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Three-Dimensional Stereophotogrammetry in the Evaluation of Craniosynostosis: Current and Potential Use Cases

Tareq Abdel-Alim, BSc,[*†] *Rik Iping, MSc,*[‡] *Eppo B. Wolvius, MD, PhD,*[§] *Irene M.J. Mathijssen, MD, PhD,*[||] *Clemens M.F. Dirven, MD, PhD,*[*] *Wiro J. Niessen, PhD,*[†¶] *Marie-Lise. C. van Veelen, MD, PhD,*[*] *and Gennady V. Roshchupkin, PhD*[†#]

Abstract: Three-dimensional (3D) stereophotogrammetry is a novel imaging technique that has gained popularity in the medical field as a reliable, non-invasive, and radiation-free imaging modality. It uses optical sensors to acquire multiple 2D images from different angles which are reconstructed into a 3D digital model of the subject's surface. The technique proved to be especially useful in craniofacial applications, where it serves as a tool to overcome the limitations imposed by conventional imaging modalities and subjective evaluation methods. The capability to acquire high-dimensional data in a quick and safe manner and archive them for retrospective longitudinal analyses, provides the field with a methodology to increase the understanding of the morphological development of the cranium, its growth patterns and the effect of different treatments over time.

This review describes the role of 3D stereophotogrammetry in the evaluation of craniosynostosis, including reliability studies, current and potential clinical use cases, and practical challenges. Finally, developments within the research field are analyzed by means of bibliometric networks, depicting prominent research topics, authors, and institutions, to stimulate new ideas and collaborations in the field of craniofacial 3D stereophotogrammetry.

We anticipate that utilization of this modality's full potential requires a global effort in terms of collaborations, data sharing, standardization, and harmonization. Such developments can facilitate larger studies and novel deep learning methods that can aid in reaching an objective consensus regarding the most effective treatments for patients with craniosynostosis and other craniofacial anomalies, and to increase our understanding of these complex dysmorphologies and associated phenotypes.

Key Words: Three-dimensional photogrammetry, craniofacial, craniosynostosis, stereophotogrammetry, surface imaging

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Craniosynostosis is a congenital condition that involves premature fusion of one or more of the cranial sutures.[1–4] Its prevalence is estimated at 4 to 5 out of every 10,000 children and has consistently increased over the past 2 decades.[5–8] Different types of craniosynostosis are distinguished based on the affected suture and the resulting head shape (Fig. 1). When left untreated, the resulting abnormal cranial morphology can lead to functional problems in addition to the cosmetic concerns. These problems include inhibition of brain growth, increased intracranial pressure (ICP), developmental delay and visual impairment.[9–13] Surgery is still the primary treatment.

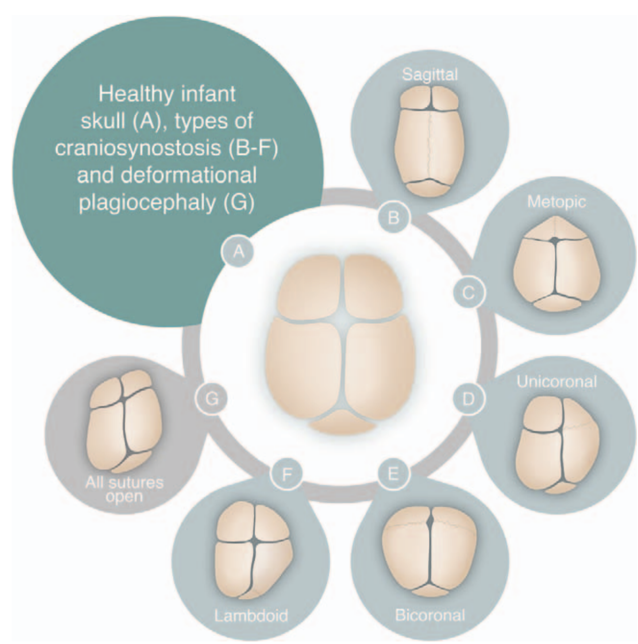

FIGURE 1. Types of infant skull deformities: (A) normocephaly (B) sagittal synostosis (C) metopic synostosis (D) unicoronal synostosis (E) bicoronal synostosis (F) lambdoid synostosis (G) deformational plagiocephaly.

From the *Department of Neurosurgery; †Department of Radiology and Nuclear Medicine; ‡Research Intelligence and Strategy Unit; §Department of Oral- and Maxillofacial Surgery; ||Department of Plastic, Reconstructive Surgery, and Hand Surgery, Erasmus MC, University Medical Center, Rotterdam; ¶Faculty of Applied Sciences, Delft University of Technology, Delft; and #Department of Epidemiology, Erasmus MC, University Medical Center, Rotterdam, the Netherlands.
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Address correspondence and reprint requests to Gennady V. Roshchupkin, PhD, Department of Radiology and Nuclear Medicine; Department of Epidemiology Erasmus MC, Medical Center, Rotterdam, the Netherlands; E-mail: g.roshchupkin@erasmusmc.nl
Marie-Lise. C. van Veelen and Gennady V. Roshchupkin jointly supervised this work.
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Early diagnosis plays an essential role in the planning and treatment of the condition. As the pediatric skull becomes more rigid, the number of available treatment options decreases, while the extent and complexity of the surgery increases. Pediatric patients are often exposed to a significant amount of radiation to obtain computed tomography (CT) images and skull X-rays for the evaluation of the cranial morphology and fused sutures.[14–16] However, concerns have been raised due to susceptibility of the young child to radiation.[15] To minimize exposure during follow up, the outcome of surgical treatment is often visually assessed.[17,18]

Three-dimensional stereophotogrammetry is a technique used to reconstruct a digital model of the subject's surface from multiple 2D images taken from different angles. Such a modality can overcome the limitations imposed by subjective evaluation methods without exposing the young child to radiation or sedation. This provides clinicians and researchers with a reproducible instrument that enables cranial shape analysis and evaluation of the condition and treatment effects over time. The short acquisition time makes it suitable for pediatric patients.

Multiple studies have demonstrated the potential of 3D stereophotogrammetry in the evaluation of craniosynostosis. Research topics include the development and application of novel quantitative methods to study cranial shapes, volumes, and growth patterns, as well as objective evaluation of treatment efficacy and outcome over time.[19–32]

This review describes the reliability, current and potential clinical use cases, and limitations of 3D stereophotogrammetry in the evaluation of craniosynostosis, to make it more accessible to surgeons in the field of craniofacial surgery. Developments within the research field are visualized to stimulate new ideas and collaborations.

TECHNICAL ASPECTS OF THREE-DIMENSIONAL STEREOPHOTOGRAMMETRY

Fundamental Principles and Data Representation

In modern 3D stereophotogrammetry, optical sensors are used to acquire 2D images from different angles. These images are then reconstructed into a digital model of the subject's surface. In the simplest case, two images are required for the 3D reconstruction of a surface (Fig. 2). When the relative positions and orientations of the two sensors (s_1, s_2) are defined, the exact location of a particular point on the underlying sampled surface can be defined as a distance (h) from the baseline connecting the two focal points (f). This distance is derived from the disparity between the two images (d_1, d_2) and by extending this principle, the 3D (x,y,z) coordinates are obtained.

The most common representations of the acquired data in 3D shape analysis are point sets and polygonal meshes.[33]

In a point-based representation, the surface is described by an unstructured dataset of single spatial locations also known as a point cloud (Fig. 3, left).

In a polygonal mesh-based representation, the 3D surface is partitioned into cells or mesh elements to describe the surface as a collection of spatial points and faces enclosed by straight line segments. The resulting digital model is referred to as a mesh. In this context, the spatial points are referred to as vertices and the straight-line segments connecting the neighboring vertices are known as edges (Fig. 3, right).

The quality of a 3D model is highly dependent on the number and size of the mesh elements describing the surface. A nearly planar surface can be approximated by a few mesh elements while a more complex geometry will require a larger number of elements, especially in the areas of high curvature such as the ears.

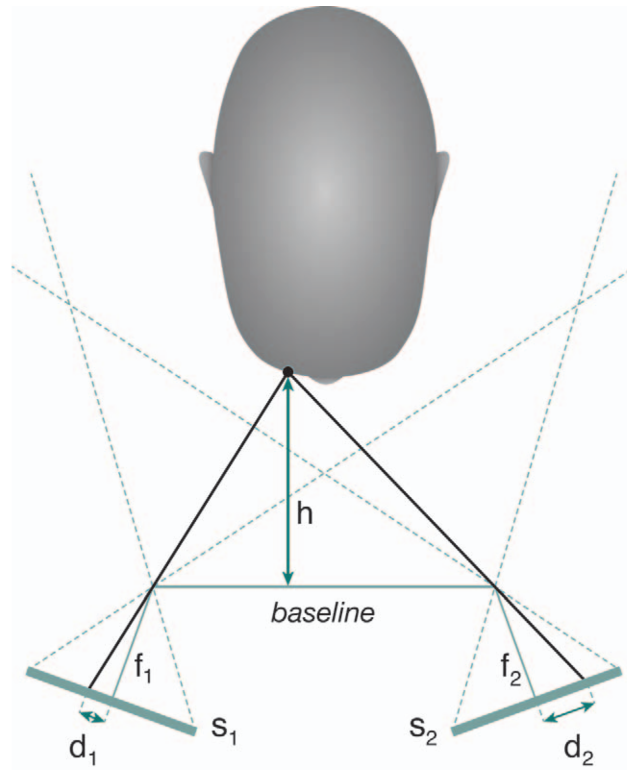

FIGURE 2. Stereophotogrammetry principle using two images (s = sensor, f = focal point, d = distance on image, h = distance to subject).

Data Processing

Depending on the type of system, setting and subject, the quality of the acquired 3D models may vary. However, for objective analysis, standardization of the data is critical. The pre-processing pipeline generally includes identification of inconsistencies, repairing, cleaning, resampling, and registration of the mesh prior to analysis (Fig. 4).

The mesh needs to be free from artifacts in the region of interest. Therefore, evaluation of the 3D mesh is preferably conducted immediately after acquisition which provides the opportunity to retake the image if necessary. In a later stage, the acquired mesh can be optimized.

Depending on the size of the subject and the system's resolution, a mesh consists of an arbitrary number of vertices. For most analysis methods the input data needs to have a consistent format. By resampling the meshes, each subject can be represented by the same number of vertices.

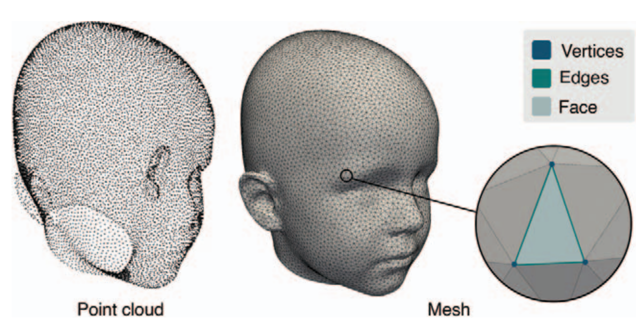

FIGURE 3. Point cloud (left) and polygonal mesh representation (right).

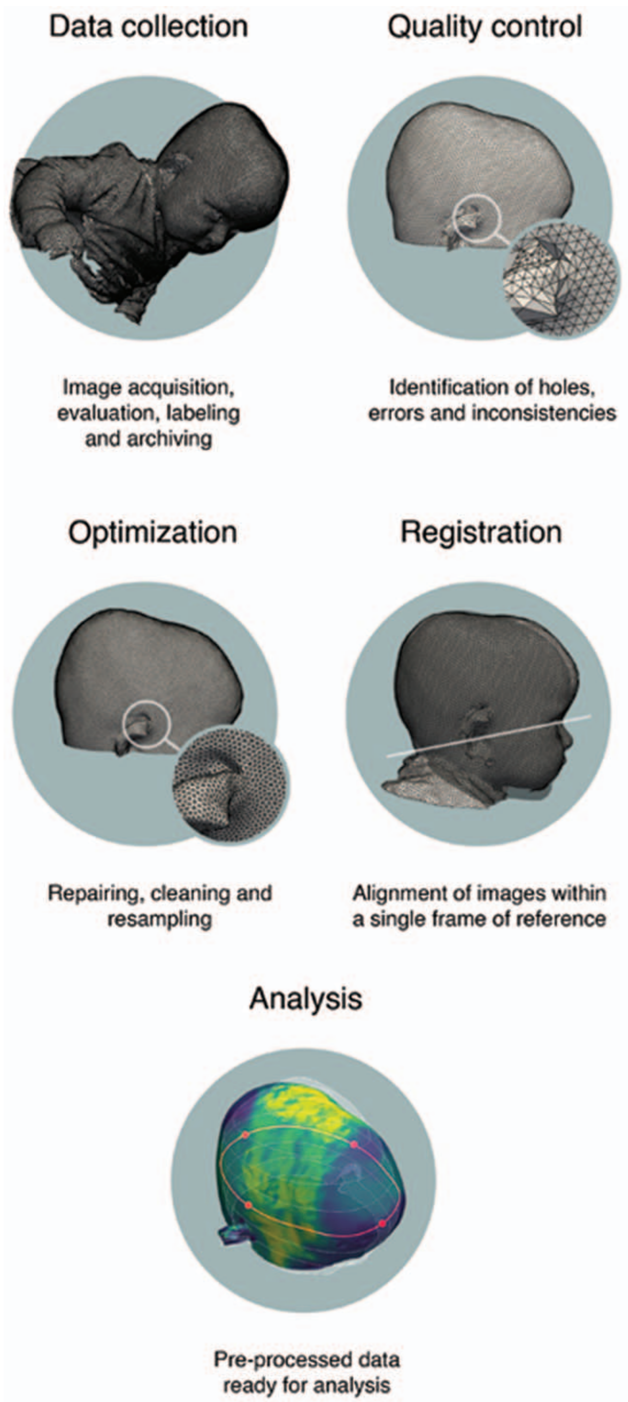

FIGURE 4. General pre-processing steps for photogrammetric data.

To analyze longitudinal differences and changes in cranial morphology, it is also important to align images in a standardized manner within a single frame of reference. The use of manually allocated facial landmarks is a widely used approach for registration. Alternatively, several fully automated registration methods have been proposed that do not require, or automatically detect, landmarks.[34–38] Popular, freely available, and open-source software programs for mesh processing, manipulation and simulations include MeshLab and Blender.

Acquisition Challenges

Three-dimensional stereophotogrammetry systems are sensitive to inadequate lighting conditions. If the subject is underexposed, the system requires a longer acquisition time that might result in movement induced artifacts and poor contrast. Both under-and over exposure of the subject result in loss of usable details and possible artifacts. To prevent loss in quality, most systems are equipped with proprietary illumination mechanisms that can be calibrated with the rest of the acquisition system to provide optimal lighting conditions. Regular calibration in accordance with the manufacturer's instructions will ensure optimal image quality.

Patients with congenital cranial anomalies such as craniosynostosis usually have a 3D image taken at a very young age. Although image acquisition itself is not time-consuming, the process can cause anxiety in young children, which consequently can result in artifacts. Medical photographers in the Erasmus MC Sophia Children's Hospital, added a small screen with animated movies next to the frontal camera of the 3dMDhead (Atlanta, GA) setup in an attempt to minimize anxiety. In addition, a designated area is reserved for a parent to comfort the child.

The surface quality of the 3D mesh can also be compromised by hairy or wet surfaces. It is therefore recommended to use a seamless (nylon) hair cap to cover the top of the head and to dry the nose and mouth before acquisition.

LITERATURE SEARCH STRATEGY

To review the existing literature on 3D stereophotogrammetry in relation to craniosynostosis, a search string was designed to extract publications from Web of Science. After screening and assessment of the articles in the publication set, a total of 27 articles were included, 19 of which discuss cranial use cases and 8 address the reliability and validity of 3D stereophotogrammetry in craniofacial applications (Fig. 5). An overview of the utilized materials in the reviewed studies is presented in Supplementary Table 1, http://links.lww.com/SCS/C251.

All reviewed articles were in English and had to address 3D stereophotogrammetry in a craniofacial context. The search string included a combination of the following keywords:

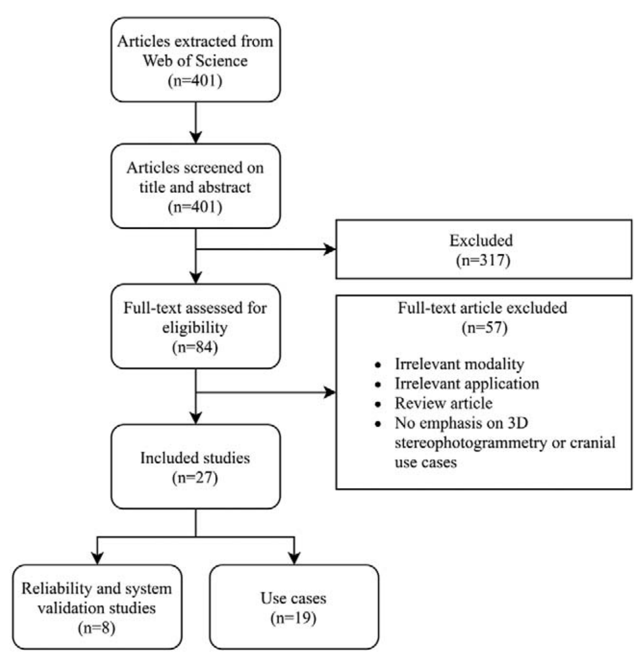

FIGURE 5. Search strategy flowchart.

1) 3D photogrammetry or stereophotogrammetry;
2) craniosynostosis (or subtypes);
3) cranial or head.

The search strategy is elaborated in *Supplementary Methods: Search strategy*.

RELIABILITY OF THREE-DIMENSIONAL STEREOPHOTOGRAMMETRY

Several studies have assessed the reliability of 3D stereophotogrammetry in terms of accuracy, bias, reproducibility, and repeatability.[39–45]

Traditional Anthropometric Methods

Direct measurements using callipers are still common in many craniofacial centers and serve as an acceptable ground truth for the evaluation of photogrammetry systems. Wong et al[39] measured linear distances between multiple defined craniofacial landmarks in 20 healthy adults and showed that measurements from 3D stereophotogrammetry were unbiased and highly accurate (mean absolute difference < 1 mm) with respect to direct anthropometry. A few years later, Schaaf et al[40] examined the reliability in a clinical setting in children with non-synostotic cranial deformations ($n = 100$). Repeated measurements conducted by multiple clinicians showed excellent reliability, concluding with the confident statement that 3D stereophotogrammetry could safely replace direct measurements. High accuracy and reliability with negligible errors were also demonstrated in studies using inanimate samples with different photogrammetry systems.[41,42] Nord et al[43] acknowledged the high technical precision, however, hypothesized that it might not be reliable for accurate landmark identification. In their study, 27 landmarks were evaluated six times in eight healthy subjects and showed that high reliability was achieved, contradicting the hypothesis. Heike et al[44] also reported precise 3D landmark identification with good repeatability and deemed it likely for 3D stereophotogrammetry to be more accurate than direct measurements, specifically in challenging facial areas (eg, around the eyes). Identification of landmarks obscured by hair as well as landmarks around the lips were reportedly easier by means of direct measurements with proper patient compliance.

Identification of specific craniofacial landmarks that correspond to the underlying bone structures such as the gonion, gnathion, zygion and glabella, appear to be challenging to reliably identify using surface imaging modalities.[43,44]

It should be said that direct measurements have served as extremely valuable tools in cephalometric analysis and generation of large normative craniofacial datasets. However, 2D measurements and ratios do no longer cover the whole spectrum of clinically relevant parameters as they are unable to capture the complexity of the 3D cranium and its evolution over time. 3D stereophotogrammetry enables more elaborate analysis of the cranium including volumetric analysis of the cranial vault, which is usually based on CT or Magnetic Resonance Imaging (MRI).

Volumetric Analysis Using Three-dimensional Stereophotogrammetry

A commonly used measure in volumetric analysis is the estimated volume of the cranial cavity as outlined by the cerebral contours, referred to as the intracranial volume (ICV). Several cranial reference planes have been described in 3D stereophotogrammetry literature for the alignment and subsequent analysis of 3D images (Fig. 6).[27,30,32,40,41,45,46] The planes are described by the following landmarks in the sagittal plane:

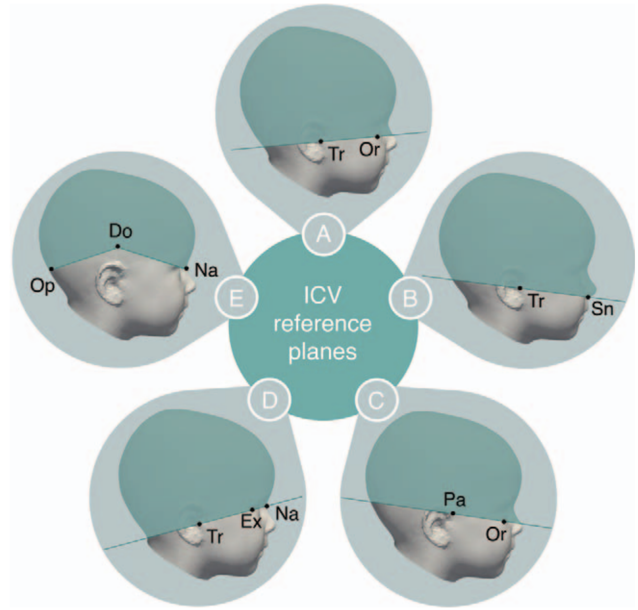

FIGURE 6. Intracranial volume (ICV) reference planes: (A) infra-orbital rim (Or) – tragus (Tr), (B) subnasal (Sn) – tragus (Tr), (C) infra-orbital rim (Or) – preaural (Pa), (D) lateral-canthus (Ex) – tragus (Tr), nasion (Na) – tragus (Tr), (E) opisthion (Op) – two dorsum sellaes (Do) – nasion (Na).

infra-orbital rim – tragus[40,41] (Fig. 6A)
subnasal - tragus[27] (Fig. 6B)
infra-orbital rim – preaural[46] (Fig. 6C)
lateral-canthus – tragus[45] (Fig. 6D)
nasion – tragus[32] (Fig. 6D)
opisthion – two dorsum sellaes – nasion[30] (Fig. 6E)

McKay et al[45] was one of the first to investigate the reliability of ICV measurements using 3D stereophotogrammetry in comparison to traditional CT. 60 patients were analyzed using multiple reference planes to approximate the ICV. At the time, the strongest correlation factor (0.91) was found using the axial plane through the lateral canthus and tragus (Fig. 6D). Very high inter-rater reliability was demonstrated using multiple datasets acquired by different photographers.

Reliability

The reviewed reliability studies all demonstrated high reliability for different photogrammetry systems. It is evident that the validated photogrammetry systems can serve as a reliable, complementary imaging modality with sub-millimeter accuracy and the capability to archive high-dimensional data for anthropometric and volumetric analysis of the face and cranium. However, its actual potential becomes more apparent in studies that use the acquired high-dimensional data in novel ways, for example, to gain insight into the complex growth and development of the cranium and the effect of treatment thereon.

CRANIAL USE CASES OF THREE-DIMENSIONAL STEREOPHOTOGRAMMETRY

Craniosynostosis and the Healthy Skull

An important requirement in the analysis of cranial deformations is a thorough understanding of the healthy cranium. 3D stereophotogrammetry enables researchers to study cranial shape variations, and growth patterns within the healthy population, providing the field with high-dimensional reference data that can be used for a variety of purposes including diagnosis, classification, surgical planning, quantification of malformations and evaluation of different treatments.

Craniofacial asymmetries occur in many cases of craniosynostosis and correcting this deformity is often one of the surgical aims. To achieve this aim, the definition of healthy asymmetry should first be understood.

Cho et al[19] used 3D stereophotogrammetry to study baseline asymmetry and its limits within the healthy pediatric population ($n = 533$). The authors found a mean head asymmetry (<3.6 mm) and mean facial asymmetry (<3.2 mm) in 99.7% of their healthy sample, which can serve as an objective measure of asymmetry.

In a recent study, Meulstee et al[28] analyzed 3D stereophotogrammetry ($n = 130$) and CT ($n = 170$) images from patients without morphological malformations to gain insight into the actual growth patterns during the first years of life. Presented growth maps in combination with extracted cephalometric data showed that anterior cranial growth in the first year of life is predominant after which notable growth occurs in posterior regions. Understanding what is assumed healthy will help to guide treatments in the future.

Reduced growth at the site of the affected suture is seen in patients with craniosynostosis, restricting volumetric growth of the cranium. Raised ICP is associated with a small ICV measure.[9,13] Therefore, surgical treatment is not only aimed at correcting the abnormal shape and asymmetries, but also at increasing the volume of the cranial cavity to minimize restriction and enable healthy development of the brain. There is however still no consensus in the literature on the exact relationship between craniosynostosis and ICV.

Seeberger et al[27] studied the intracranial volumes of preoperative patients with sagittal synostosis ($n = 71$) and healthy patients ($n = 829$) using 3D stereophotogrammetry. Significantly reduced intracranial volumes were found in male children with sagittal synostosis compared to the age- and gender-matched controls. A statistically insignificant reduced volume was found in a small group of female patients ($n = 9$). Other studies reported increased ICV measures in patients with sagittal synostosis compared to normative values based on 3D photogrammetry data.[32] Different outcomes between studies might be influenced by differences in sample size, age at measurement, the chosen normative reference data, or by differences in the selected reference plane. Thus, the exact relationship remains to be investigated.

Effect of Treatment in Craniosynostosis

Several studies utilized 3D stereophotogrammetry to evaluate different surgical techniques. Van Veelen et al[32] compared patients with sagittal synostosis who underwent an extended strip craniectomy ($n = 59$), a minimally invasive technique that is preferred for early intervention (age < 6 months), to patients who underwent late total cranial remodeling ($n = 36$). Pre-operative volume measurements from 3D stereophotogrammetry were correlated to CT. This enabled evaluation of the post-operative volumes from the acquired 3D images ($n = 129$) without having to subject a patient to another CT scan. The results showed a larger post-operative volume in patients who underwent a late total cranial remodeling.

De Jong et al[21] used 3D stereophotogrammetry to evaluate endoscopically assisted strip craniectomy with helmet therapy in patients with trigonocephaly ($n = 26$). 3D images ($n = 86$) were obtained before and after surgery to quantify the immediate effect of surgery on cranial shape and volume, uncorrected for natural growth due to lack of healthy photogrammetric data. Instead, CT scans of healthy children were reconstructed as a reference to identify changes in growth patterns and prominent areas of growth for different age groups. They were able to show that treated patients had a nearly similar shape and volume growth pattern over time with respect to the healthy subjects.

Wilbrand et al[22] demonstrated that surgery resulted in an increase in the anterior volume of trigonocephalic patients ($n = 12$), an increase of the CI of scaphocephalic patients ($n = 8$), and increased symmetry ratios in both anterior plagiocephaly ($n = 7$) and posterior plagiocephaly ($n = 1$). Significant post-operative cephalometric improvements and similar volumes were found by Linz et al[31] in a group of 20 patients with sagittal synostosis operated using broad median craniectomy, active tilting of the forehead and bitemporal greenstick fracturing.

Freudlsperger et al[23] showed that pre-operative frontal intracranial volumes were significantly lower in patients with metopic synostosis ($n = 18$) compared to their healthy age- and sex-matched control group ($n = 634$). No significant differences in intracranial volumes between the two groups were observed post-operatively.

Automated Classification and Quantification

For the diagnosis of craniosynostosis, imaging modalities such as CT or plain radiography are often used to provide clinicians with accurate information about the intracranial structures. There are however promising developments based on 3D atlas segmentation from CT where intracranial landmarks and structures can be propagated onto a new patient's surface mesh who had no CT taken.[30] Cranial bones of the closest normal head shape in this atlas are propagated to the 3D image to approximate the locations of the cranial bones and to quantify the local malformations. A type of supervised learning model (support vector machine classifier) based on the acquired local malformations was used to detect craniosynostosis from the 3D images with a significant increase in accuracy (91.03%) compared to detection based on traditional cephalometric measures (78.21%). Nevertheless, understanding the exact relationship between local intracranial anomalies and their subsequent effect on the global cranial morphology remains an important topic of study.

To prevent unnecessary treatment, machine learning algorithms can also provide valuable objective information in cases that are difficult to classify.[47] For example, closure of the metopic suture in healthy children occurs during infancy and can be accompanied by a benign visible ridge that does not require surgery. However, the resulting shape resembles the triangular shaped forehead seen in patients with trigonocephaly. Cho et al[47] studied prominent orbitofrontal regions in 43 patients presenting with some degree of orbitofrontal dysmorphology. To understand how much dysmorphology triggers surgical intervention, a popular unsupervised learning algorithm (K-means clustering) was used for automated classification into 2 groups: benign metopic ridge and metopic craniosynostosis. The algorithm showed a 96% agreement with the decisions made by the surgeons whether or not to operate. Four surgeons were then asked to re-evaluate the two cases where no agreement was found. In the first case, the surgeons were split 50:50. In the second case, all four surgeons agreed with the algorithm.

RESEARCH FIELD OVERVIEW

It is apparent that sample sizes are small in most of the reviewed studies and that there is no standardized protocol for 3D surface imaging as there is in the field of Radiology. This makes the reproducibility and objective comparability of study results difficult. Such problems are often resolved when large scale collaborations are present within a field. Therefore, we felt the need to analyze the current 3D stereophotogrammetry research field in order to investigate its collaborative nature, or lack thereof.

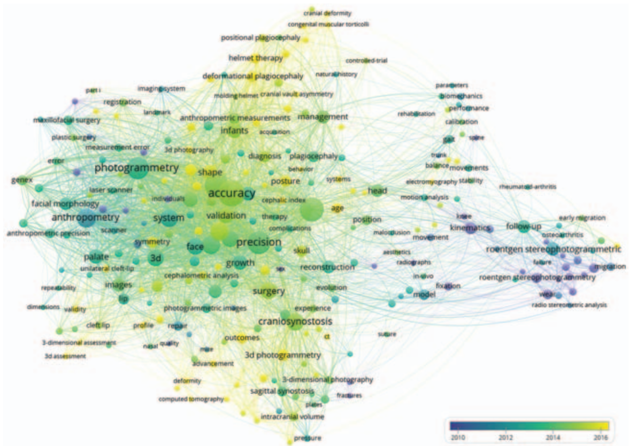

FIGURE 7. Bibliometric network of research topic attention (keyword threshold = 3, color scale reflects the average normalized publication year of all individual keywords).

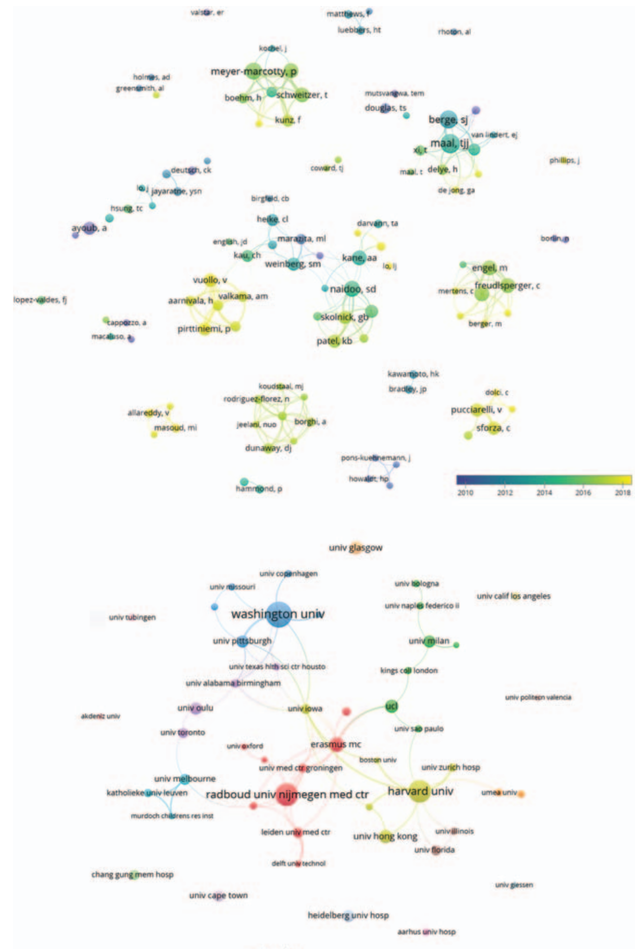

FIGURE 8. (upper) co-authorship map reflecting active researchers and groups (publication threshold = 3, color scale indicates the average publication year per author), (lower) institution map reflecting participation based on the affiliations on the publications (publication threshold = 3, labeled by color based on the strength of their co-publication relations).

The development of research topics in the field of 3D stereophotogrammetry related to craniosynostosis is visualized in (Fig. 7). The largest and most active topics of attention include 3D stereophotogrammetry reliability studies, craniofacial analysis, cosmetic applications, and anthropometric studies. In more recent years, the field seems to have shifted towards a more outcome driven approach in which 3D stereophotogrammetry is applied as a technique to facilitate objective assessment of specific treatments and planning with an increasing focus on the pediatric population. Considering the focal point in time (ie, color of the spheres) in combination with the large number of publications of studies (ie, size of the spheres) regarding the reliability and accuracy of 3D stereophotogrammetry, it is reasonable to suggest that these topics have remained popular and that the modality is subjected to continuous development.

Several groups worldwide are active in this specialized research field. On the level of groups and individuals there is limited collaboration (Fig. 8, upper). Though there is some interconnection in the core of the network of research groups that publish together, it seems that most of the groups operate individually and that there are not many connections yet between the more recently active groups in this research field. The number of active institutions (Fig. 8, lower) is somewhat smaller than the active research groups, implying that different research groups from the same institutions could be active in this field, sometimes without internal links between the groups. In practice, collaborations may exist without the mentioning of a co-author on a publication. There are relations observable between the active institutions though these ties are thin and sometimes based on a single co-authored paper.

We hypothesize that the reason for this lack in collaborations is the result of both technical and privacy concerns. Not every craniofacial center with a 3D stereophotogrammetry setup has the technical expertise and/or assistance to process and analyze raw 3D data. Available open-source frameworks often require programming knowledge to understand and use. From the clinician's perspective, there is the need for an accessible and user-friendly analysis framework that enables the user to simply provide an input image and in return provides automatic processing and analysis.

The other reason might result from privacy concerns regarding data sharing. This is problematic in terms of transparency and reproducibility of the research. It also limits the use of promising deep learning methods that require sufficiently large datasets for training. Solutions to facilitate deep learning techniques in a multi-institutional setting, without the need of sharing the raw data, are upcoming.[48,49]

Although the prevalence of craniosynostosis is rising globally, the number of patients presenting with craniosynostosis in each center is still relatively small. In addition, not all acquired data is usually suitable for pre-processing and analysis, which reduces this already small sample size even more.

Global collaborations and data sharing within the research field, in addition to the development of improved pre-processing methods and open-data frameworks, are ways to minimize loss and shortage of data. An example of an open-data platform for 3D surface anthropometry has been developed by Delft University of Technology, named DINED Mannequin. Large open-source software platforms such as 3DSlicer and ParaView, provide researchers with a platform for sharing of data processing, analysis, and visualization methods. Such developments can facilitate larger studies, which in turn can provide the field with a better understanding of these complex cranial dysmorphologies and associated phenotypes.

Bringing together expertise is often key to advance research. Present links (Fig. 8) could well be used to facilitate new or renewed collaborative research projects and ideas.

Methods used to generate these visualizations are described in Supplementary Methods: Bibliometric visualization.

CONCLUSION AND FUTURE DIRECTIONS

Three-dimensional stereophotogrammetry is a highly reliable, safe, and quick surface imaging modality with submillimeter accuracy that is applicable for the evaluation of craniofacial anomalies such as craniosynostosis. It provides clinicians and researchers with a reproducible instrument that enables acquisition and archiving of high-dimensional data for quantitative analysis, without subjecting the patient to harmful radiation or sedation, and is therefore especially suitable in young children.

Multiple craniofacial centers worldwide have implemented 3D stereophotogrammetry and their research provided a better understanding of the high-dimensional morphological intricacies of the cranium, its growth patterns, and the efficacy of different treatments over time.

With the rapid increase in technological developments, 3D stereophotogrammetry is expected to play an ever-important role in the future of diagnostics and treatment management of craniosynostosis and other craniofacial anomalies. Promising future directions include the development of novel machine learning methodologies that enable an entirely new patient-specific approach in which the short- and long-term effects of different treatments can be predicted, modelled, and compared at the level of each cranial bone. The development of automated pipelines that address registration, quantification and classification are also gaining popularity within the field. Such developments can be utilized to optimize the treatment plan and to aid surgeons in their decision-making process to ultimately provide each child with the most effective treatment.

There is however still a lot of potential that remains to be utilized. To overcome the technical and privacy challenges in the research field, the development of accessible and open-source frameworks for 3D image pre-processing and analysis are required, which ideally should be validated in a multi-center setup. As visualized in the research field overview, there is limited collaboration between centers and researchers. Consequentially, most of the research in the field involved a relatively small sample size and was not replicated, despite the consistent increase in prevalence of the disease and increasing number of publications. Therefore, there is an urgent need to make the research more transparent and reproducible, and to start collaborating on a larger scale. During these joint projects, it is important to involve clinicians to standardize clinical decision-making workflows and to understand their needs in daily clinical practice. Such collaborations will lead to the development and implementation of 3D stereophotogrammetry guidelines for clinicians to improve the therapeutic management of patients and the use of this modality.

Accessible analytical frameworks and large-scale collaborations that address harmonization of data standards are desired to facilitate larger studies and novel deep learning methods. This will help in the pursuit of reaching an objective consensus regarding the most effective treatment options, and to increase our understanding of craniosynostosis and other complex dysmorphologies.

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