pathogens can easily get stuck in between the layers and threaten cross-contamination. However, the right choice of material and the right settings could drastically improve the adhesion of the layers, leaving little to no space for pathogens or bacteria to get stuck in.

Furthermore, a decision was made together with the client to proceed towards designing 3D printed, reusable connectors, that would be printed at the hospital's 3D printing lab.

The designed solution would then be treated the same way as the rest of the consumables (tubes, collection canisters), avoiding the need of behavioural changes in the use of consumables. The mismatch of consumables and their unpredictable availability means that the dimensioning of these connectors can vary even on a daily basis, since consumables are always unavailable. With local, on-sight manufacturing, the hospital would be able to print custom made connectors to fit the exact need at the moment of application. Masanga should be given the opportunity to use this as a long term solution, not just a one-time solution where the connectors fit the dimensions only of the consumables that are currently available, without taking into consideration the availability of consumables in the future.

Appendix 6

GENERAL AND CONTEXTUAL TRIAGE

Appendix G Software Version of Triage

The following pages contain the text of the software version of the both triages.

Page 1: Risk Assessment

Please select any of the following common regulatory categories that may apply to this product:

- ☐ This product is to be primarily used by children
- ☑ This is a medical product
- ☐ This is safety equipment product (e.g. helmet, safety glasses, harness, respirators)
- ☐ This is a component of heavy, motorized machinery
- ☐ This is a component used in a machine for transporting people (e.g. vehicles, bicycles, carts, wagons)
- ☐ This product is used to support or protect other products (e.g. cases, covers)
- ☐ NONE OF THESE APPLY

Please select any of the following descriptions that apply to this children's product.

If this is not a product for children, you may go back and uncheck this box.

- ☐ Is the product to be used by children under the age of 5?
- ☐ Does the product bear the weight of the child in any way?
- ☐ NONE OF THESE APPLY

Please select any of the following descriptions that apply to this protective device.

If this is not a protective device, you may go back and uncheck this box.

- ☐ Does the product protect the head, face, eyes, or vital organs?
- ☐ Is the product designed to protect limbs or appendages from possible injury or strain?
- ☐ Is the product designed to protect from minor injuries (e.g. bruises, cuts, scrapes)?
- ☐ NONE OF THESE APPLY

Please select any of the following descriptions that apply to this heavy machinery component.

If this is not a heavy machinery component, you may go back and uncheck this box.

- ☐ Is the product used to directly control a motor vehicle (e.g. brakes,steering, start-stop button)?
- ☐ Is the product used to protect the user at all (e.g. seat-belts, safety kill-switch)?
- ☐ Is the product expected to bear the weight of the user?
- ☐ NONE OF THESE APPLY

Please select any of the following descriptions that apply to this transport component.

If this is not a transportation component, you may go back and uncheck this box.

- ☐ Is the product used to directly control a motor vehicle (e.g. brakes,steering, start-stop button)?
- ☐ Is the product used to protect the user at all (e.g. seat-belts, safety kill-switch)?
- ☐ Is the product expected to bear the weight of the user?
- ☐ NONE OF THESE APPLY

Page 2 - Product Usage

Is this product used to prepare, serve, or store food, drinks, or medicines?

- ○ Yes
- ✓ No

Is this product a component of an electronic devices?

Any product or device that uses electricity

- ✓ Yes
- ○ No

Is this product typically exposed to heat sources? (e.g. stoves, hot lamps, open flames, hot liquids…)?

- ○ Yes
- ✓ No

Does the product require regular cleaning (after each use or every few uses)?

- ✓ Yes
- ○ No

How is the product typically cleaned?

Select all that apply

- ☑ Cleaned with water
- ☐ Cleaned/Sterilized with heat
- ☑ Cleaned by brushing/scraping
- ☑ Cleaned/Sterilized with chemicals
- ☐ Cleaned/Sterilized with ultraviolet light
- ☐ Cleaned with other method not listed here

How is this product otherwise cleaned?

____

What chemicals are typically used to clean this product?

- ☑ Isopropyl alcohol (Rubbing alcohol, hand sanitizer, etc)
- ☐ Acetone (nail-polish remover)
- ☐ Ammonia-based Houehold cleaner
- ☑ Hydrogen peroxide (some detergents)
- ☑ Other cleaning chemicals not listed
- ☐ Please note the chemical used to clean this product Chlorine

Is the product expected to regularly come into contact with hazardous/concentrated chemicals during its use?

e.g. household cleaning chemicals, reagents commonly found in laboratories

- ○ Yes
- ✓ No

Will the product be exposed to any of the following chemicals?

- ☐ Isopropyl alcohol
- ☐ Acetone
- ☑ Ethanol
- ☑ Hydrocholoric Acid
- ☐ Ammonia
- ☐ Hydrogen peroxide
- ☐ Orthophosphoric Acid
- ☐ Nitric Acid
- ☐ Sulfuric Acid
- ☐ Acetic Acid
- ☐ Other cleaning chemicals not listed

Please describe these other chemicals.

____

Is the product to be typically used and/or stored outdoors?

- ○ Yes
- ✓ No

Does the product's use involve rubbing or sliding against other surfaces?

Alternatively phrased, does the product see a lot of wear-and-tear

- ✓ Yes
- ○ No

Should friction be minimized between the product and the surface during this rubbing or sliding?

- ✓ Yes
- ○ No

Page 3 - Material Selection

Please choose a general category of material that the original product or component is currently made from.

- ○ Ceramics (glasses, stone, some building materials…)
- ○ Metals
- ✓ Polymers (plastics, rubbers, other synthetic materials…)
- ○ Natural Materials, Composites, and Foams

Please choose a specific material from [selected category].

If you don't know, scroll down to the bottom and select "I don't know"

Examples uses of [material]. PC , PU DP, Nylon, PP

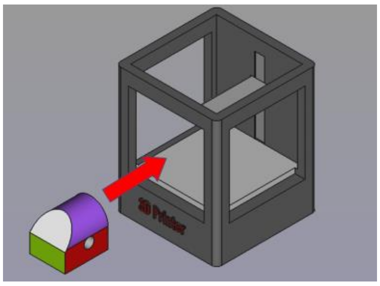
If this seems incorrect, please go back and change your material before proceeding.
Note: Your specific material does not need to be listed among the examples to proceed.

What is the mass of the original product? (in grams)

2gr

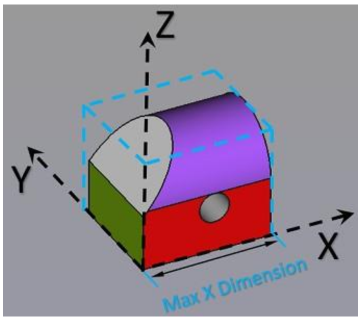
Page 4 - Printer Size Check

Products that are unable to fit within the print volume of the available 3D printer are not able to be 3D printed without Some redesign.



Place the object in front of you so that it is able to come to a stable point of rest on a flat surface. Identify the X, Y, and Z orientations, and measure the maximum dimension of the product along each axis.

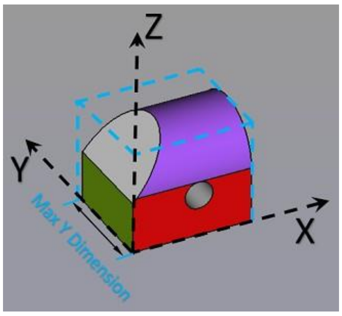
If you only have a drawing, you may be able to figure out the max dimension along each axis by just examining the drawing.



What is the maximum X dimension of the product (mm)?

Not the maximum dimensions on the printer…

12

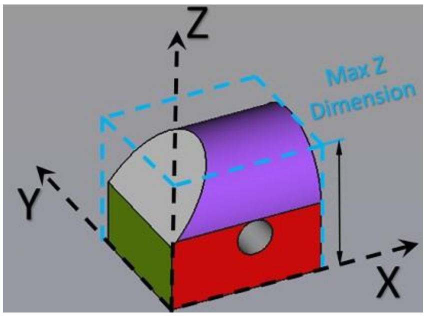


What is the maximum Y dimension of the product (mm)?

Not the maximum dimensions on the printer…

12

____



.What is the maximum Z dimension of the product (mm)?

Not the maximum dimensions on the printer…

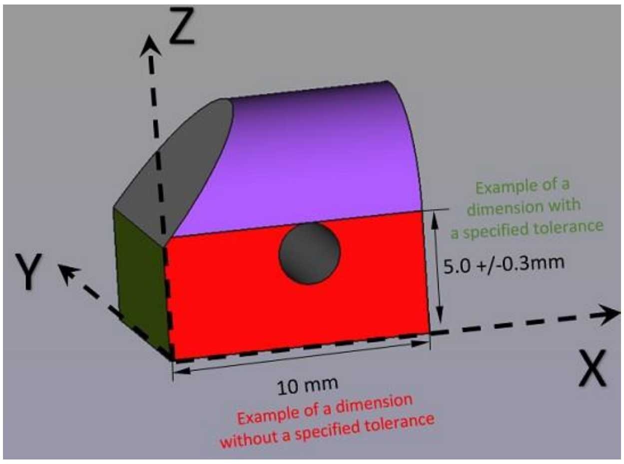
60

____

307

Page 5 - Dimensional Accuracy

3D printers are limited in their ability to print objects that require especially high precision.



Does this product contain any dimensions with specified, required tolerances?

Depending upon the orientation of the dimension of required tight-tolerancing, the product's print orientation may need to be adjusted.

- ✓ Yes
- ○ No

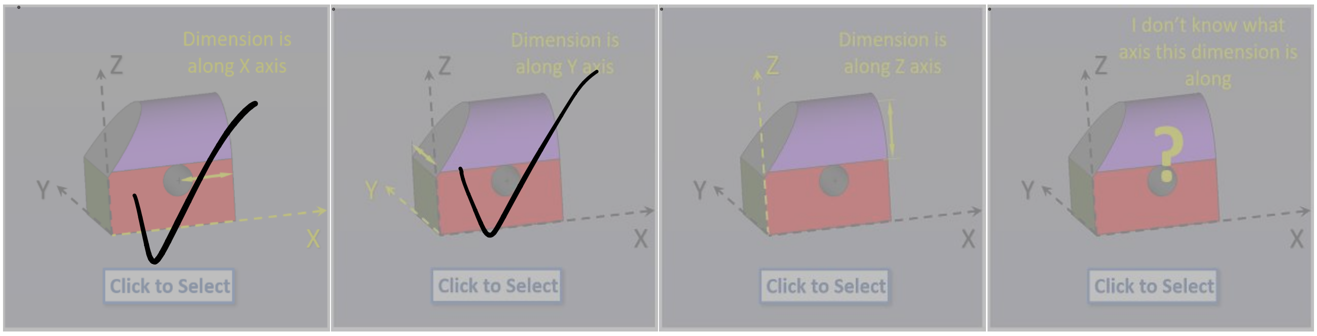
What is the value of the dimension (i.e. ??+/-XX)?

0.5mm

What is the value of the tolerance (i.e. XX+/-??)?

+/- 0.2m

In what direction is this dimension/tolerance?



Add another small feature?

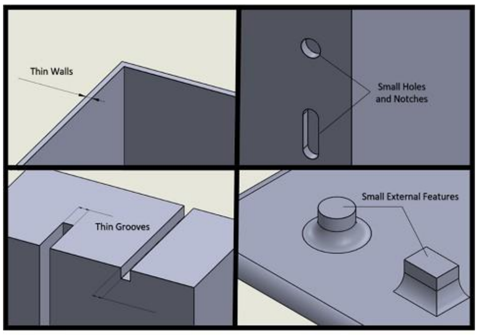
If the dimension with specific tolerances is repeated multiple times on the product and exists on the same face, you may put input the dimension only once.

- ○ Yes
- ○ No

Page 6 - Printer Resolution

Most 3D printers are limited in their ability to print products that include especially small dimensions (<2mm).

Here are Some of features that may have small dimensions that are difficult to 3D print.



Some examples of features that may push the limits of a 3D printer's resolution if their dimensions are too small.

Are there any dimensions less than 2mm present on this product?

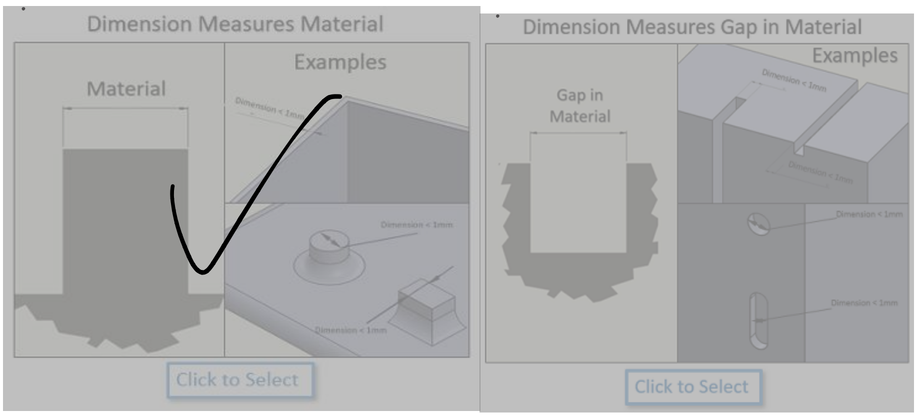
- ✓ Yes
- ○ No

What is the value of this small dimension (in mm)?

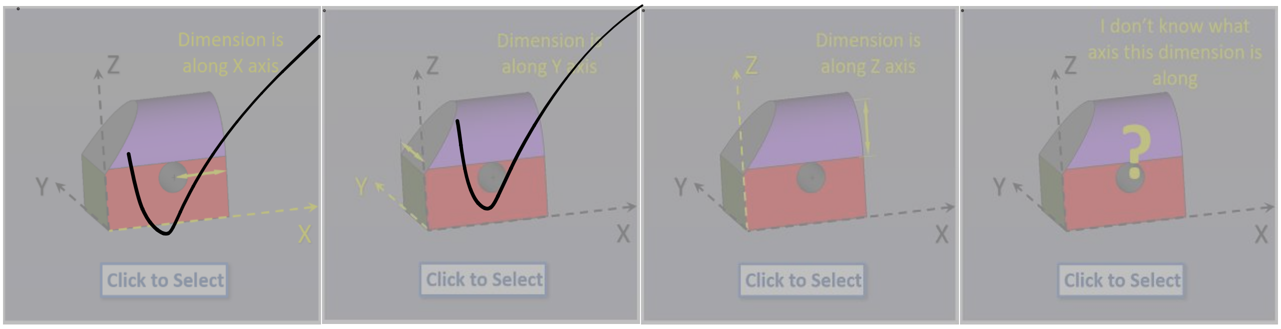
0.5 m
___

Does this dimension measure where material is or where there is a gap in material (holes and grooves)?

i.e. Does the dimension measure where material is or where empty space is?

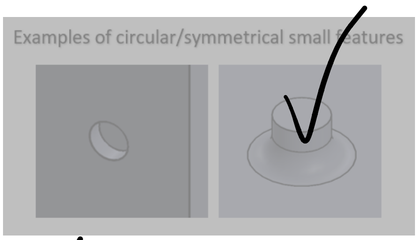


In what direction is this dimension/tolerance?



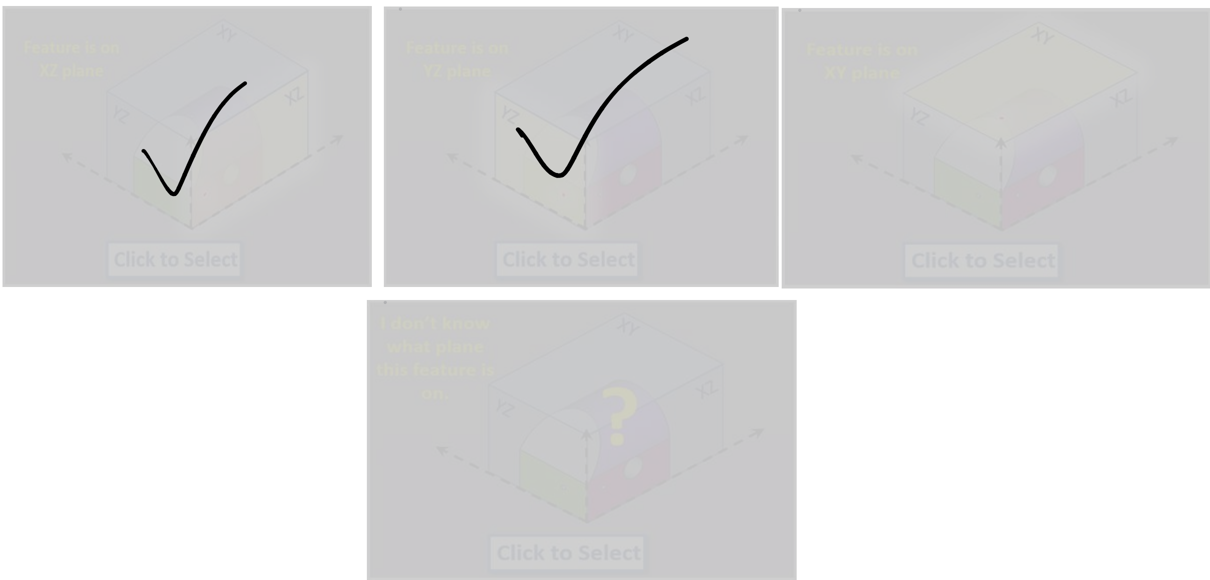
Is this small dimension a diameter for a small feature, like a hole or a cylinder?

If the cross dimension is a different sized than the input dimension, then add a new small dimension.



- ✓ Yes
- ○ No

What is the face that that small-dimensioned circular feature is on?



311

Page 7 - Contextual Appropriateness

Is there someone present in this scenario with expertise/training to operate a 3D printer?

- ✓ Yes
- ○ No

Is this a particularly complicated product that requires specialized testing to determine that it is correctly doing its job?

- ○ Yes
- ✓ No

Is there someone present who can verify that the product is working correctly once it is printed?

If the product is being considered for long-term deployment, there needs to be someone to see the mechanisms for quality control.

- ✓ Yes, they will also be given a benchmark part to compare against
- ○ No

Is there an electrical power source available at this location?

- ✓ Yes
- ○ No

Is this electrical source subject to frequent outages?

(At least one outage/day, including both intentional and unintentional outages.)

- ✓ Yes, but the problem has been fixed recently
- ○ No

Are there supply chains in place that are able to deliver 3D printing material?

- ✓ Yes
- ○ No

Page 8 - Economics

What does the original product cost? (USD per unit)

Please include the cost of delivery

0.5 - 2 $

How many of the product are needed? (# of units)

Weekly for ~20 surgeries; depending on number of reuses

Approximately how long does it take to deliver this product in the given scenario? (# of days)

Rn can take months, in this envisioned case, few hours

Please select the 3D printer available in this scenario

Give your browser a moment to load after selecting

- ○ Duplicator Pro
- ○ Print-it-Now 2
- ○ RoboMaker

Ultimaker S5, 3

Please select a material (filament) being considered in this scenario

Give your browser a moment to load after selecting

- ✓ ABS
- ○ Polycarbonate (PC)
- ○ Polypropylene (PP)
- ○ Nylon
- ○ P

✓PLA

✓PETG

Appendix 7

MANUFACTURING FACILITY AT MASAGNA

Manufacturing facility at Masanga Hospital

This chapter will analyze the traits of the manufacturing process, with respect to the available device, the manufacturing environment, the part geometry, slicer settings and the material choice for the production.

Device available (done)

Masanga Hospital is equipped with two 3D printers: an Ultimaker 3+ and an Ultimaker S5. The printers are stored and used in a separate room at the hospital, serving as a mini fab-lab. The room is currently used as a Covid-19 response center, hence the printers are kept at the office of one of the doctors and currently not in use. This poses as a slight disadvantage in the graduation project as the plan was to print samples of the connectors there for design & manufacturing validation, but currently battling the pandemic is more important, so the printing is rescheduled until further notice, after the termination of the graduation project. In the period of the graduation project, the prototyping and testing will be simulated on the Ultimaker S5 at the faculty’s Digital Fabrication Lab.

Both printers are considered to produce prints with a high quality, the S5 being a more advanced, professional 3D printer. There are a number of notable differences that make the S5 a more suitable choice.
The S5 has a larger build volume and a higher power output. This means that it can produce larger or more prints in one run and is more powerful, hence can produce higher quality prints. It comes with a user-friendly software and interface, allows wireless operation and multiple users sharing the same printer through a mobile app. Given these facts we can assume that this would be a benefit if less skilled staff operates the printer. If they experience software issues with the part code, the part can easily be reviewed by an expert located elsewhere through the app. However this is just an assumption that can only be verified upon “real-life” testing or project implementation. Another benefit however of the Ultimaker S5 are the glass doors, which maintain an even environmental temperature and prevent dust from entering.

The printing properties and the operation parameters are identical, making both printers suitable for printing the connectors. Both printers can handle a vast array of materials Performance of the S3 should still be tested when possible.

Conclusion:

- The hospital is equipped with two high quality, advanced printers

- The printers are suitable to print the tubing connectors as they produce high quality prints and can work with most FDM filaments
- Both printers should be tested in real life

For more information on the specific information on the available printers see Appendix X.

3D Printing Environment

When it comes to 3D printing, the environment where the printer is situated can greatly influence the performance of the device and the quality of the final product [x]. Factors such as dust and humidity could potentially harm either the device itself or the material filament. The environmental temperature is not taken into consideration as most materials and the printers can work on temperatures higher than 32℃ [x].

The 3D printing lab at the hospital (currently transformed into a COVID-19 response center) is kept quite clean and the temperature is regulated by air conditioning. What could be a threat to the quality of 3D printing is the humidity of the room, which is hard to determine remotely and especially while the lab is not in function. This will be taken into consideration to deliver as advice to the client on how to combat the possible effects of exposure to humidity of the 3D printing.

Appendix 8

PRICE OF 3D PRINTED CONNECTOR

Finances

1 roll of filament = 750gr
1 connector ~ 3gr
Filament price: 40€

1 connector costs 0.16€

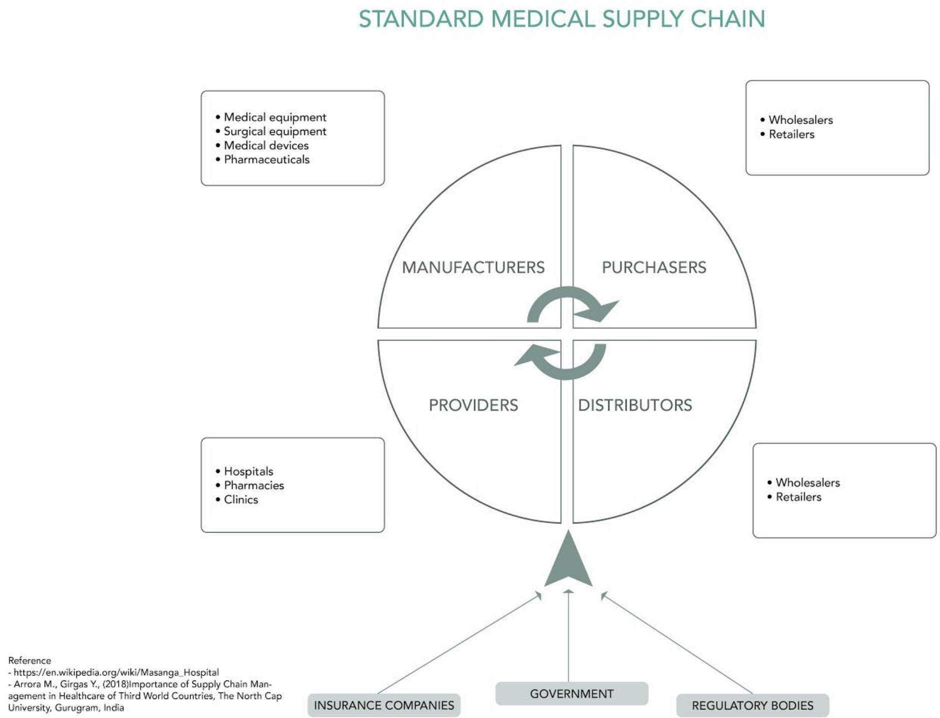
Appendix 9

SUPPLY CHAIN FOR MASAGNA

Supply chain of Masanga Hospital

A supply chain, as defined by Oxford Dictionary is the sequence of processes involved in the production and distribution of a commodity. Analysis on the common supply chain for HIC hospitals [1] (Fig. 1) demonstrates the separate parties involved in the supply chain:

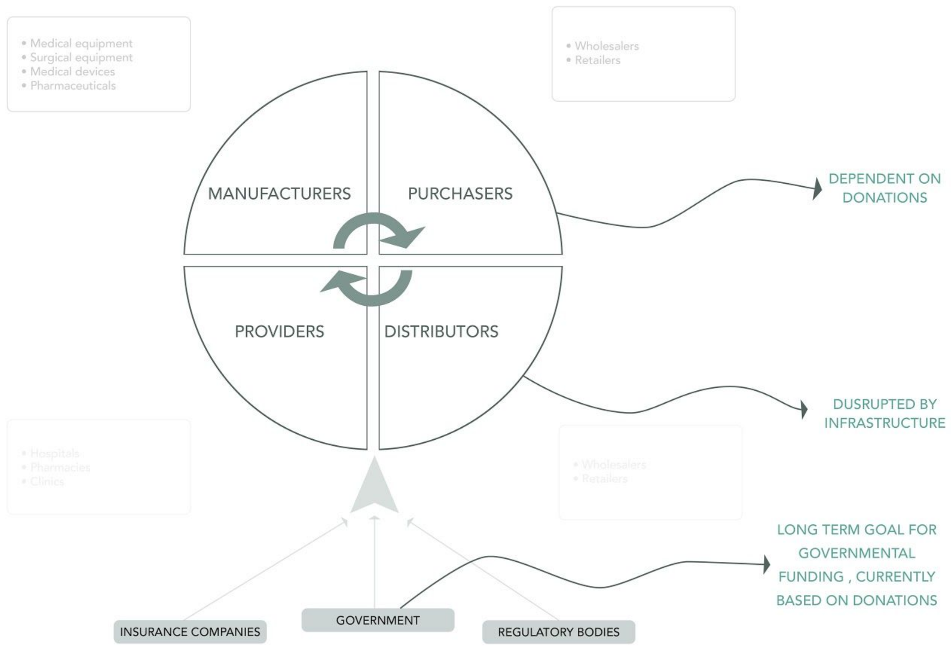
- Manufacturers
- Purchasers
- Providers
- Distributors



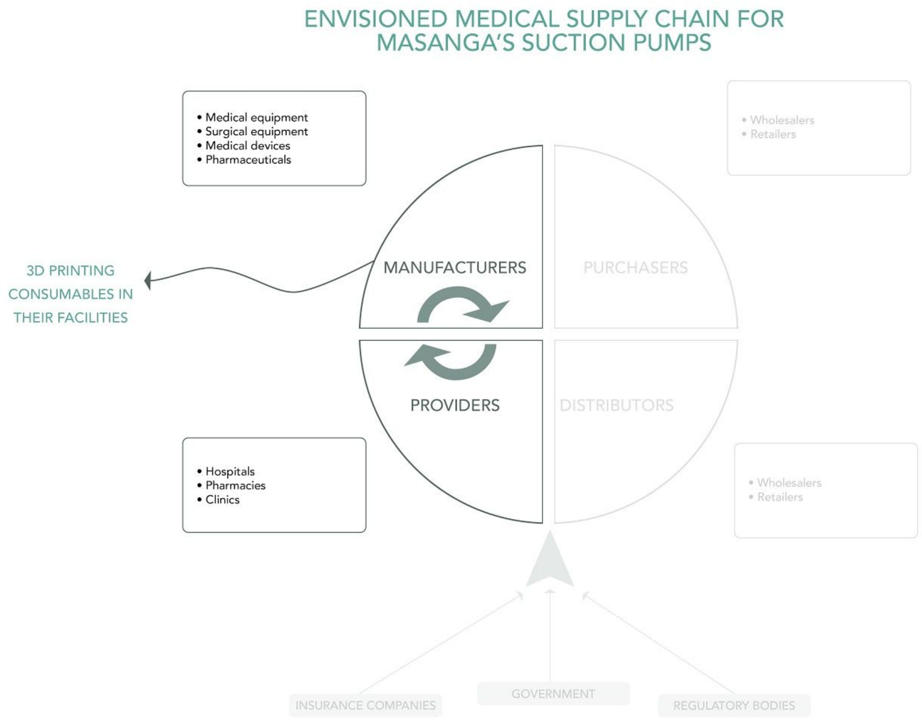
From communication with Frank van Raaij [2], Peter Bo Jorgensen [3] and Jan Henk Dubbink [4] it was discovered that the financial constraints and infrastructural disruptions rummage Masanga's supply chain system. Supplies are missing almost every day. Frank mentioned that often when they order supplies or are expecting a container from the Netherlands, the shipments can get stuck at customs for extended periods of time, sometimes even months at a time. By the time they reach Masanga, most of the supplies come damaged or with a passed expiration date.

From the interviews it was possible to understand which actor in the Masanga Group plays the role of which supply chain party and what is their current limitation.

OBSTACLES IN MASANGA'S MEDICAL SUPPLY CHAIN



Lack of finances and infrastructural issues are the main contributors towards this issue. However, the contextual research and especially the research of Masanga have shown that although Sierra Leone does not have an industry that could engage in the production of consumables, Masanga Hospital has the potential to become a producer of their own consumables, at their own ground by using their 3D printers for production of consumables. Given this information, it was possible to create an **Envisioned Supply Chain** for Masanga Hospital, where Masanga would act as the manufacturer of the design solution that would improve the use of their surgical suction pump.



Printing the tubing connectors for the suction pump could be a starting point for Masanga on their journey of locally producing more reusable and custom consumables.

References

1. Arora, M, Girgas, Y (2018), Importance of Supply Chain Management in Healthcare in Third World Countries, International JOurnal of Supply and Operation Management, February 2018, Volume 5, Issue 1, pp. 101-106
2. Van Raaij, F. (2020, June 27th), Phone call
3. Jorgensen, P. (2020, July 1st), Phone call
4. Dubbink, J. H, (2020, July 6th), Interview

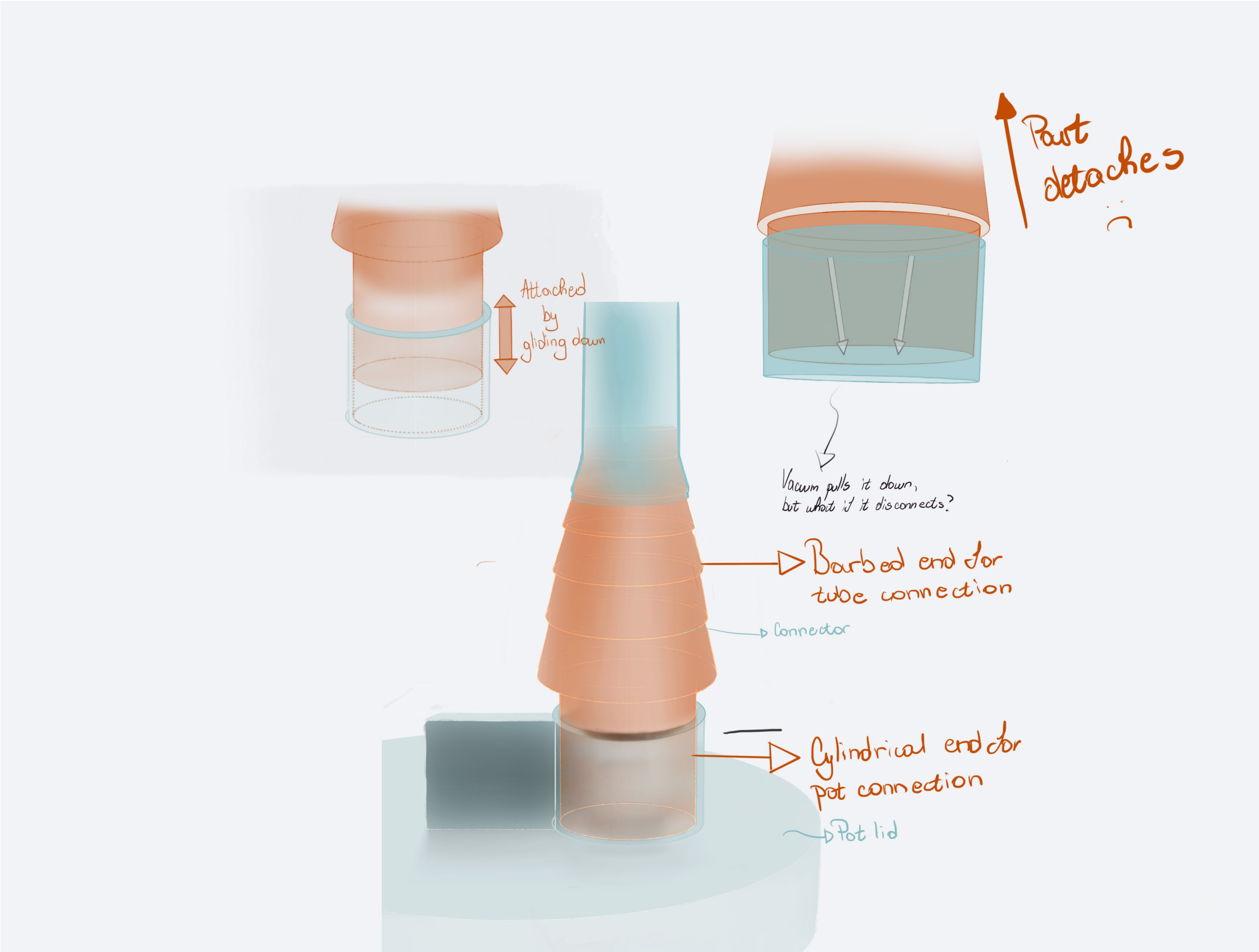
Appendix 10

MANUFACTURING MATERIAL COMPARISON

	ABS	PLA	PETG	Tough PLA	TPU	TPA	TPC	Nylon
Printer compatibility (Ultimaker S5 & 3+)	Y/Y	Y/Y	Y/Y	Y/N	Y/N	Y/N	Y/N	
Ultimate strenght	40 MPa	65MPa	53 MPa	78 MPa	49.99 MPa			40 - 85 MPa
Durability	8/10	4/10	8/10					5/10
Stiffness	5/10	7.5/10	5/10					5/10
Elastic range	/	/	/	/	600 - 700 %	370–497%	350–530%	/
Termal expansion	90µm/m-°C	68 µm/m-°C	60 µm/m-°C	µm/m-°C	µm/m-°C	µm/m-°C	µm/m-°C	95 µm/m-°C
Maximum service temperature	98 °C	68 °C	73 °C	~ 60 °C	80 °C			95 °C
Density	1.04 g/cm3	1,24 g/cm3	1.23 g/cm3	1.24 g/cm^3	1.20g/cm3	1.1g/cm3	1.22 g/cm3	1.06 - 1.14 g/cm3
Price per kg	10 - 40 $	10 - 40 $	20 - 60 $	20 - 60 $	69.95 $			25 - 65 $
Extruder temperature	220 - 250 °C	190 - 220 °C	230 - 250 °C	205 -220 °C	210–230 °C	220–230 °C	220–260 °C	220 - 270 °C
Bed temperature	95 - 110 °C (Required)	45 - 60 °C (Optional)	75 - 90 °C	35 - 50 °C	0 - 60 °C	30–60 °C	90–110 °C	70 - 90 °C (Required)
Nozzle size								
Flexible								
Elastic								
Impact resistant								
Soft								
Water resistant								
Dissolvable								
Heat Resistant								
Chemically Resistant								

Appendix 11

EMBODIMENT ITERATION


Part detaches
Attached by gliding down
Vacuum pulls it down, but what if it disconnects?
Barbed end for tube connection
Connector
Cylindrical end for pot connection
Pot lid

Appendix 12

FAILURE MODE ELEMENT ANALYSIS

Item	Module	Severity (1 - 5)	Probability (very low 1, low 2, mid 3, high 4, very high 5) Evidence Level (1 - 5)	Score (1 - 25)	Risk or Problem	Root cause	Agreed Solution on root Cause	Agreed Action
1	Mechanical	5	1	5	The connector breaks	The user presses it too hard	Test material properties (strength), improve 3D printing paramet	0.1mm layer height as optimal layer height
2	Mechanical	5	1	5	The connector breaks	The connector is exposed to high tension	Test material properties (strength), improve 3D printing paramet	0.1mm layer height as optimal tensile propert
3	Mechanical	5	1	5	The connector breaks	Negative pressure collapses the connector	Test material properties (stregth), improve 3D printing paramete	0.1mm layer height printed at 40mm/s speed,
4	Mechanical	5	2	10	Fluids leak from connector	Inadequate layer adhesion	3D printing resolution should be higher	0.1mm layer height printed at 40mm/s speed,
	Embodiment	5	2	10	Fluids leak from connector	Connector dimensions are inadequate	Check component dimensions again, initial	Dimensions verified against commercial conn
	Embodiment	3	2	10	Air leaks from connector	Connector dimensions are inadequate	Check component dimensions again	Dimensions verified against commercial conn
5	Mechanical	3	3	9	Air leaks from connector	Inadequate layer adhesion	Improved 3D printing resulotion, print speed and print cooling	0.1mm layer height printed at 40mm/s speed,
6	Embodiment	4	4	16	Suction flow is blocked	Internal diameter of the connector is too small	Internal diameter might need increasing; printing settings shoulc	5mm smallest OD, 3,5mm smallest ID
7	Embodiment	4	4	16	Suction flow is blocked	Suctioned media gets stuck inside	Improve internal smoothness of connector	Straight, smooth internal wall line
8	Mechanical/Chemical	5	3	15	Connector disconnects from tubing	Material wears off due to exposure to chemicals	Test material against expected chemicals	chosen as production material
9	Mechanical	5	2	10	Connector disconnects from tubing	Material wears off from use	Test material against wear properties	
10	Electronics	4	1	4	Battery explodes	Overloading/underloading of battery	Integrate a component in the circuit to regulate the load	Buy charger with integrated charge control
11	Electronics	4	3	12	Battery explodes	Overheating by short circuit	Isolation to prevent short circuits from happening	Place battery in a battery box
12	Electronics	4	2	8	Battery explodes	Overheating by sun exposure	Instruct user to keep battery pack away from sun	Place battery in a battery box
13	Electronics	5	2	10	Suction pump breaks down	Break down by short circuit	Integrate a component in the circuit to prevent machine damage	Install fuse with appropriate amperage
14	Embodiment/Chemical	5	2	10	Cross contamination	Pathogens get stuck in corners of connector	Test cleaning of connectos	Connector infected with ATS, cleaning succes
15	Mechanical/Chemical	5	1	5	Cross contamination	Pathogens penetrate the material	Test material properties against pathogen exposure	Connector infected with ATS, cleaning succes
16	Embodiment	3	2	6	Connector cuts tube	Barb edges are too sharp	Adjust file settings, adjust print settings	0.1mm layer height printed at 40mm/s speed,
17	Mechanical	3	2	6	Connector cuts tube	Connector has a defect	Check connector for damage	Dispose connector if damaged

Appendix 13

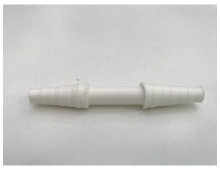
3D PRINTING RECORDS

3D printing Records & Findings

Name	Date	Part name		Part mass	Material cost	Part cost		Printer
Asja	02.07.2020	PLA connector v1		4gr	33/0.75kg	1.76		Ultimaker 2+

Image of slice

Image of Part



Final Part

Configuration	
Material	PLA
Duration	1h 7'
Mass	4gr
Cost/Kg	33/0.75kg
Part cost Eur	1.76
Layer height	Default
Initial layer height	Default
Line width	0.35
Infill	100%
Print Speed	60mm/s
Number of slower layers	/
Fan Speed	Default
Initial Fan Speed	
Travel Speed	
Z Hop Speed	
Enable Retraction	
Avoid printed parts when travelling	
Z Hop When Retracted	
Z Hop only over printed parts	
Brim	Y
Support	

What was learnt?

Upper part experiences material warping due to lack of support

The brim removes the fillet added to the last round rib, post processing might be necessary; The ribs are very sharp, could hurt the user

What can be used in future?

Like in original part, the first rib should be under an angle where it starts to prevent warping of material; Test with adjusted settings, this print used generic settings from cura just to test it out

Dimensional Accuracy (mm)

		From drw	Part
W (top/bottom)	B1	5	
	B2	5/7	
	B3	6/8	
	B4	7/9	
	B5	8/10	
	B6	9/11	
	B7	10/12	
H		58.19	
ID (top/bottom)		4/10	

Special techniques

Performance

Due to material stifness, it is harder to remove it from the tube, however the fit is tight

3D printing Records & Findings

Name	Date	Part name		Part mass	Material cost	Part cost		Printer
Asja	27.08.2020	PLA connector v1		4gr	33/0.75kg	1.76		Ender 3 Pro

Image of slice

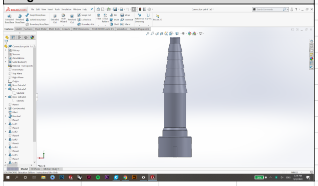


Image of Part

Final Part

Configuration	
Material	PLA
Duration	1h 7'
Mass	4gr
Cost/Kg	33/0.75kg
Part cost Eur	1.76
Layer height	Default
Initial layer height	Default
Line width	0.35
Infill	100%
Print Speed	60mm/s
Number of slower layers	/
Fan Speed	Default
Initial Fan Speed	
Travel Speed	
Z Hop Speed	
Enable Retraction	
Avoid printed parts when travelling	
Z Hop When Retracted	
Z Hop only over printed parts	
Brim	Y
Support	N
Retraction	
Retraction distance	5mm
Retraction speed	45
Retraction Retract Speed	45
Retraction Prime Speed	45
Retraction Extra Prime Amount	0
Retraction Minimum Travel	1.5
Maximum Retraction Count	100

What was learnt?

The walls of the outer cilinder is too thin and could break easily;
A very clear line is visible where the nozzle starts the layer
The barb parting lines are not printed straight
The barb profile is not strong enough
Internal cavity resulted in warping because of lack of support

What can be used in future?

Increase wall thickness, Improve internal geometry; Add fillets to smoothen transitions, improve internal geometry; Try printing the parts at a larger distance to see how it influences the outer surface

Dimensional Accuracy (mm)

		From drw	Part
W (top/bottom)	B1	5	
	B2	5/7	
	B3	6/8	
	B4	7/9	
	B5	8/10	
	B6	9/11	
	B7	10/12	
H		58.19	
ID (top/bottom)		4/10	

Special techniques

Performance

The connector is very easily disconnected from the tube (not good), needs a stronger barb profile with sharper edges; Internal detachment of layers happened

3D printing Records & Findings

Name	Date	Part name	Part mass	Material cost	Part cost	Printer
Asja	04.09.2020	Connection point 1. V5	9g/ 3gr pp			Ultimaker 2+

Image of slice

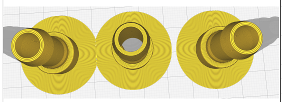


Image of Part

Final Part

Configuration

Material	PLA
Mass	9gr
Cost/Kg	39.5
Part cost Eur	
Layer height	0.1
Initial layer height	0.2
Line width	0.25
	0.3
	0.35
Infill	120%
Print Speed	50 mm/s
Travel Speed	120 mm/s
Z Hop Speed	10 mm/s
Enable Retraction	Y
Avoid printed parts when travelling	Y
Z Hop When Retracted	Y
Z Hop only over printed parts	Y
Brim	Y
Support	No

What was learnt?

The oozing is extreme, even with added retraction settings

There is a line on the side of the print which can be a result of the filament, a mechanical issue or a temperature control problem

Special techniques

Three separate versions of the part are printed, each with different line width to see how it influences the strength of the part. The widths are 0.25, 0.3 and 0.35

Material retraction was added to see how it influences printing between parts

The different widths are also done to test how it influences layer adhesion

What can be used in future?

The travel speed can be increased to reduce the oozing

The parts can be flipped upside down to reduce the overhangs caused by the barbs

Remove the angled part at the top of the connector

Performance

The barbs are "leaking" down a bit due to gravity

Support was generated accidentaly, which could interfere with the performance of the print

The parts were a disaster! The oozing between them is extreme and there is a clear line of where the printer was stopping the perimeters.

The last "barb" is supposed to be angled at the top, however in none of the prints this was printed properly. This is because from the first layer the printer is asked to print a very small overhang that is supposed to further hold the whole part thtoughout the printing. Also coud be the reason for the shitty top layers

Dimensional Accuracy (mm)

		From drw	P1	P2	P3
W (top/bottom)	B1	5	5	/	4.9
	B2	5/7	5/6.5	/	4.95/6.5
	B3	6/8	6/~7.4	/	6.7/7.5
	B4	7/9	~6.8/8.5	/	7/8.6
	B5	8/10	~8.1/9.5	7.8/9.5	8.1/9.4
	B6	9/11	9/10.5	8.8/10.5	9/10.5
	B7	10/12	10/11.5	10.1/11.3	10/11.1
H		58.19	58	45.2	58.1
ID (top/bottom)		3.42/10	~3.8/10	x/9.9	~3.8/10

*Dimensions were measured with analog caliper; Digital in future for accuracy

3D printing Records & Findings

Name	Date	Part name	Part mass	Material cost	Part cost	Printer
Asja	04.09.2020	Connection point 1. V5	9g/ 3gr pp			Ultimaker 2+

Image of slice

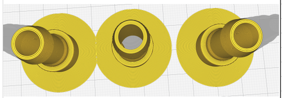


Image of Part

Final Part

Configuration	
Material	PLA
Duration	3h
Mass	9gr
Cost/Kg	39.5
Part cost Eur	
Layer height	0.1
Initial layer height	0.2
Line width	0.25
	0.3
	0.35
Infill	120%
Print Speed	50 mm/s
Travel Speed	120 mm/s
Z Hop Speed	10 mm/s
Enable Retraction	Y
Avoid printed parts when travelling	Y
Z Hop When Retracted	Y
Z Hop only over printed parts	Y
Brim	Y
Support	No

What was learnt?

This was the second print where the oozing was drastically improved and almost inexistent. The only difference was the printer that the part was printed on. Proper servicing is important

Oozing also occurs on the inside of the parts

The barbs are "leaking" down a bit due to gravity

There is a line on the side of the print which can be a result of the filament, a mechanical issue or a temperature control problem

Special techniques

Three separate versions of the part are printed, each with different line width to see how it influences the strength of the part. The widths are 0.25, 0.3 and 0.35

Material retraction was added to see how it influences the oozing when printing between parts

The different widths are also done to test how it influences layer adhesion

What can be used in future?

The travel speed can be increased to reduce the oozing

The part geometry can be modified to reduce the number of bridges that need to be printed

The parts can be flipped upside down to reduce the overhangs caused by the barbs

Manually leveling the build plate can lead to a better print

Performance

The oozing is extreme, even with added retraction settings

Support was generated accidentaly, which could interfere with the performance of the print

The last "barb" is supposed to be angled at the top, however in none of the prints this was printed properly, which also coud be the reason for the shitty top layers

Dimensional Accuracy (mm)

		From drw	P1 (0.25)	P2 (0.3)	P3 (0.3)
W (top/bottom)	B1	5	4.83	4.98	4.82
	B2	5/7	4.98/6.60	5.01/6.65	4.90/6.65
	B3	6/8	6.08/7.64	6.38/7.69	6.15/7.59
	B4	7/9	7.14/8.72	7.20/8.76	7.17/8.66
	B5	8/10	8.24/9.64	8.33/9.74	8.23/9.62
	B6	9/11	9.19/10.7	9.29/10.71	9.29/10.74
	B7	10/12	10.33/11.64	10.32/11.56	10.28/11.63
H		58.19	57.84	57.91	57.94
ID (top/bottom)		3.42/10	3.66/9.71	3.69/9.64	3.59/9.65

3D printing Records & Findings

Name	Date	Part name	Part mass	Material cost	Part cost	Printer
Asja	07.09.2020	Connection point 1. V6				Ultimaker 2+

Image of slice

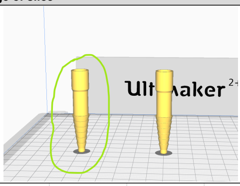
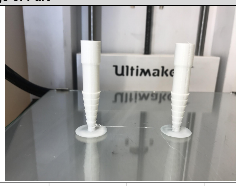


Image of Part



Final Part

Configuration

Material	PLA
Duration	1H 37'
Mass	4gr
Cost/Kg	
Part cost Eur	
Layer height	0.1
Initial layer height	0.2
Line width	0.25
Infill	100%
Print Speed	50
Travel Speed	120
Z Hop Speed	10mm/s
Enable Retraction	Y
Avoid printed parts when travelling	
Z Hop When Retracted	
Z Hop only over printed parts	
Brim	Y
Support	N

What was learnt?

Flipping the parts over drastically improves the quality of the barb edges and the barbs are not "leaking" anymore

Special techniques

The parts were flipped 180deg in order to relieve the 90deg overhangs of the barbs

The part geometry was modified by removing the outer grasping cilinder of the connector. This was done because it is very hard to print that segment without any required support and the distance between the two cilinders is too small, which can lead to the part not fitting at all on the pot

What can be used in future?

A higher initial layer can improve the dimensional quality as the part goes up

Initial flow settings can improve the quality of the first layers

Performance

Gaps and blobs occured in the bottom part of the print, especially in the transition point between the first and second barb. Afterwards the print quality increased and the holes and zits disappeared and the print ran smoothly

The quality of the barbs drastically improved after changing the direction of the prints

A line is still visible on the side of the print. This line causes an uneven barb edge which if shapr can damage a tube. It even adds small zits on the barb edge

Layer adhesion seems good

Dimensional accuracy is drastically improved compared to previous models. However flipping the print orientation probably adds weight to the initial layers of the barbs, which make them "fall" to the side, hence they end up being bigger.

Dimensional Accuracy (mm)

		From drw	P1 (0.25)
W (top/bottom)	B1	5	**5.1**
	B2	5/7	**5.15/6.76**
	B3	6/8	**6.23/7.94**
	B4	7/9	**7.35/8.79**
	B5	8/10	**8.27/9.91**
	B6	9/11	**9.27/10.87**
	B7	10/12	**10.26/11.89**
H		58.19	**57.95**
ID (top/bottom)		3.42/10	**3.12/9.79**

3D printing Records & Findings

Name	Date	Part name	Part mass	Material cost	Part cost	Printer
Asja	07.09.2020	Connection point 1. V6				Ultimaker 2+

Image of slice

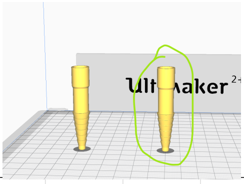


Image of Part

Final Part

Configuration

Material	PLA
Duration	1H 37'
Mass	4gr
Cost/Kg	
Part cost Eur	
Layer height	0.1
Initial layer height	0.2
Line width	0.25
Infill	100%
Print Speed	50
Travel Speed	120
Z Hop Speed	10mm/s
Enable Retraction	Y
Avoid printed parts when travelling	
Z Hop When Retracted	
Z Hop only over printed parts	
Brim	Y
Support	N

What was learnt?

Flipping the parts over drastically improves the quality of the barb edges and the barbs are not "leaking" anymore

The dimensional accuracy is drastically improved when the print orientation is flipped because of a more even weight distribution and a smooth incremental layer addition

What can be used in future?

A higher initial layer can improve the dimensional quality as the part goes up

Initial flow settings can improve the quality of the first layers

On the first barb the top is inward angled, which requires the initial layer of the print to be done on a very thin surface. Try removing that part for an even internal diameter and to offer a larger initial surface

Dimensional Accuracy (mm)

		From drw	P1 (0.25)
W (top/bottom)	B1	5	**4.85**
	B2	5/7	**4.97/6.78**
	B3	6/8	**6.19/7.89**
	B4	7/9	**7.21/7.79**
	B5	8/10	**8.27/9.89**
	B6	9/11	**9.22/10.88**
	B7	10/12	**10.25/11.90**
H		58.19	**57.95**
ID (top/bottom)		4/10	**3.26/9.75**

Special techniques

The parts were flipped 180deg in order to relieve the 90deg overhangs of the barbs

The part geometry was modified by removing the outer grasping cilinder of the connector. This was done because it is very hard to print that segment without any required support and the distance between the two cilinders is too small, which can lead to the part not fitting at all on the pot

The difference between V7 and V6 is only in the added filets between the barbs. This was done because in the slicer these points seemed very fragile, like the layer adhesion was not good enough since in the model the line between them was very sharp and distinct. Visually at least, no difference can be seen.

Performance

Gaps and blobs occured in the bottom part of the print, especially in the transition point between the first and second barb. Afterwards the print quality increased and the holes and zits disappeared and the print ran smoothly

The quality of the barbs drastically improved after changing the direction of the prints

A line is still visible on the side of the print. This line causes an uneven barb edge which if shapr can damage a tube. It even adds small zits on the barb edge

Layer adhesion seems good

3D printing Records & Findings

Name	Date	Part name		Part mass	Material cost	Part cost		Printer		
Asja	07.09.2020	Connection point 1. V6						Ultimaker 2+		

Image of slice

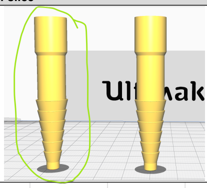


Image of Part

Final Part

Configuration

Material	PLA
Duration	1h 21m
Mass	2gr
Cost/Kg	
Part cost Eur	
Layer height	0.1
Initial layer height	0.2
Line width	0.25
Infill	100%
Print Speed	60
Travel Speed	150
Z Hop Speed	
Enable Retraction	Y
Retraction Extra Prime Amount	0
Retraction Minimum Travel	1.5
Maximum Retraction Count	100
Avoid printed parts when travelling	Y
Z Hop When Retracted	N
Z Hop only over printed parts	
Fan Speed	100
Initial Fan Speed	70
Brim	Y
Support	N

What was learnt?

What can be used in future?

Dimensional Accuracy

L
W
H
ID

Special techniques

Due to the extrusion problems occured in the prime layers of the last iteration, the initial fan speed was increased from 0 to 70 to see whether cooling at the start will contribute to a better and more even print

The retraction minimum travel was increased from 0.5 to 1.5 as it showed good results in a precious print

The printing speed was increased from 50 to 60 to test how it might affect the print

The travel speed was increased to give less time for oozing

The initial travel speed (first layer only) was reduced to 70% because in the first printing attempt one of the parts separated and fell off

In the part geometry a fillet was added at the top layer to make it smoother for tube insertion

Performance

The prints start printing very well, but oozing occurs continuously.

The prints fail as soon as the printer moves from the barbs towards the shaft of the connector.

The filet added on the last barb does not print well because it is too small and the brim always leaves some leftover material

3D printing Records & Findings

Name	Date	Part name		Part mass	Material cost	Part cost		Printer		
Asja	07.09.2020	Connection point 1. V6						Ultimaker 2+		

Image of slice

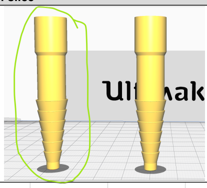


Image of Part

Final Part

Configuration

Material	PLA
Duration	1h 21m
Mass	2gr
Cost/Kg	
Part cost Eur	
Layer height	0.1
Initial layer height	0.2
Line width	0.25
Infill	100%
Print Speed	60
Travel Speed	150
Z Hop Speed	
Enable Retraction	Y
Retraction Extra Prime Amount	0
Retraction Minimum Travel	1.5
Maximum Retraction Count	100
Avoid printed parts when travelling	Y
Z Hop When Retracted	N
Z Hop only over printed parts	
Fan Speed	100
Initial Fan Speed	70
Brim	Y
Support	N

What was learnt?

Something went really wrong here. The prints were tried on 3 or 4 different printers and failed on every one at a different point in time during the prints. It all stated when the print and travel speeds were increased or changed in any way. Most probable reason is the added **initial fan speed,** which I assumed would result with faster drying that would contribute to a more stable bottom of the print. this proved to be extremely **WRONG!** The result was the exact opposide with: **UNEVEN EXTRUSION, BLOBS AND ZITS, HOLES, OOZING, PRINT MISPLACEMENT &** (possibly unrelated) **NOZZLE CLOGGING OF 2 PRINTERS** (oops ...)

What can be used in future?

Both the print speed, travel speed and initial fan could have been causes of the failures (print speed for fact). The other two factors should be tested independently to see how the print performance reacts.

Do not remove the fillet or chamfer immediately, but try first and print with fixed parameters.

Do not exclude printing with a brim yet, try again with raft with fixed parameters, but raft takes a lot more time and so far hasn't been useful at all. the brim however might lead to a better layer adhesion and hold the layer from the sides.

Dimensional Accuracy

L
W
H
ID

Special techniques

Due to the extrusion problems that occured in the prime layers of the last iteration, the initial fan speed was increased from 0 to 70 to see whether cooling at the start will contribute to a better and more even print

The retraction minimum travel was increased from 0.5 to 1.5 as it showed good results in a previous print

The printing speed was increased from 50 to 60 to test how it might affect the print

The travel speed was increased to give less time for oozing

The initial travel speed (first layer only) was reduced to 70% because in the first printing attempt one of the parts separated and fell off

In the part geometry a fillet was added at the top layer to make it smoother for tube insertion

Performance

The print failed 3 times, each time at a different progress level.

Either all printers suck, or te chamfer and fillet need to be removed instantly

The dimensions though are the most accurate ones so far

3D printing Records & Findings

Name	Date	Part name	Part mass	Material cost	Part cost	Printer
Asja	07.09.2020	Connection point 1. V6				Ultimaker 2+

Image of slice

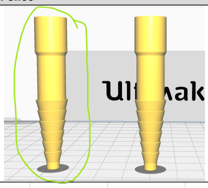


Image of Part

Final Part

Configuration

Material	PLA
Duration	1h 21m
Mass	2gr
Cost/Kg	
Part cost Eur	
Layer height	0.1
Initial layer height	0.2
Line width	0.25
Infill	100%
Print Speed	50
Travel Speed	130
Z Hop Speed	5
Enable Retraction	Y
Retraction Extra Prime Amount	0
Retraction Minimum Travel	1.5
Maximum Retraction Count	100
Avoid printed parts when travelling	Y
Z Hop When Retracted	N
Z Hop only over printed parts	
Fan Speed	100
Initial Fan Spee	70
Brim	Y
Support	N

What was learnt?

If the initial layer surface is too thin compared to the upcoming layers, the print will fail most probably (:

What can be used in future?

The brim shoul be replaced with a raft because it is thicker and will provide better support for the part as the initial layers are extremely thin

Manual leveling of the build plate

Dimensional Accuracy

L

W

H

ID

Special techniques

Due to the extrusion problems that occured in the prime layers of the last iteration, the initial fan speed was increased from 0 to 70 to see whether cooling at the start will contribute to a better and more even print

The retraction minimum travel was increased from 0.5 to 1.5 as it showed good results in a precious print

The printing speed was increased from 50 to 60 to test how it might affect the print

The travel speed was increased to give less time for oozing

The initial travel speed (first layer only) was reduced to 70% because in the first printing attempt one of the parts separated and fell off

In the part geometry a fillet was added at the top layer to make it smoother for tube insertion

Performance

The print failed 3 times, each time at a different progress level.

Either all printers suck, or te chamfer and fillet need to be removed instantly

The dimensions though are the most accurate ones so far

3D printing Records & Findings

Name	Date	Part name	Part mass	Material cost	Part cost	Printer
Asja	07.09.2020	Connection point 1. V6				Ultimaker 2+

Image of slice

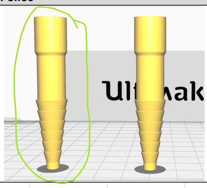


Image of Part

Final Part

Configuration	
Material	PLA
Duration	1h 21m
Mass	2gr
Cost/Kg	
Part cost Eur	
Layer height	0.1
Initial layer height	0.5
Line width	0.25
Infill	100%
Print Speed	50
Travel Speed	130
Z Hop Speed	5
Enable Retraction	Y
Retraction Extra Prime Amount	0
Retraction Minimum Travel	1.5
Maximum Retraction Count	100
Avoid printed parts when travelling	Y
Z Hop When Retracted	N
Z Hop only over printed parts	
Fan Speed	100
Initial Fan Speed	70
Brim	Y
Support	N

What was learnt?

What can be used in future?

REMOVE FILLETS, CHAMFERS, LITERALLY ANYTHING ON THE BOTTOM

Dimensional Accuracy

L
W
H
ID

Special techniques

In this FOURTH (maybe even 5th or 6th attempt), the initial layer height was increased from 0.2mm to 0.5mm HOPING for a better buildplate adhesion

During printing the speed of the print was decreased from 100% to 70% after which the quality of the print increased dramatically

Performance

The initial layers are disasterous, most probably due to the super high printing speed

3D printing Records & Findings

Name	Date	Part name	Part mass	Material cost	Part cost	Printer
Asja	07.09.2020	Connection point 1. V6				Ultimaker 2+

Image of slice

Image of Part

Final Part

Configuration

Material	PLA
Duration	18min
Mass	2gr
Cost/Kg	
Part cost Eur	
Layer height	0.1
Initial layer height	0.2
Line width	0.25
Infill	100%
Print Speed	50
Travel Speed	130
Z Hop Speed	5
Enable Retraction	Y
Avoid printed parts when travelling	Y
Z Hop When Retracted	y
Z Hop only over printed parts	
Build Plate Adhesion	Brim
Support	/
EXPERIMENTAL	
Use Adaptive Layers	Y
Adaptive Layers Maximum Variation	0.2
Adaptive Layers Variation Step Size	0.01
Overhanging Wall Angle	90
Overhang Wall Speed	100
Enable Bridge Settings	y

What was learnt?

Something went terribly wrong the moment I started to play with the speed. It is either just the printing speed or combination of printing speed and fan speed

What can be used in future?

In cases where a single part is printed, the print speed should be reduced as there is no gap in between for the layers to dry properly.

Dimensional Accuracy

L
W
H
ID

Special techniques

For the first time only a single piece was printed instead of two as usual.

The experimental settings on Cura were tested to see whether overhangs would be printed better.

Performance

Another disaster

The layers are inconsistent and the adhesion is terrible

3D printing Records & Findings

Name	Date	Part name		Part mass	Material cost	Part cost		Printer
Asja	07.09.2020	ABS prints v.1						Original Prusa Mini

Image of slice

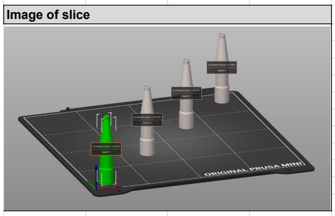


Image of Part

Final Part

Configuration	
Material	ABS
Duration	3h 39'
Mass	7.38gr
Cost/Kg	
Part cost Eur	0.21
Layer height	0.1 mm
Initial layer height	
Line width	
Infill	100%
Print Speed	40mm/s
Number of slower layers	4
Fan Speed	15%
Initial Fan Speed	15%
Travel Speed	150mm/s
Z Hop Speed	
Enable Retraction	
Avoid printed parts when travelling	
Z Hop When Retracted	
Z Hop only over printed parts	
Brim	Y
Support	N

What was learnt?

The reduction in printing speed and fan speed has given amazing layer adhesion results

The barb edges are quite smooth because the parts were printed in orientation with the barbs facing upwards.

What can be used in future?

Printing in the opposite direction would give better results in the barb edge sharpness

Dimensional Accuracy	
L	57.91
W	
H	
ID	

Special techniques

The connectors were printed in a sequence for the first time. Although 2 prints failed, the surface quality is higher than in any parts printed before.

Performance

Appendix 14

LAYER HEIGHT TEST

Effect of Layer Height on Tensile Properties in 3D Printed Objects

Introduction

In FDM 3D printing models are built by depositing layers of molten filament on top of each other, which due to their molten state fuse with each other to form an adhered model. Deposited layers however are not flat, but rather rounded at the edges (Fig. 1), which leaves small gaps on the surface of the product, making them unsmooth and prone to porosity and dirt entering in the gaps.

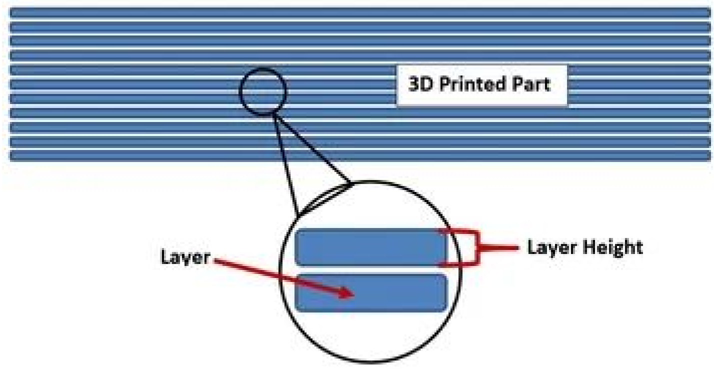


Figure 1: Layer deposition in FDM 3D printing

When opting for excellent layer adhesion and surface smoothness for parts printed with a 0.4mm nozzle, layer heights of 0.1mm and 0.05mm are the recommended setting [1]. Parts printed with a 0.05mm layer adhesion are presumed to have a better and smoother surface finish than those printed with 0.1mm layer height (Fig. 2).

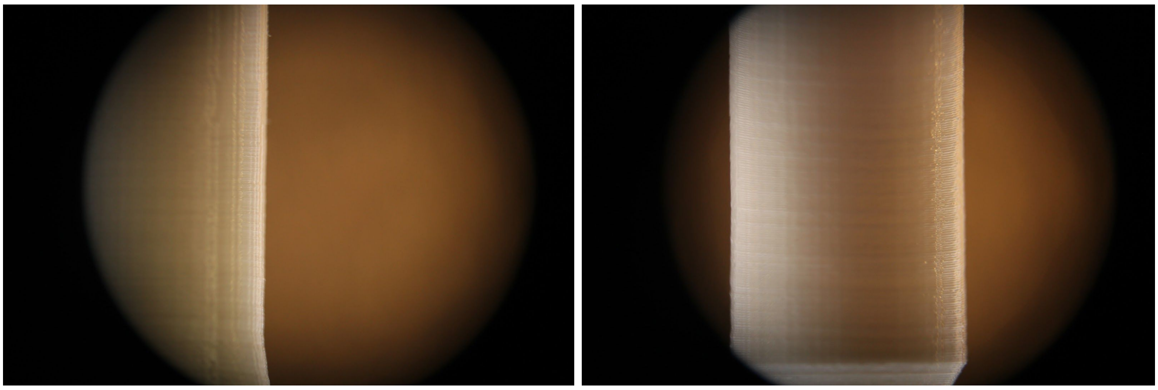


Figure 2: Left: 0.05mm layer height; Right: 0.1mm layer height

Connectors were printed with both layer heights and the findings were:

- Printing with 0.05mm layer height takes about 3x longer than with 0.1mm layer height
- Upon surface inspection under a microscope no evident difference can be seen in the layer smoothness
- The printability of the parts was slightly reduced, with filament “leaks” visible on the outer surface of the connectors (Fig. 3)

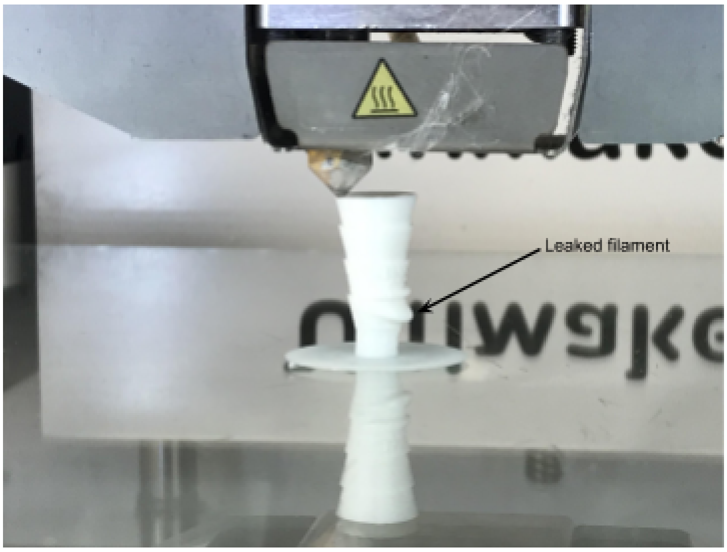


Figure 3: Connector printed with 0.05mm layer height

However, because of the end use of the parts there could still be a benefit of printing them with 0.05 layer height, if for example it will result with better tensile properties and with the right slicer settings it might produce better parts, despite the aforementioned drawbacks of extra printing time and reduced printability, which could in return increase their durability and lifespan.
Therefore, the goal of this test is to determine whether printing with 0.05mm layer thickness would exhibit better tensile properties for the connectors.

Method

Sample preparation

The testing was performed on tensile dog bone samples, modeled according to the ASTM D638 Standard (Appendix, Fig. 1). The samples were printed in white PLA from Ultimaker on an Ultimaker 2+ printer. The gcodes were prepared on the Ultimaker Cura 4.7 slicer (Appendix, Table 1). The samples were all printed with the same slicer settings as modifications in the slicer settings add additional variables to the end results.

Tensile test

The tensile testing was performed using a Zwick & Roell 10 kN stage with no pretension applied. The samples were deformed at 5mm/min until they broke and the results were gathered on the software TestXpert II. The gage thickness in the model was constant at 3.1mm for the samples printed with 0.1mm layer height, but varied between 3.1 and 3.68 along the surface of the 0.05mm samples. The median gage width was 12.88 mm.

Result analysis

Due to the anisotropic properties of parts 3D printed in the vertical direction [x], the samples displayed insignificant elongation before break. The layers at the weakest points simply separate from each other and the samples snap.Therefore, the ultimate strength was the only property calculated. Due to the low number of samples, the results were analysed in Microsoft Excel.

Results

The tensile testing did not go as successfully as planned, due to the reduced printability of the tensile samples printed with 0.05 mm layer height. During the deformation both 0.05mm samples broke at the clamped part on the top, as compared to the 0.1mm layer height samples that broke in the narrow area, where tensile samples should break. The reason for this was the improper clamping of the samples due to their uneven gage thickness across the surface, a result of the filament “leaking”, especially at the top of the parts. The 0.05mm samples were tested again without the broken off top part. The samples printed with 0.1mm layer height showed a median ultimate tensile strength approximately 2 times higher than the samples printed with 0.05mm layer height (Table 1).

Sample	Stress at break (MPa)	Median Stress at break (MPa)
1. 0.1 PLA	28.343	**30.796**
2. 0.1 PLA	33.249	
3. 0.05 PLA	17.689	**15.969**
4. 0.05 PLA	14.249	

Table 1: Stress at break of tested samples

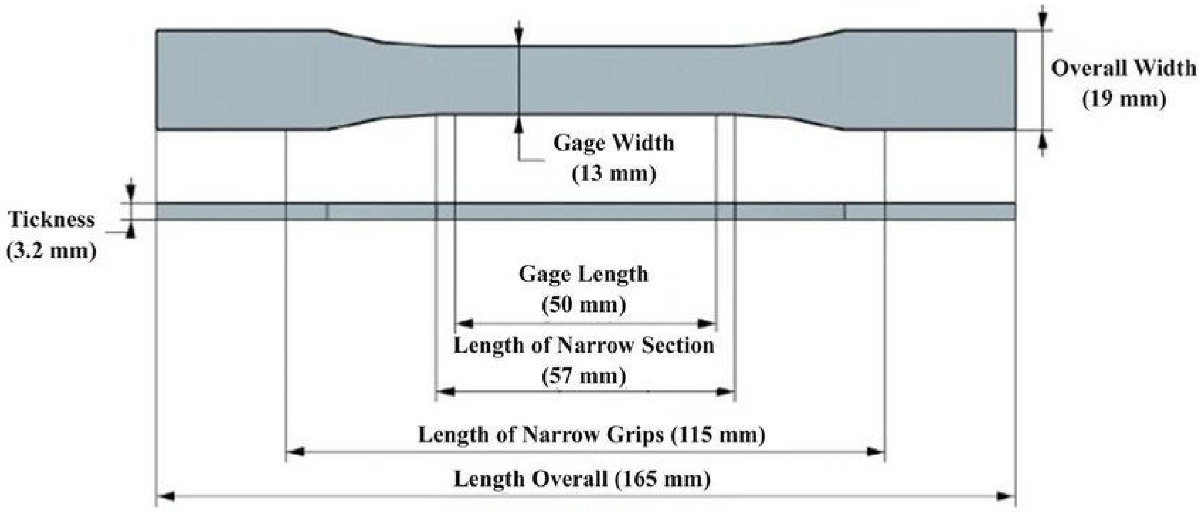
Conclusion

The test showed that samples printed with 0.1mm layer height exhibited better tensile properties than parts printed with 0.05mm layer height. Other important deciding factors in this case were the reduced print quality and the presence of leaks and uneven surface detected both in the tensile samples and the connector samples printed. Printing the connectors with 0.1 mm layer thickness results in better tensile properties, constant performance and quality, for a shorter print time and with no noticeable difference in layer adhesion.

References

[1] All3DP, 2018, 3D Printing Layer Height: How Much Does It Matter?,
https://all3dp.com/2/3d-printer-layer-height-how-much-does-it-matter/

Appendix



	Sample 0.05 mm	Sample 0.1 mm
Layer height	0.05 mm	0.1mm
Print temperature	220℃	220℃
Print bed temperature	60℃	60℃
Print speed	40mm/s	40mm/s
Fan speed	15%	15%
Brim	Yes	Yes
Printing time (per sample)	8h 48m	4h 26m
No. of samples	2	2

Appendix 15

HUMIDITY EXPOSURE TEST

Influence of Exposure to Humidity on tubing connectors 3D printed in PETG and ABS

Introduction

In the time between their manufacturing and their use, connectors might be left in storage exposed to the elements. Sierra Leone is a country with a Relative Humidity (RH) of about 80% throughout the entire year [1], an RH that the connectors would be exposed to for a continuous period of time. Some 3D printing filaments are hygroscopic, meaning that they absorb moisture from the environment, which in result could lead to dimensional expansion of the parts/filament, filament degradation and increased fragility [2].
Therefore, it is important to inspect whether prolonged exposure to humidity would affect the connectors printed with PETG filament and ABS filament. The goal of this test is to understand whether prolonged exposure to high humidity affects the 3D parts, by exposing them to humidity and measuring the changes in weight and dimensions post exposure.

Hypothesis

The PETG connector will absorb less humidity than the ABS connector due to PETG's better water resistance properties.

Method

Sample preparation:

For this test a total of four samples were 3D printed (Fig. 1). Two of the test samples were 3D printed with ABS filament and two with PETG filament. The ABS connectors were printed with white ABS on a Prusa Original Mini. The PETG connectors were printed with grey PETG filament from Prusa on a Prusa i3 MK3.

The slicer settings applied to the prints were prepared in Prusa's Slicr (Table 1). The applied settings were optimized for water-tight layer adhesion.

	ABS sampes	PETG samples
Layer height	0.1mm	0.1mm
Print temperature	255℃	240℃
Print bed temperature	100℃	60℃
Print speed	40mm/s	40mm/s
Brim	Yes	Yes
No. of samples	2	2

Table 1: Slicer settings for 3D printing connectors

The weight of the samples was recorded on a Kern ABT 320-4M (Table 2) before they were placed in the humidity chamber. The height, weight and top/bottom wall thickness were measured with a digital caliper before the test to detect dimensional changes (Table 3).
The connectors' surface was also examined under a microscope for comparison (Fig. 2).

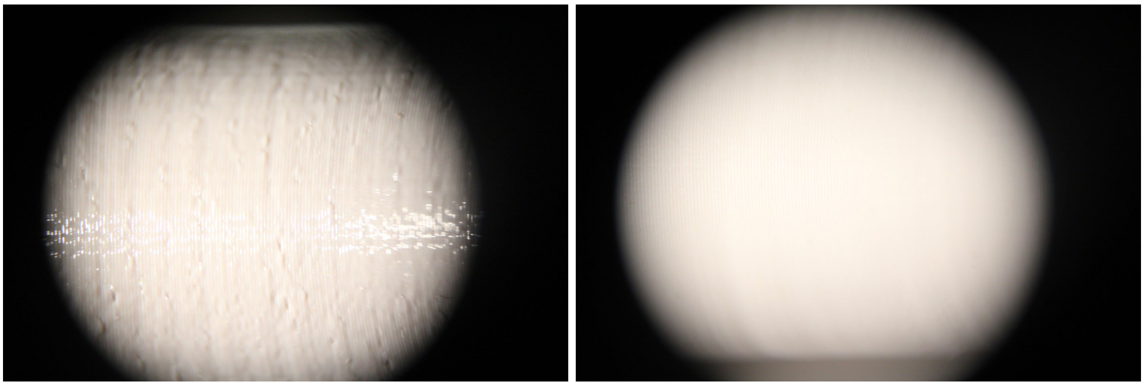


Fig. 2: Left: PETG connector under microscope before humidity exposure; Right: ABS connector under microscope before humidity exposure

Humidity exposure:

Two samples, one in PETG and one inABS were placed in a ESPEC AL 01 humidity chamber at 32℃ and 88% RH for fourteen consecutive days. After 15 days in the humidity chamber, the weight and dimensions of both the PETG and ABS connector were measured again. The other two printed connectors were left as control samples to inspect potential changes in the surface finish.

Results

The weighing (Table 2) and measuring (Table 3) showed no changes in both the PETG and the ABS connectors. Their surface finish also remained the same pre and post exposure (Fig. 3).

Date	**13.10 (pre-test)**	**26.10 (post-test)**
PETG connector	2.046 gr	2.0469 gr
ABS connector	1.749 gr	1.7487 gr

Table 2: Pre and post testing weight of connectors

Date	**13.10**		**26.10**	
Material	PETG	ABS	PETG	ABS
Height	58.03mm	57.94mm	58.03mm	57.94mm
Width top/bottom	5.4/11.82mm	4.82/11.74mm	5.4/11.82mm	4.82/11.74mm
Wall thickness top/bottom	1.14/0.97mm	1.02/1.18mm	1.14/0.97mm	1.02/1.18mm

Table 3: Dimensions of connectors pre and post testing

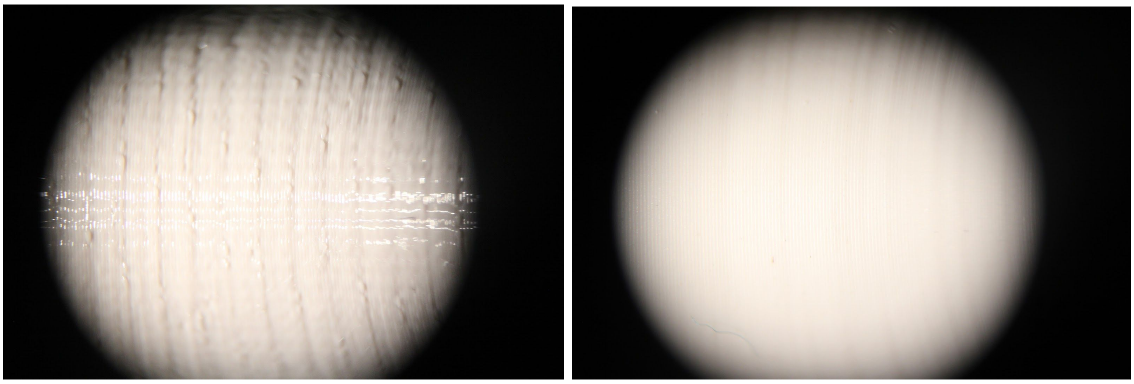


Figure 3: Left: PETG connector under microscope after humidity exposure; Right: ABS connector under microscope after humidity exposure

Conclusion

Connectors printed with PETG and ABS will not be affected by prolonged humidity exposure in Sierra Leone. Both materials are a safe choice regarding water tightness and their hygroscopic properties.

References

[1] https://www.worlddata.info/africa/sierra-leone/climate.php
[2]https://blog.gotopac.com/2018/03/01/how-3d-printer-filament-storage-cabinets-instantly-improve-3d-print-part-quality/

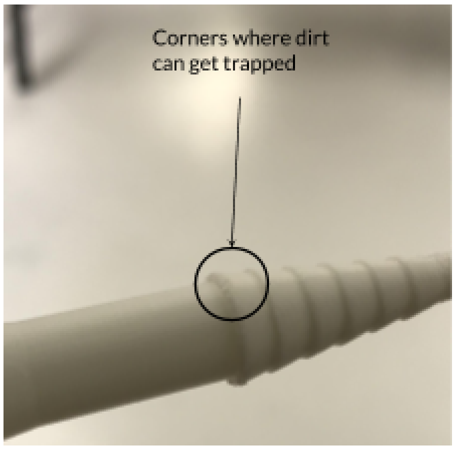
Appendix 16

INFECTION TEST

ATS Infection Test Protocol

To test the cleaning of 3D printed components after exposure to Artificial Test Soil (ATS)

The purpose of the test is to assess the ease of cleaning of FDM 3D printed suction tubing connectors. The test is meant to show whether infectants can be thoroughly removed from the part and whether they get trapped between layers of the deposed material or in the corners of the part. This test is an addition to the previously discussed chlorine test. The tests will be performed at the end of the chlorine testing.



Equipment:

- 3D printed connectors in ABS and PETG
- Artificial test soil (ATS) made of egg white and red food coloring
- Chlorine bath (explanation in previously sent protocol)
- Polypropylene container
- Paper towels for drying the parts
- Microscope
- Weighing scale
- UV Lamp
- Fresh tap water for rinsing

Protective Equipment:

- Splash resistant safety goggles with a face shield
- Protective coat
  - Complete suit protecting against chemicals, The type of protective equipment must be selected according to the concentration and amount of the dangerous substance at the specific workplace.
- Protective gloves
  - Full contact Material: Nitrile rubber Minimum layer thickness: 0,11 mm
- Fume Hood

Test:

1. Weight part and note down the weight pre-infection
2. In a plastic container whisk one egg white with a few drops of red food coloring. Egg white is chosen because it contains proteins and carbohydrates, two main organic contaminants remaining on used surgical tools. The red dye is added to replicate the color of blood and for better visibility of the infectant.
3. With a brush or syringe apply the egg mixture on the printed parts, especially around edges, corners and the inside opening.
4. Lay parts of a paper towel and let infectant dry for 2 hours (Worst Case Scenario)
5. Weight infected parts again and note down post-infection weight
6. Soak infected parts in chlorine bath and let sit for 30 minutes (WHO protocol)
7. Remove parts from mixture, rinse in fresh water and let dry
8. Inspect parts under microscope and UV light for residual contaminant
9. Weight parts post-cleaning

Disposal

When the test is done, the chemical mixture will be stored in a container marked with the name of the chemical. The chemical mixture will be left on the bottom shelf at the chemical cabinet at the Lab and the staff will be informed so they can organize the disposal.

Influence of Connector Embodiment On the Cleaning of Post-Surgical Contamination

Introduction

During their use in the suction pump system, the 3D printed tubing connectors are constantly exposed to biological fluids either passing through them or accidentally contacting them on the outside surface.

The connectors are hollow on the inside where the fluids pass and residual contamination could easily remain present and unnoticed post cleaning (Fig. 1a). The embodiment of the connectors also involves the presence of seven barbs on the outside surface, with small edges between them. Upon infection, the infectious fluid could dry out and leave residue stuck between the barb edges (Fig. 1b).

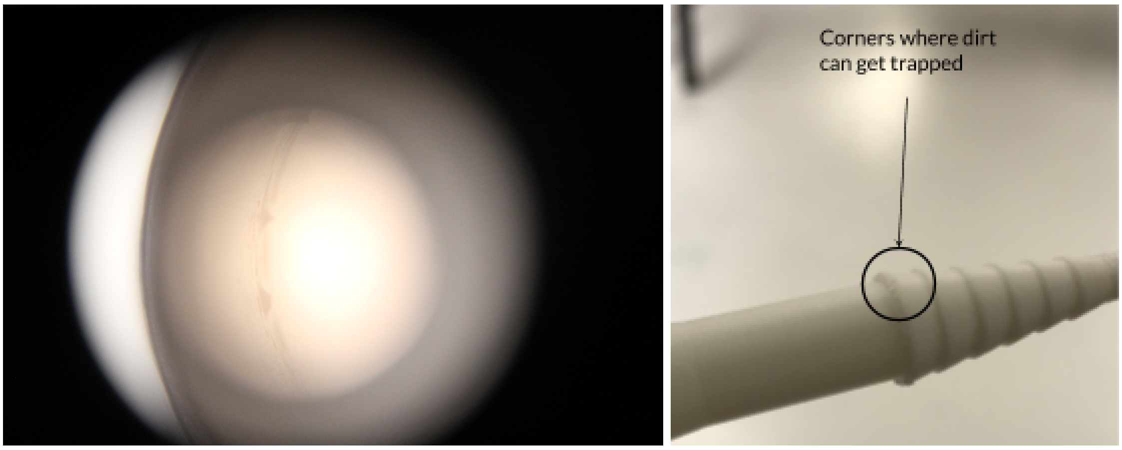


Figure 1: A (left) Internal surface where infection can occur; B (right) Outer surface where contamination can occur

In FDM 3D printing layers are deposed on top of each other. The edges of each layer are round, leaving micro gaps between the edges of each layer (Fig. 2) where contamination can enter and remain there even after cleaning.

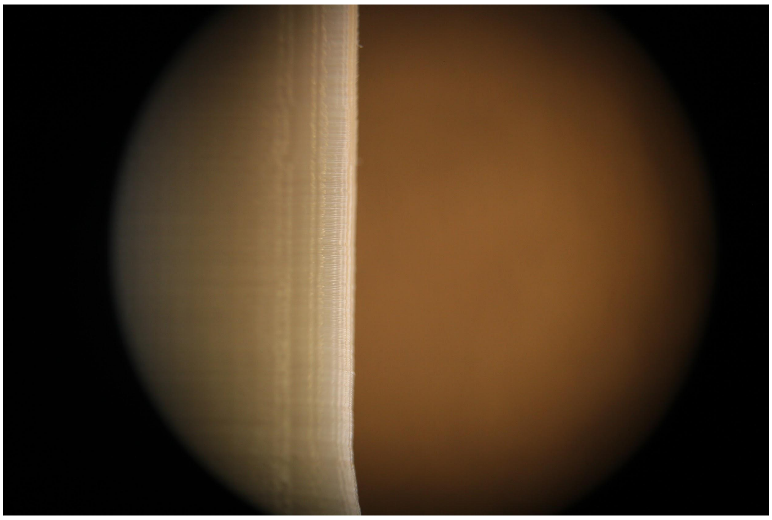


Figure 2: Connector layer structure under microscope

The goal of this test is to inspect whether the embodiment of the connectors and the production material allow for thorough cleaning with the standard cleaning method upon infection.

Hypothesis

Residual contamination will remain between the print layers and on the inside of the connectors and between the barb edges.

Method

Sample preparation:

For this test a total of four samples were 3D printed. Two of the test samples were 3D printed with ABS filament and two with PETG filament (Fig. 3). The ABS connectors were printed with white ABS on a Prusa Original Mini. The PETG connectors were printed with orange PETG filament from Prusa on a Prusa i3 MK3.

Figure 3: Left: White ABS connector; Right: Orange PETG connector;

The slicer settings applied to the prints were prepared in Prusa's Slicr (Table 1).

	ABS sampes	PETG samples
Layer height	0.1mm	0.1mm
Print temperature	255℃	240 ℃
Print bed temperature	100℃	60 ℃
Print speed	40mm/s	40mm/s
Brim	Yes	Yes
No. of samples	2	2

Table 1: Slicer settings for 3D printing connectors

The weight of the connectors was recorded prior to infection on a Kern ABT 320-4M (Table 3).

Infection procedure

Figure 4: The connectors soaked in ATS

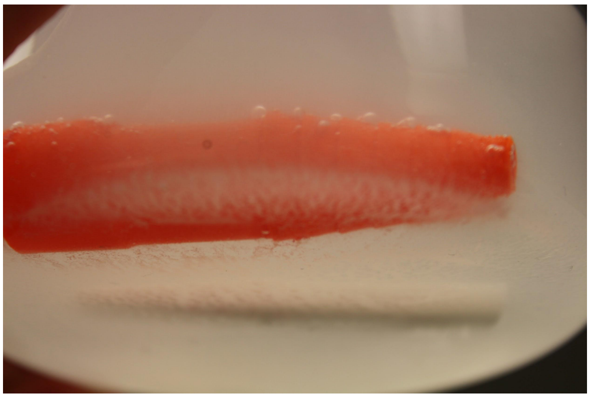
The connectors were infected with Artificial Test Soil (ATS). Because medical grade ATS is hard to obtain, the ATS used in this test was made out of egg white with red food coloring. Egg white was chosen as a substitute due to the quantity of protein and carbohydrates present in it, which are two of the main ingredients found in blood and in the residue found on surgical instruments after use. The food colouring was added to replicate the red colour of blood and to make the staining more visible.

Two respective samples, one in ABS and one in PETG were soaked and coated in the egg mixture for about 5 minutes to make sure they are evenly coated (Fig. 4).
The contaminated connectors were left to air dry for two hours, as the "worst case scenario". When dry, the connectors were weighed again (Table 3) to determine how much weight was added as a result of the contamination.

The contaminated connectors were examined under a UV lamp where the contamination could be vividly detected (Fig. 6).

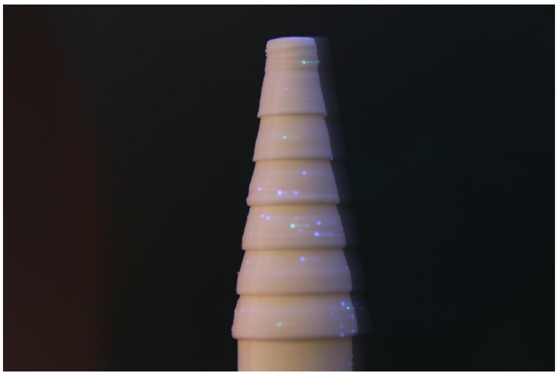
Figure 6: Connector inspected under UV light after contamination

Cleaning



Following the standard cleaning method for surgical instruments at Masanga Hospital, the contaminated connectors were soaked in a 0.5% Chlorine bath, in a glass container for 10 minutes as recommended by the World Health Organization (Table 2) . While the connectors were soaking in the Chlorine bath it was possible to see the contaminants detaching from the surface of the connectors and sedimenting at the bottom of the container. Post soaking the connectors were thoroughly rinsed under tap water. The rinsed connectors were then tap dried and left to air dry for additional two hours.

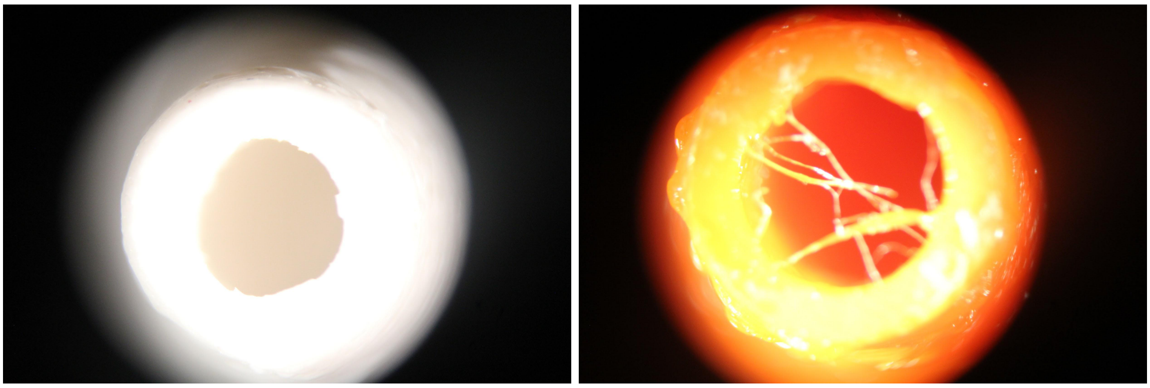
Results



The cleaned and dried connectors were inspected again under a UV Lamp where it was determined that no residual contamination was left on any of the presumed locations on the connectors.

Initially it was presumed that there was residual contamination, but it was later determined that the sparkle-looking particles were actually transferred on the connector surface through the surface of the protective gloves and were not from the ATS.

Contamination was entirely removed from the internal surface of the connectors, with no residue left behind (Fig).



The clean connectors were weighed again to determine whether there is still residual contamination that is adding to the weight of the connectors.

Weighing stage	**PETG sample**	**ABS samples**
Pre-contamination	2.0735 gr	1.7645 gr
Contaminated	2.1478 gr	1.8001 gr
Post-contamination	2.0734 gr	1.7646 gr

Table 3: Weight changes pre and post contamination

Conclusion

The standard cleaning method used at Masanga is sufficient for the removal of surgical contamination. As long as the method is properly applied every time and the connectors are thoroughly rinsed afterwards, no contamination should remain unnoticed, including in the micro surfaces between the layers. A recommendation would be to visually inspect the connectors post cleaning to ensure that all of the contamination is removed.

Appendix 17

CHEMICAL COMPATIBILITY TEST

Testing Protocol

For testing exposure of ABS and PETG to chlorine

This test is done to replicate a potential cleaning method for 3D printed parts. The goal of the test is to see how FDM 3D printed parts made of ABS and PETG react to repetitive exposure to a chlorine bath as a cleaning solution.

Equipment:

- 3D printed samples of ABS and PETG
- HTH Calcium Hypochlorite (High Test Hypochlorite) 70%
- Tap water
- Polypropylene container
- Weighing scale

Protective Equipment:

- Splash resistant safety goggles with a face shield
- Protective coat
    - Complete suit protecting against chemicals, The type of protective equipment must be selected according to the concentration and amount of the dangerous substance at the specific workplace.
- Protective gloves
    - Full contact Material: Nitrile rubber Minimum layer thickness: 0,11 mm
- Fume Hood

Preparation:

1. Weigh the test samples and document their weight
2. Inspect part surface and layer structure under microscope and document
3. Prepare chlorine solution of 1000ppm in a transparent polypropylene container
    a. Add 3g of HTH to 2l of water
    b. Stir for 10 seconds
    c. Let solution sit for 30 minutes before use

Calcium Hypochlorite is used for swimming pools, so when poured into water it just dissolves without additional chemical reactions and is therefore safe to work with, as long as it is not exposed to any other chemical. Avoid contact with any acid!

Test:

1. Soak samples in chlorine solution for 10 minutes [WHO]
2. Repeat 25 cycles of 10 min soaks
3. Weigh parts again
4. Inspect part surface and layer structure under microscope

Disposal

When the test is done, the chemical mixture will be stored in a container marked with the name of the chemical. The chemical mixture will be left on the bottom shelf at the chemical cabinet at the Lab and the staff will be informed so they can organize the disposal.

Testing Protocol

For testing exposure of ABS and PETG to Hydrochloric Acid

This test is done to replicate a potential cleaning method and exposure to gastric juices for 3D printed parts. The goal of the test is to see how FDM 3D printed parts made of ABS and PETG react to repetitive exposure to hydrochloric acid as a potential method of cleaning and exposure to gastric juices, a common occurrence in the application of the parts .

Equipment:

- 3D printed samples of ABS and PETG
- Hydrochloric Acid Solution 0.1M or Pure Hydrochloric Acid
- Tap water
- Glass or PVC container
- Weighing scale

Protective Equipment:

- Splash resistant safety goggles with a face shield
- Protective coat
- Protective gloves
- Fume Hood

Preparation:

1. Weigh the test samples and document their weight
2. Observe part surface and layer structure under microscope and document
3. Pour 0.1M Hydrochloric Acid Solution in a glass container

Test:

1. Soak samples in Hydrochloric acid solution for 10 minutes
2. Repeat 25 cycles of 10 min soaks
3. Weigh parts again
4. Inspect part surface and layer structure under microscope

Disposal

When the test is done, the chemical mixture will be stored in a container marked with the name of the chemical. The chemical mixture will be left on the bottom shelf at the chemical cabinet at the Lab and the staff will be informed so they can organize the disposal.

Resources:

- https://sciencing.com/dispose-hydrochloric-acid-8419934.html
- https://www.denhaag.nl/en/in-the-city/nature-and-environment/separating-waste-and-recycling/separating-waste-domestic-chemical-waste-kca.htm
- https://www.denhaag.nl/en/waste-and-recycling/dropping-off-your-waste.htm
- https://www.chemicalsafetyfacts.org/hydrochloric-acid/

Changes in Mechanical Properties After Chemical Treatment of Polyethylene Terephthalate Glycol and Acrylonitrile Butadiene Styrene

Introduction

Reuse of medical consumables is a common practice at LRS hospitals due to unavailability of spare consumables meaning that the tubing connectors will be subjected to repetitive use and cleaning between uses during their lifespan. The standard cleaning procedure performed at Masanga hospital is soaking the consumables in a Chlorine bath [1].
During certain abdominal surgical procedures gastric juice is extracted from the patient's body. One of the main ingredients of gastric juice is Hydrochloric acid used by our stomach to process food [2]. At a higher concentration Hydrochloric acid is extremely porous [3]. Gastric juice has a relatively low concentration of Hydrochloric acid with only 0.1 M, but repetitive exposure could affect the mechanical properties of a 3D printed part on the long run after continuous exposure.

Different plastics have a different chemical compatibility [4] (Appendix, Fig. 1).
Choosing the right material for the manufacturing of the connectors is essential to deliver a safe design solution. Chemical treatment of plastics comes with the risk of:

- The material absorbing the chemical
- The chemical deteriorating the material
- The chemical affecting the tensile properties of the material.

These influences pose a threat to both the patient and the staff by using chemically infected parts, using porous or parts with holes as a result of deterioration or parts that easily break due to lowered tensile strength [5].

Research done on Polylactic Acid (PLA) [6] showed that repetitive chemical treatment in a Chlorine bath and Cidex OPA makes 3D printed parts become porous, hence PLA was immediately excluded as an option [7]. The materials considered for the medical connectors are Polyethylene terephthalate glycol (PETG) and Acrylonitrile Butadiene Styrene (ABS), based on the ease of printing, hygroscopic properties and the information available on their chemical compatibility. However, there is very little knowledge on how these materials react when treated with a Chlorine solution and also how repeated exposure to Hydrochloric acid will affect the mechanical properties of parts 3D printed with these materials. Therefore, the goal of this test is to determine which PETG or ABS 3D printing filament would be more suitable for the production of the connectors, based on how their mechanical properties change upon chemical treatment, in particular:

- Weight changes (Result of material's porosity)
- Tensile Strength properties
- Surface quality

Hypothesis: Parts 3D printed with PETG will have better chemical compatibility compared to parts printed with ABS

Method

Sample preparation

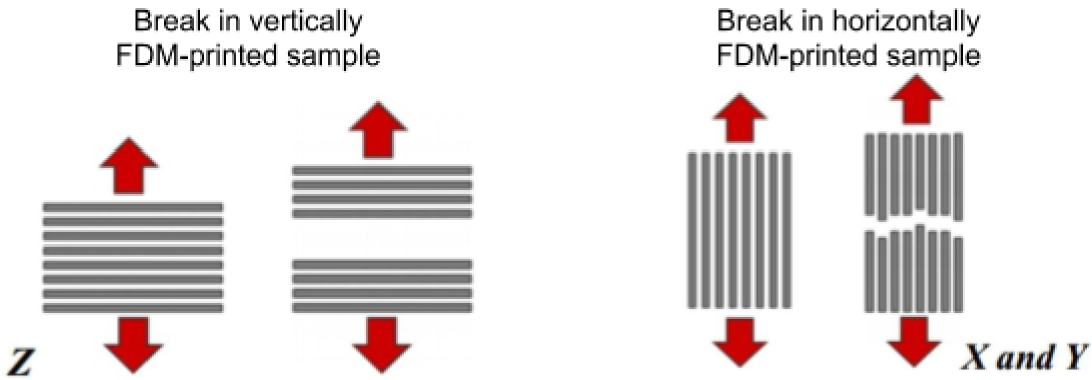
The testing was performed on tensile dog bone samples, modeled according to the ASTM D638 Standard (Appendix, Fig. 2). Two batches of tensile samples, one in ABS and one in PETG were printed for this test. Each material batch consisted of six samples. Of the six samples of each batch, four were used in the test and two were left untreated as control samples. The ABS samples were printed with white ABS filament from Prusa on a Prusa Mini Original. The PETG samples were printed with orange PETG filament from Prusa on an Creality 3D Ender 3. Table 1 shows the slicer settings. Each sample was weighed on a Kern ABT 320-4M (Table 2 & 3).

	ABS sampes	PETG samples
Printer	Prusa Original Mini	Creality 3D Ender 3
Layer height	0.1mm	0.1mm
Print temperature	255℃	240℃
Print bed temperature	100℃	60℃
Print speed	40mm/s	40mm/s
Brim	Yes	Yes
No. of samples	6	6

Table 1: Slicer settings for 3D printed tensile samples

Print orientation effect on mechanical properties

The samples were printed in a vertical orientation, which is an uncommon practice for tensile samples as it influences the anisotropy of the 3D printed parts [8], but this approach was taken because the medical connectors are printed in the same orientation. Therefore the goal was to replicate the geometry of the connectors as much as possible with the tensile samples. All samples were printed with the same quality, corresponding with the quality of printing the connectors.



Surface inspection

The surface quality of each sample was inspected under a microscope in the middle of the narrow section of the samples before and after the test.

Chemical treatment procedure

From each material batch, two samples were left as untreated as control samples, two were treated with Hydrochloric acid and two were treated with Chlorine. For clarity the samples were defined as follows:

- ABS samples 1 & 2: treated with Chlorine
- ABS samples 3 & 4: treated with Hydrochloric Acid
- ABS samples 5 & 6: control samples left untreated
- PETG samples 1 & 2: treated with Chlorine
- PETG samples 3 & 4: treated with Hydrochloric Acid
- PETG samples 5 & 6: control samples left untreated

The samples treated with Hydrochloric Acid underwent 25 cycles of 10 minute soaks in a ready-made 0.1 M Hydrochloric Acid solution (Sigma Aldrich). Between each cycle the samples were wiped off of excess chemical liquid and afterwards they were rinsed 3 times and dried using paper towels.

The samples treated with Chlorine underwent 25 cycles of 10 minute soaks in a Strong 0.5% Chlorine Solution made with 70% High Test Hypochlorite Powder (xxxx), according to WHO standards [9]. See Table 3 in Appendix for details on the recipe for the Chlorine solution.

Each sample was weighed on a Kern ABT 320-4M (Table 2 & 3) after the 10th cycle and after the 25th cycle. The samples were left to dry overnight before the last weighing after the 25th cycle to minimize weighing errors due to residual moisture.

Tensile test

The tensile testing was performed using a Zwick & Roell 10 kN stage with no pretension applied. The samples were deformed at 5mm/min until they broke and the results were gathered on the software TestXpert II [10]. The gage width was measured at the thinnest middle part of each sample. The gage thickness was measured at the middle of each sample. The median gage width and thickness for the respective batches of materials are shown in Table 2.

	ABS Samples	**PETG Samples**
Median gage width	12.82 mm	12.84 mm
Median gage thickness	2.97 mm	2.92 mm

Table 2: Median gage thickness and width of test samples

Results

Treatment effect on sample weight

The weight changes of the PETG samples can be seen in Table 3 and for the ABS samples in Table 4, including the median weight changes for each material sample set treated. The weight changes at the 10th cycle were also recorded, however not influential to the final test as there was a possibility of leftover liquid on the surface of the samples when measured.

	1. Chlorine	**2. Chlorine**	**3. Acid**	**4. Acid**	**5. Control**	**6. Control**
Weight before	9.8061gr	9.2711gr	9.3365gr	9.3068gr	9.328gr	8.675gr
At 10th cycle	9.826gr	9.2815gr	9.3531gr	9.3143gr	/	/
Weight after	**9.813gr ↑**	**9.2679gr ↓**	**9.3343gr ↓**	**9.304gr ↓**	/	/
Median weight ↑/↓	**0.017% ↑**		**0.020% ↓**		/	/

Table 3: Weight changes of PETG samples

	1. Chlorine	2. Chlorine	3. Acid	4. Acid	5. Control	6. Control
Weight before	7.684gr	7.6527gr	7.7141gr	7.6702gr	7.6786gr	7.6687gr
At 10th cycle	7.709gr	7.6767gr	7.7465/7.7414gr	7.6934gr	/	/
Weight after	7.706gr	7.6622gr	7.73gr	7.7083gr	/	/
Median weight ↑/↓	**0.205% ↑**		**0.351% ↑**		/	/

Table 4: Weight changes in ABS samples

From the PETG samples, apart from one sample that showed an increase in weight, all other samples showed a decrease in weight, which means that they did not absorb liquid during the chemical treatment.

On the other hand, all ABS samples demonstrated an increase in weight, a result of absorption of liquid during treatment.

All samples were affected more by the treatment with Hydrochloric Acid compared to the Chlorine treatment.

Treatment effect on surface quality

The surface quality of each sample was recorded before and after the chemical treatment (Table 5 & 6). The samples were numerically marked before the test and each sample was inspected at the same point both before and after the test. The surface of all samples from both materials remained unchanged.

	1. Chlorine	2. Chlorine	3. Acid	4. Acid

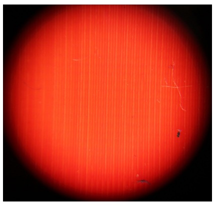
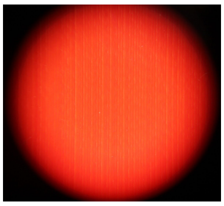
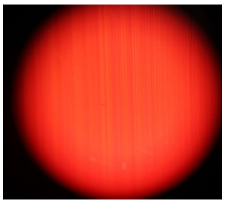
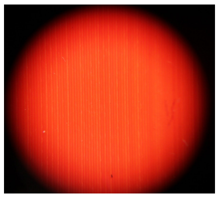
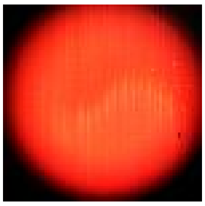
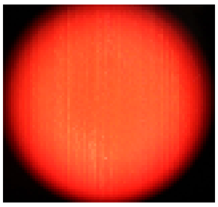
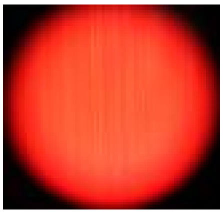
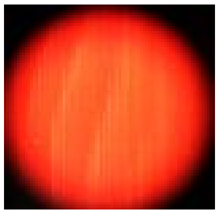
Before treatment				
After treatment				

Table 5: Surface quality changes in PETG samples

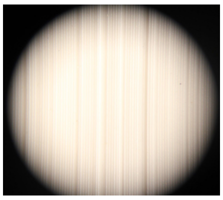
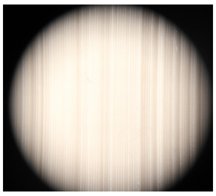
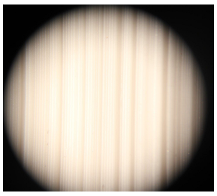
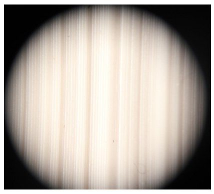
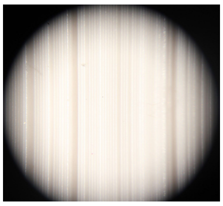
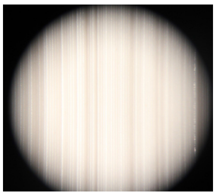
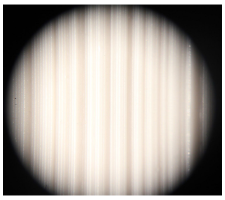
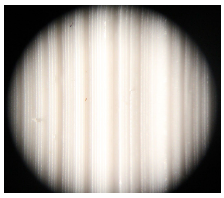
	1. Chlorine	**2. Chlorine**	**3. Acid**	**4. Acid**
Before treatment				
After treatment				

Table 5: Surface quality changes in ABS samples

Treatment effect on tensile properties

Due to the layered production of the samples, upon break all samples just snapped at the breaking point without elongation, or simply said the layer separated from each other. Therefore only the stress at break was calculated for the purpose of this test.

	Stress (MPa)	**Median Stress (MPa)**	**MedianStrength ↑ / ↓ (%)**
Control sample 1	15.918		
Control sample 2	15.45	15.684	/
1. Chlorine	24.04	18.204	**16.0673% ↑**

sample			
2. Chlorine sample	12.368		
3. Acid sample	12.627		
4. Acid sample	9.765	11.196	**28.6151% ↓**

Table 6: Stress at break of PETG samples

	Stress (MPa)	**Median Stress (MPa)**	**Median Strength ↑/↓ (%)**
Control sample 1	17.663		
Control sample 2	13.7911	15.727	/
1. Chlorine sample	17.606		
2. Chlorine sample	18.17	17.888	**13.7403% ↑**
3. Acid sample	10.102		
4. Acid sample	16.932	13.517	**14.0525% ↓**

Table 7: Stress at break of ABS samples

In both materials Hydrochloric acid treatment resulted in a decrease of strength, a result of the material deteriorating, especially evident in the PETG samples with a decrease of 28.615%. Chlorine treatment increased the strength of both materials, particularly in PETG with 16.0673%.

Discussion

Treatment effect on weight of samples

Both chemical treatments resulted in a weight increase of the ABS samples. This means that after continuous reuse the samples will absorb the chemical they are treated with, which if transferred onto skin or internally in the human body could pose a risk of burning or poisoning. Although the increase values are quite low with 0.205% after Chlorine treatment and 0.351% after Hydrochloric acid treatment, PETG samples did not result in weight increase, a result of PETG's water tightness, which makes it ideal for applications where contact with fluid would be frequent.

Treatment effect on surface quality

Surface quality remained the same on all samples (PETG and ABS). However, due to the 3D printing orientation, the top parts of the ABS were not printed properly and layer separation was evident before the chemical treatment. In these sections of the ABS samples layer separation was even more visible post treatment, making those areas brittle and weak. But overall, in the areas with optimal print quality that were inspected, no change in surface quality was detected.

Treatment effect on tensile properties

Both materials showed an increase in strength after being treated with Chlorine, which means that reuse up to 25 times would not pose a risk to the staff or the user no matter which material is used. As for treatment with Hydrochloric acid, the median strength was drastically reduced for both materials, and in particular in PETG with a decrease of 28.6151%. This was found as a surprise as literature research (Appendix, Fig. 1) suggest that PETG exhibits better resistance against Hydrochloric Acid.

Limitations

The main limitation to this test was the number of samples tested. Performing the test with more samples would have given more relevant results. Another limitation was the fact that the samples were printed on two different printers, however the quality of the prints was inspected prior to the test and the only significant downside identified was the lowered print quality at the top of the ABS samples. This limitation however did not influence the end results as that area of the samples was clamped in the tensile meter and was not subject to stress as much as the middle narrow surface of the samples.

Conclusion

This test showed a median strength increase of 16.0673% and 13.7403% after Chlorine treatment for PETG and ABS printed samples respectively, followed by a 28.6151% and 14.0525% decrease after Hydrochloric acid treatment for PETG and ABS samples respectively. From a mechanical point of view, both materials are safe for the production of reusable tubing connectors. The final decision however is to proceed with PETG for the manufacturing of the tubing connectors, mainly due to PETG's impeccable water resistance properties. The ABS samples absorb both the Chlorine solution and the Hydrochloric acid, which on the long run could be harmful for the patient and the staff if the absorbed chemicals are transferred to the human body. As this project is the starting ground for Masanga's engagement in 3D printing other consumables as well in the future, PETG is a safer option for the production of reusable medical consumables to be frequently subjected to chemical treatment.

References

[1] Interview with Jan Henk Dubbink

[2] How To Make Simulated Stomach Acid March 13, 2018
By Adam Cloe https://sciencing.com/simulated-stomach-acid-4856282.html

[3]https://en.wikipedia.org/wiki/Hydrochloric_acid#:~:text=Concentrated%20hydrochloric%20acid%20dissolves%20many,chlorides%20that%20can%20be%20analyzed.
[4] Savonen, B., (2019), A Methodology for Triaging Product Needs for Localized Manufacturing With 3D Printing in Low-Resource Environments, The Pennsylvania State University, The Graduate School, College of Engineering
[5] Savonen, B., (2019), A Methodology for Triaging Product Needs for Localized Manufacturing With 3D Printing in Low-Resource Environments, The Pennsylvania State University, The Graduate School, College of Engineering
[6] Fleischer, J. C., Diehl, J. C., Wauben, L. S. G. L., Dankelman, J., (2020), The Effect of Chemical Cleaning on Mechanical Properties of Three-Dimensional Printed Polylactic Acid, Journal of Medical Devices, [DOI: 10.1115/1.4046120]
[7] Private conversation with Julie Fleischer, September, 2020
[8] Teton Simulation, (2019) Introduction to Anisotropy of 3D Printed Parts, https://www.tetonsim.com/blog/post/introduction-to-anisotropy-of-3d-printed-parts
[9] World Health Organization (WHO), (2006), Collecting, preserving and shipping specimens for the diagnosis of avian influenza A(H5N1) virus infection, Guide for field operations, October 2006
[10] Fleischer, J. C., Diehl, J. C., Wauben, L. S. G. L., Dankelman, J., (2020), The Effect of Chemical Cleaning on Mechanical Properties of Three-Dimensional Printed Polylactic Acid, Journal of Medical Devices, [DOI: 10.1115/1.4046120]

Appendix

Figure 1: Chemical compatibility of common 3D Printing filaments from Heikkinen et. al., 2018, seized from Savonen, 2019

Table 28: Filament Compatibility Results (Median Values) from Heikkinen *et al.*, 2018

	Common 3D Printer Filaments				
Chemical Compound	PETG	Nylon	Polypropylene	ABS	Polycarbonate
Isopropyl Alcohol	Good Compatibility	Good Compatibility	Good Compatibility	Good Compatibility	Moderate Compatibility
Acetone	Poor Compatibility	Good Compatibility	Good Compatibility	Poor Compatibility	Poor Compatibility
Ethanol	Good Compatibility	Moderate Compatibility	Good Compatibility	Good Compatibility	Good Compatibility
Hydrochloric Acid (HCL)	Good Compatibility	Poor Compatibility	Good Compatibility	Moderate Compatibility	Good Compatibility
Ammonia (NH_3)	Moderate Compatibility	Moderate Compatibility	Good Compatibility	Good Compatibility	Poor Compatibility
Hydrogen Peroxide (H_2O_2)	Good Compatibility	Poor Compatibility	Good Compatibility	Good Compatibility	Moderate Compatibility
Phosphoric Acid (H_3PO_4)	Moderate Compatibility	Poor Compatibility	Good Compatibility	Good Compatibility	Good Compatibility
Nitric Acid (HNO_3)	Poor Compatibility	Poor Compatibility	Moderate Compatibility	Poor Compatibility	Poor Compatibility
Sulfuric Acid (H_2SO_4)	Poor Compatibility	Poor Compatibility	Good Compatibility	Poor Compatibility	Poor Compatibility
Acetic acid (CH_3COOH)	Poor Compatibility	Poor Compatibility	Good Compatibility	Poor Compatibility	Poor Compatibility

Figure 2: Tensile dog bone sample dimensions according to ASTM D638 Standard

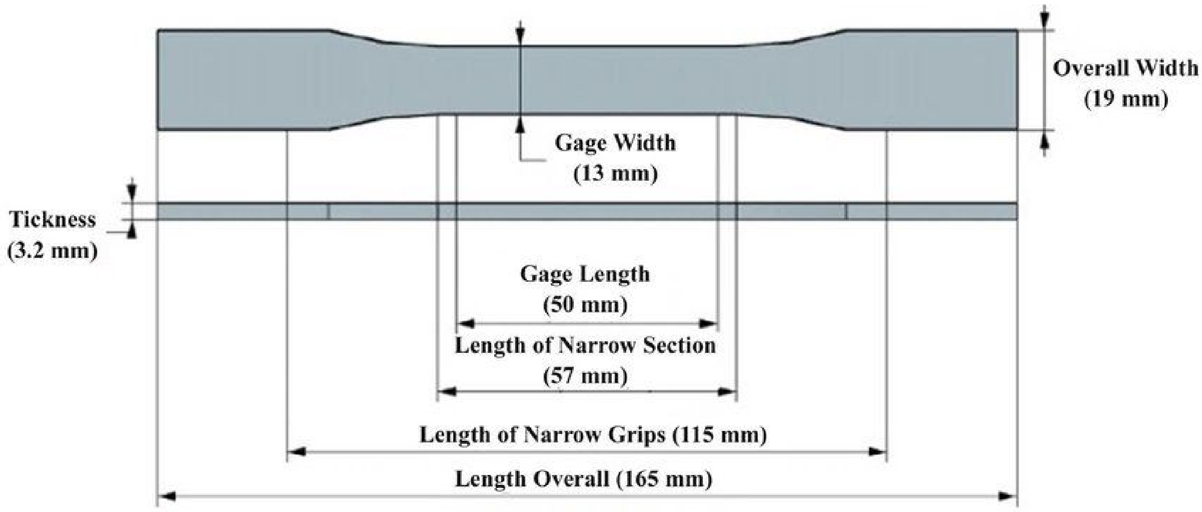


Table 3: Chlorine solution using High Test Hypochlorite powder

Chlorine product	0.5% solution
Calcium hypochlorite powder of granules (70%) High Test Calcium Hypochlorite	3gr HTH in 2l of water

Appendix 18

BATTERY MATH

Picking a car battery with the correct energy capacity to power a surgical suction pump

Introduction

In their regular application in vehicles, car batteries are used to provide the initial power to the motor, which afterwards continues working using fuel [1]. Therefore car batteries are commonly meant for providing that initial charge, instead of powering the vehicle for an extended period of time.

In this project's application, the car battery is meant to serve as a power source for an extended period of time, estimated between 1 and 2 hours. A decision was made to go for a deep cycle battery as they are suitable for applications where discharging and recharging is going to occur often [2].

In order to pick the right battery, it is important to calculate how much battery capacity is needed to power the suction pump available at Masanga considering its power parameters (Table 1).

Power parameters of Medela Median surgical suction pump	
Power inlet	230 V AC
Power consumption	110 W
Run time	~ 2h

Table 1: Power parameters of suction pump

A battery's capacity is measured in Ampere hours. Ampere hour or amp hour is a unit for electric charge, where the dimension of electric current is multiplied by time. It is equal to the charge transferred by a steady current of one ampere flowing for one hour [3]. Knowing how many amps are needed to power a device is necessary for picking the right battery.

Calculation

Since for the suction pump only the voltage and wattage are known, it is necessary to calculate the amps needed to power it. Knowing the watts, the amps can be calculated easily [4] to get the amp hours required from the battery.

Step 1: Convert watts into amps

To get the amp hours from the watts, the watts are used to calculate the watt hours of the device. Watt hours is a unit for the energy stored. The estimated time the battery would need to power the device is 2 hours and from there:

$$Watt\ h = W * H = 110 * 2 = 220\ Watt\ h$$

Because the battery has a DC load and the device has an AC load, a load inverter is incorporated in the system. Inverters have an efficiency of ~85%. Taking into account the inverter efficiency:

$$Watt\ h\ /\ efficiency = 220\ /\ 0.85 = 258.82\ Watt\ h$$

Since watts = amps * volts, dividing the watt hours by the voltage gives the amp hours required:

$$Amp\ h = Wh\ /\ volts = 258.82/12 = 21.56\ Amp\ h\ (C)$$

where C = amp hours.

Step 2: Cycle life consideration

Running a battery down to 0 during each cycle can harm the battery and lower its life span. If a battery is intended to be used for multiple cycles, it should not be left to run past 80% of its charge and 20% should be left in the battery. This extends the number of cycles the battery can deliver, which is essential in a frugal setting such as Sierra Leone where the maximum capacity should be pulled out of the equipment purchased. From that:

$$C' = C/0.8 = 26.95\ amph$$

where C’ = amp hours at 80% discharge.

Step 3: Rate of discharge considerations

Deep cycle lead acid batteries have a rate or “depth” of discharge of about 50%. A rule of thumb suggests that for a 1h discharge rate you only get half capacity. Therefore:

$$C'' = 26.95/0.5 = 53.9\ amp\ h$$

Where C’’ = amp hours at 50% discharge. An expert electrical engineer was consulted [5], who suggested that might be too low and that a battery with capacity of 35-36 amp hours would also be sufficient for this application.

Conclusion

For the application of powering the surgical suction pump at Masanga Hospital, a 12V deep cycle lead acid battery with min. 35 amp hours should be sufficient for providing power for 2 hours.

References

1. Compare Car Battery Technologies: Which Battery Technology is Right for Your Vehicle, (cited 2020, November 10th), Available at
https://www.autobatteries.com/en-us/battery-technology-types/overview
2. Car Battery Types, (cited 2020, November 10th), Available at
https://www.aa.co.nz/cars/owning-a-car/batteries/car-battery-types/
3. Ampere hour, (cited 2020, November 10th), Available at
https://en.wikipedia.org/wiki/Ampere_hour
4. How to calculate battery run time (cited 2020, November 10th), Available at
https://www.powerstream.com/battery-capacity-calculations.htm
5.Wim de Wilt, electrical engineer, Personal interview (2020, November 12th)

DESIGN FOR OUR future

TU Delft

IDE Master Graduation

Project team, Procedural checks and personal Project brief

This document contains the agreements made between student and supervisory team about the student's IDE Master Graduation Project. This document can also include the involvement of an external organisation, however, it does not cover any legal employment relationship that the student and the client (might) agree upon. Next to that, this document facilitates the required procedural checks. In this document:

- The student defines the team, what he/she is going to do/deliver and how that will come about.
- SSC E&SA (Shared Service Center, Education & Student Affairs) reports on the student's registration and study progress.
- IDE's Board of Examiners confirms if the student is allowed to start the Graduation Project.

USE ADOBE ACROBAT READER TO OPEN, EDIT AND SAVE THIS DOCUMENT

Download again and reopen in case you tried other software, such as Preview (Mac) or a webbrowser.

STUDENT DATA & MASTER PROGRAMME

Save this form according the format "IDE Master Graduation Project Brief_familyname_firstname_studentnumber_dd-mm-yyyy". Complete all blue parts of the form and include the approved Project Brief in your Graduation Report as Appendix 1 !

family name: Mucha

initials: A given name: Asja

student number: 4827414

street & no.:

zipcode & city:

country: The Netherlands

phone:

email:

Your master programme (only select the options that apply to you):

IDE master(s): ★ IPD ◯ DfI ◯ SPD

2nd non-IDE master:

individual programme: - - (give date of approval)

honours programme: ◯ Honours Programme Master

specialisation / annotation: ★ Medisign

◯ Tech. in Sustainable Design

◯ Entrepeneurship

SUPERVISORY TEAM **

Fill in the required data for the supervisory team members. Please check the instructions on the right !

** chair: Dr. ir. Jan Carel Diehl dept. / section: SDE/DfS

** mentor: Stefan Persaud dept. / section: SDE/PAD

2nd mentor:

organisation:

city: country:

comments (optional)

Chair should request the IDE Board of Examiners for approval of a non-IDE mentor, including a motivation letter and c.v..

Second mentor only applies in case the assignment is hosted by an external organisation.

Ensure a heterogeneous team. In case you wish to include two team members from the same section, please explain why.

APPROVAL PROJECT BRIEF

To be filled in by the chair of the supervisory team.

chair Dr. ir. Jan Carel Diehl date 30 - 05 - 2020 signature jdiehl

Digitally signed by jdiehl
Date: 2020.05.30 12:20:09 +02'00'

CHECK STUDY PROGRESS

To be filled in by the SSC E&SA (Shared Service Center, Education & Student Affairs), after approval of the project brief by the Chair. The study progress will be checked for a 2nd time just before the green light meeting.

Master electives no. of EC accumulated in total: ______ EC

Of which, taking the conditional requirements into account, can be part of the exam programme ______ EC

List of electives obtained before the third semester without approval of the BoE

YES all 1st year master courses passed

NO missing 1st year master courses are:

name ______ date - - signature ______

FORMAL APPROVAL GRADUATION PROJECT

To be filled in by the Board of Examiners of IDE TU Delft. Please check the supervisory team and study the parts of the brief marked **. Next, please assess, (dis)approve and sign this Project Brief, by using the criteria below.

- Does the project fit within the (MSc)-programme of the student (taking into account, if described, the activities done next to the obligatory MSc specific courses)?
- Is the level of the project challenging enough for a MSc IDE graduating student?
- Is the project expected to be doable within 100 working days/20 weeks ?
- Does the composition of the supervisory team comply with the regulations and fit the assignment ?

Content: APPROVED NOT APPROVED

Procedure: APPROVED NOT APPROVED

comments

name ______ date - - signature ______

Improving the use of surgical suction pumps in low resource hospitals

project title

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

start date 11 - 05 - 2020

09 - 10 - 2020 end date

INTRODUCTION **

Please describe, the context of your project, and address the main stakeholders (interests) within this context in a concise yet complete manner. Who are involved, what do they value and how do they currently operate within the given context? What are the main opportunities and limitations you are currently aware of (cultural- and social norms, resources (time, money,...), technology, ...).

This graduation project is a self initiated project on improving the use of surgical suction pumps with a focus on hospitals in low-income countries such as Sub-Saharan countries, with applicability in makeshift hospitals in areas of conflict or disaster in the Global South .

Over the last 100 years, surgery has become a necessary component of public health and a safe and reliable tool in the fight against diseases. Sadly, the situation in low-income countries, often referred to as the Base of The Pyramid is quite different for a number of reasons, with availability and reliability of equipment being most prominent. The hospitals are equipped with donated equipment, but when a device breaks down usually it cannot be fixed due to lack of financial resources, lack of spare parts or expertise. Failure can occur as a result of the device's own malfunction, misuse and low level of care and responsibility by the staff and contextual factors like working on an unstable power grid or exposure to the elements. After failure, the devices most often end up disposed in wastelands around the hospitals, with a lot of parts and components still in good shape. (Fig. 1)

In surgery, suction is used to remove blood or other fluids from the area being operated on to allow surgeons to view and work on the area (Wikipedia, 2020). The surgical suction pump was chosen for this project in a consultation with Dr. Jonathan Vas Nunes, a Dutch tropical doctor working in Masanga Hospital in Sierra Leone. They have experienced several issues with cleaning and sterilizing the pumps, especially with the tubes that transfer the fluids outside of the body. The tubes are usually unique to every producer and hard to sterilize. Getting the suitable tubes is expensive or logistically tough due to the limited supply chain which is why they want a design solution that enables them to operate the existing device with any available, universal, sterile tube (like blood or urine catheter lumens). Additionally, due to the number of daily power grid failures, they prefer a device that can work on a battery charge for at least 30 minutes in a situation of power loss (Fig. 2). A personal reason of choice was that surgical suction pumps are used in almost every type of surgery and are necessary for allowing the surgeon a clear field of view, which contributes to a higher chance of success of the surgery.

As a result of the aforementioned contextual issues such as lack of care and exposure to elements, the doctors would prefer sturdier products that can easily be fixed or re-produced locally in case of a failure.

The design solution that will arise from this project is envisioned to be used by doctors and nurses in the aforementioned contexts, including local staff and expat tropical doctors. The goal is to create a design solution that can be produced locally in the existing Fab Labs and fall in the ownership of a local hospital, a tropical medicine NGO such as Doctors Without Borders, SurgeonsOverSeas, Red Cross ets., or in the ownership of the independent tropical doctor who can also produce it and transport it from their home country to the hospital in the field.

Ref.
- van Boeijen, A.G.C., Daalhuizen, J.J., Zijlstra J. & van der Schoor, R., (eds) (2013) Delft Design Guide, Models, Approaches and Perspectives: Base of the Pyramid (BOP) & Emerging Markets, Amsterdam, BIS Publishers
- https://www.sscor.com/
- https://www.medelahealthcare.com/solutions/professional-vacuum-solutions/surgical-airway-suction

space available for images / figures on next page

introduction (continued): space for images

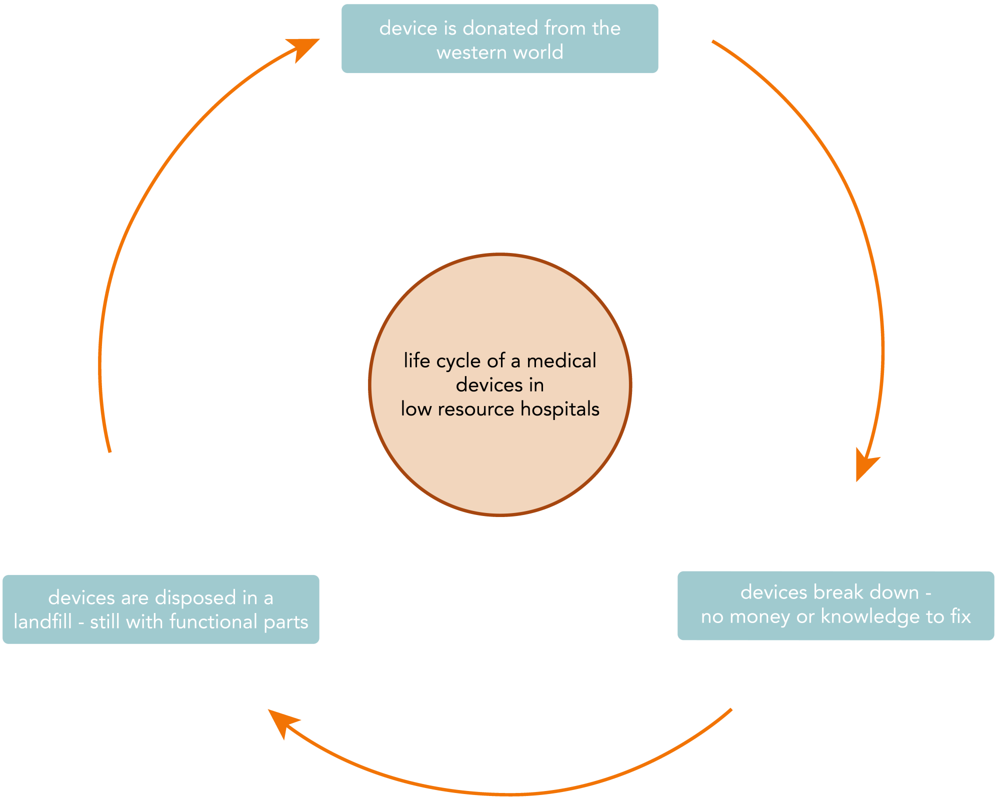


image / figure 1: Life cycle of medical devices in low resource hospitals

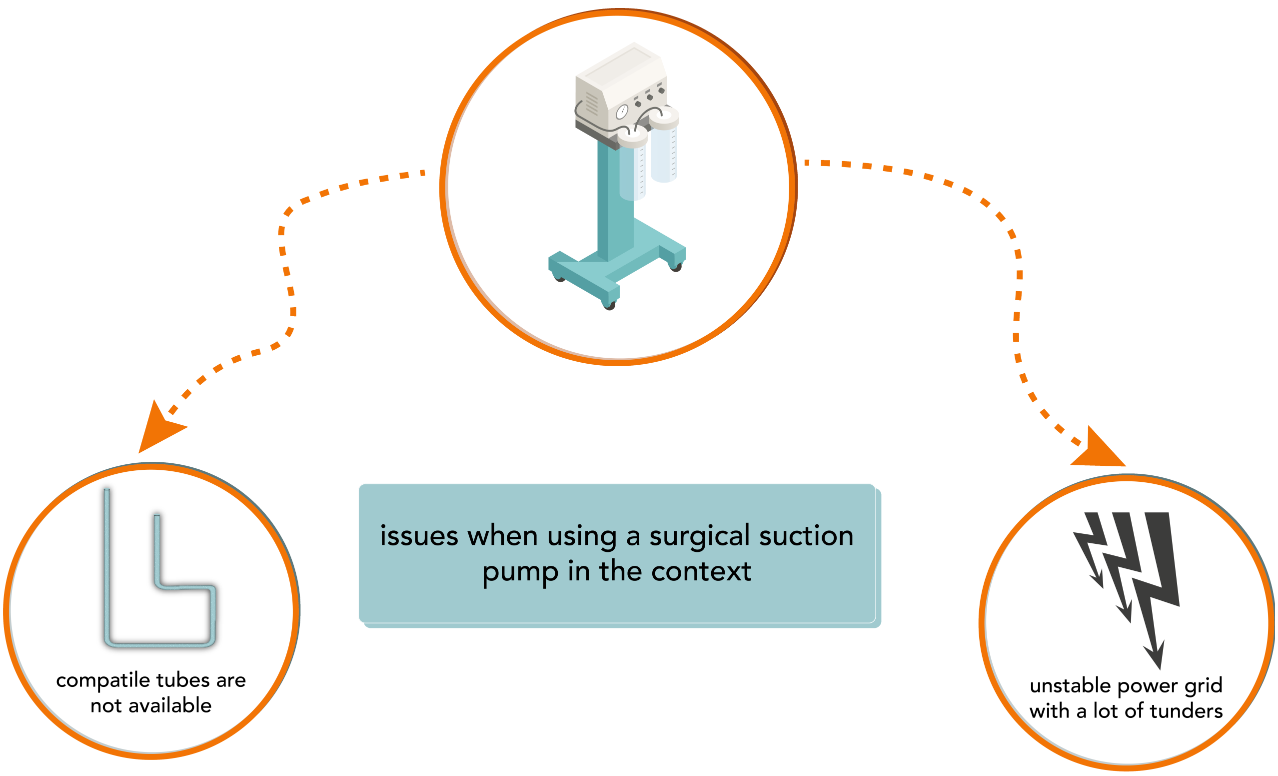


image / figure 2: Issues when using surgical suction pumps in the context

Initials & Name A Mucha Student number 4827414

Title of Project Improving the use of surgical suction pumps in low resource hospitals

PROBLEM DEFINITION **

Limit and define the scope and solution space of your project to one that is manageable within one Master Graduation Project of 30 EC (= 20 full time weeks or 100 working days) and clearly indicate what issue(s) should be addressed in this project.

Even though many of the hospitals in low-income counties receive donations in the form of medical devices from the Western World, these devices are not compatible for long term use in the local context.
The use of the suction pump involves using additional consumables, such as tubes, catheters and hydrophobic filters. Some of the consumables can be reused, depending on the brand, but some are non-reusable. Usually every pump manufacturer produces consumables compatible to their brand only. Due to supply chain challenges and financial reasons these specific tubes are not always available. Consequently, the pumps can not be used.
The infrastructure of the hospitals is less developed than in western hospitals, where devices operate in a stable environment, without exposure to the elements and on a stable power grid. The instability of the power grid and the frequent thunder storms pose a great threat to the functionality and quality of the devices.

The project will aim to answer the following questions:

1. How can the currently available surgical suction pumps in low resource hospitals be adapted for use in the specific context without the need of a new device?
2. How can the existing surgical suction pumps be locally adapted to work without depending on the local power grid?
3. How can the locally available manufacturing services, resources and expertise influence the design and production of adaptation add-ons or consumable for the suction pumps?

ASSIGNMENT **

State in 2 or 3 sentences what you are going to research, design, create and / or generate, that will solve (part of) the issue(s) pointed out in "problem definition". Then illustrate this assignment by indicating what kind of solution you expect and / or aim to deliver, for instance: a product, a product-service combination, a strategy illustrated through product or product-service combination ideas, ... In case of a Specialisation and/or Annotation, make sure the assignment reflects this/these.

The goal of this project is to improve the use of surgical suction pumps in low resource settings and mobile hospitals, by adapting existing pumps for compatibility with local resources, with a focus on two main aspects: 1. Post-use replacement of single-use consumables (tubes, catheters, filters) and 2. Refrain users from relying on the local power grid. The gathered knowledge will be combined to deliver a product that will deliver improved surgical suction pump use.

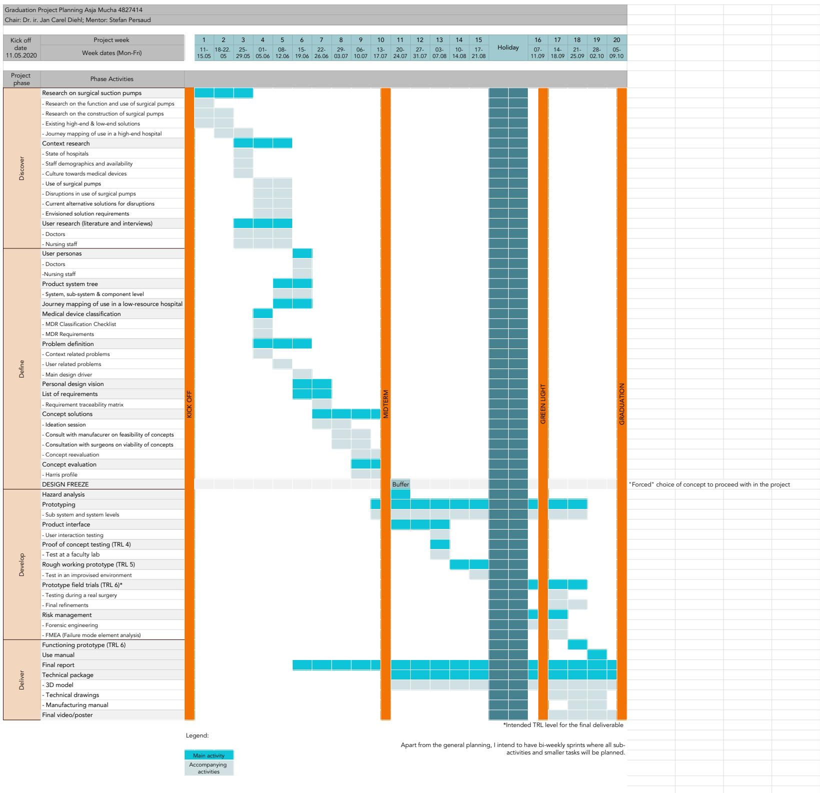
Based on the insights gathered from conversations with experts from Masanga Hospital in Sierra Leone, including doctors and an engineer who worked on fixing one of their existing pumps, the final design solution should also take into consideration the following requirements:

- Design for portability (a lightweight design the user can bring it in a suitcase from their home country)
- Improved sense of ownership for nurse and available staff
- The design should be sturdy to prevent damage from incidental falls or crashes
- The design should allow for local production and repair-ability with locally available parts
- The design should allow for attachment of any compatible available tube
- Compatibility with a 12V power grid
- A device that does not need a PCB due to lack of part available

PLANNING AND APPROACH **

Include a Gantt Chart (replace the example below - more examples can be found in Manual 2) that shows the different phases of your project, deliverables you have in mind, meetings, and how you plan to spend your time. Please note that all activities should fit within the given net time of 30 EC = 20 full time weeks or 100 working days, and your planning should include a kick-off meeting, mid-term meeting, green light meeting and graduation ceremony. Illustrate your Gantt Chart by, for instance, explaining your approach, and 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 activities.

start date 11 - 5 - 2020 | 9 - 10 - 2020 end date



The planning follows the Double Diamond principle, which consists of four stages: Discover, Define, Develop and Deliver.
The Discover and Define phase will focus on gathering information and building an understanding of the device, the user, the context and the factors and requirements that need to be considered for the final solution. The Define phase is intended to end with proposed concept solutions and a "Design Freeze" where the most promising concept will be chosen for continuation.
The Develop phase will focus on translating the gathered knowledge into the embodiment solutions for the product. It will be an iterative phase with a lot of building, testing and validation loops in order to reach the Technology Readiness Level (TRL) 6.
The Deliver phase will be devoted to preparing the final deliverables in a professional manner, suitable for both academic and commercial presentation.
Within every phase and milestone I intend to work in bi-weekly sprints where all of the tasks related to that phase will be defined. The planning also includes a two week vacation which had to be postponed due to COVID-19.

The weekly meetings with the mentor are scheduled for every Wednesday morning for 30 minutes, with one monthly meeting of between 1 and 1.5 hour. The chair meetings take place approximately once every three weeks and he receives bi-weekly updates of the work completed.

Ref.
https://www.nasa.gov/directorates/heo/scan/engineering/technology/txt_accordion1.html

MOTIVATION AND PERSONAL AMBITIONS

Explain why you set up this project, what competences you want to prove and learn. For example: acquired competences from your MSc programme, the elective semester, extra-curricular activities (etc.) and point out the competences you have yet developed. Optionally, describe which personal learning ambitions you explicitly want to address in this project, on top of the learning objectives of the Graduation Project, such as: in depth knowledge a on specific subject, broadening your competences or experimenting with a specific tool and/or methodology, ... Stick to no more than five ambitions.

I have been in the field of philanthropy for over 7 years, which has opened my eyes to the fact that not all of us around the world enjoy the same privileges that life has to offer. As I got deeper into my studies, I realized that I have the rare opportunity to combine my biggest "extra curricular" passion with medical design and shift my focus towards (re) designing medical devices for low-income regions.

My first goal for this project was to look into areas of conflict, but exploring that context is quite hard due to low access to information or target users, so I decided to shift my focus towards low resource settings, but keep in mind that the final solution could also be applicable in that context, based on my knowledge from literature research from books and journals about war surgery and surgery during crisis and natural disaster.

Alongside the regular master courses and the MVE, I have also followed the Medisign specialization and its related courses, including an internship, where I have acquired a set of skills related to the design and engineering of medical devices, their use and the rules and regulations that accompany it. I see my graduation project as an opportunity to combine all of my acquired skills and knowledge into one project, from journey mapping to standardizing a medical device and understanding the anatomy of the human body and surgical techniques from an engineer's perspective.

During the course Advanced Embodiment Design, where I first got acquainted with design for low resource settings, a great part of our focus was on design for local repairability. In this project I aspire to implement and broaden my knowledge and apply it to a more complex medical device.

FINAL COMMENTS

In case your project brief needs final comments, please add any information you think is relevant.