3D Stereophotogrammetric assessment of surgical nose procedures

Bram van Loon
2014
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3D Stereophotogrammetric assessment of surgical nose procedures

Doctoral Thesis

To obtain the degree of doctor from Radboud University Nijmegen on the authority of the Rector Magnificus prof.mr. S.C.J.J. Kortmann, according to the decision of the Council of Deans to be defended in public on Friday, March 7, 2014 at 12.30 hours precisely

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Contents

1 General introduction 3
   1.1 The nose 5
   1.2 History of rhinoplastic surgery 5
   1.3 Imaging of the nose 7
   1.4 The 3D project 8
   1.5 Aim and objectives 9
   1.6 Overview of the thesis 10
   1.7 References 12

2 Registration of three-dimensional facial photographs for clinical use 15
   2.1 Introduction 17
   2.2 Materials and Methods 17
   2.3 Results 22
   2.4 Discussion 27
   2.5 References 30

3 Variation of the face in rest using 3D stereophotogrammetry 35
   3.1 Introduction 37
   3.2 Materials and methods 37
   3.3 Results 39
   3.4 Discussion 40
   3.5 References 44

4 Three dimensional measurement of rhinoplasty results 47
   4.1 Introduction 49
   4.2 Materials and methods 49
   4.3 Results 51
   4.4 Discussion 52
   4.5 References 55
5 3D Stereophotogrammetric assessment of pre- and postoperative volumetric changes in the cleft lip and palate nose.

5.1 Introduction 61
5.2 Materials and Methods 61
5.3 Results 66
5.4 Discussion 68
5.5 References 72

6 3D stereophotogrammetric analysis of lip and nasal symmetry after primary chei-loseptoplasty in complete unilateral cleft lip repair 77

6.1 Introduction 79
6.2 Materials and Methods 79
6.3 Results 82
6.4 Discussion 86
6.5 Conclusions 87
6.6 References 88

7 Postoperative volume increase of facial soft tissue after percutaneous versus endonasal osteotomy technique in rhinoplasty using 3D stereophotogrammetry 93

7.1 Introduction 95
7.2 Materials and Methods 95
7.3 Results 97
7.4 Discussion 100
7.5 Conclusions 103
7.6 References 104

8 Volumetric changes of the nose and nasal airway two years after tooth-borne and bone-borne surgically assisted rapid maxillary expansion 107

8.1 Introduction 109
8.2 Materials and Methods 109
8.3 Results 114
8.4 Discussion 116
8.5 Conclusion 117
8.6 References 118
1

General introduction
General introduction

1.1 The nose

Through the ages man’s nose suffered great brunt. The nose has been mutilated for punishment; shot, blown off, and burned in battle; bitten, avulsed, and sloughed in peacetime; shriveled from within by disease; scorched by the sun; eroded by cancer; deformed by surgery; crunched on the road; and punched in the ring.

Not only the human nose suffered but even the noses on sculptured human statues, due to their relative prominence and fragility, are prone to injury from weather, vandalism, and accident. A good example of this is the great sphinx of Egypt, built around 2600 B.C. of sandstone. The sphinx was shaped at the bottom like a seated lion but with the head of a man (and the features of King Ka-f-ra). A great part of his nose is missing, while all else seems intact. Some say when Islam entered Egypt, a Muslim destroyed the nose to prove the Sphinx was but a statue. Others say the nose was blown off by Napoleon’s cannons. However it is far more likely that the sandstone nose, the most protruding feature of the face of the statue, suffered injury over time from sun, rain, wind, and sand storms. As the central and prominent feature of the face, minor abnormalities and discrepancies of the nose draw immediate attention. There has always been an inherent desire in man to look like his fellow man and to not appear horrible, peculiar, or different.

There has been a marked variation in the ability of man to adjust a deformed nose. Yet a huge nose, a peculiarly shaped nose, a tiny nose, a nose with part missing, or no nose at all can elicit despair. As the nose is front and center, the skill of its reduction, reshaping, and reconstruction is important, and proof of success of the surgical result rests not only in the harmony of its aesthetic proportions, relationships, and symmetry, but in its naturalness.

1.2 History of rhinoplastic surgery

The contents of this paragraph have mainly been acquired from the Wikipedia page http://en.wikipedia.org/wiki/History_of_rhinoplasty. The first description of a rhinoplastic procedure is attributed to a rhinologist, named Ni-Ankh-Sekhmet, a physician to King Sahura in the Vth Dynasty in Ancient Egypt (2487-2475 BC). His tomb was discovered in Saqqara in 1889. The false door of the tomb was removed and inspection and translation of the hieroglyphics give evidence. The most important part of the inscriptions of the whole false door is: ‘the one who healed this nose’, referring to the king’s nose. There is no indication from the inscriptions what was wrong with the king’s nose. The Ebers Papyrus (ca. 1550 BC), an Ancient Egyptian medical papyrus first described rhinoplasty as the surgical operation for reconstructing a nose destroyed by rhinectomy, such a mutilation was inflicted as a criminal, religious, political, and military punishment in that time and culture.

Rhinoplasty developed some time later in ancient India by the physician Sushruta (ca. 600 BC), who described reconstructions of the nose in the Sushruta samhita, his medico-surgical compendium. The physician Sushruta and his medical students developed and
applied plastic surgical techniques for reconstructing noses, genitalia, earlobes and parts of the body that were amputated for religious, criminal, or military punishment. Sushruta also developed the forehead flap rhinoplasty procedure. During the Roman Empire (27 BC–AD 476) Aulus Cornelius Celsus (ca. 25 BC–AD 50) published De Medicina (On Medicine, ca. AD 14), in which he described plastic surgery techniques and procedures for the correction and the reconstruction of the nose and other parts of the body. At the Byzantine Roman court of the Emperor Julian the Apostate (AD 331–363), the royal physician Oribasius (ca. AD 320–400) published the 70-volume Synagogue Medicae (Medical Compilations, AD 4th c.), which described facial-defect reconstructions with the use of autologous skin flaps to repair damaged cheeks, eyebrows, lips, and noses.

During the centuries of the European middle ages (AD 5th–15th centuries), the fifth-century BC Asian knowledge of the Sushruta samhita remained unknown. In the eleventh century, at Damascus, the Arab physician Ibn Abi Usaibia (1203–1270) translated the Sushruta samhita from Sanskrit to Arabic. In due course, Sushruta’s medical compendium travelled from Arabia over Persia to Egypt, and, by the fifteenth century, Western European medicine had encountered it as the medical atlas Cerrahiyyet-ul Haniye (Imperial Surgery, 15th c.), by Şerafeddin Sabuncuoğlu (1385–1468).

In Italy, Gasparo Tagliacozzi (1546–1599), professor of surgery and anatomy at the University of Bologna, published Curtorum Chirurgia Per Insitionem (The Surgery of Defects by Implantations,) in 1597, a manual for the surgical repair and reconstruction of facial wounds in soldiers. The illustrations featured a re-attachment rhinoplasty using a biceps muscle pedicle flap which at 2-weeks post-attachment was shaped into a nose.

In the eighteenth century, the fifth-century BC Indian rhinoplasty technique, was (re)discovered by Western medicine. The East India Company surgeons Thomas Cruso and James Findlay witnessed Indian rhinoplasty procedures and published photographs of this procedure and its nasal reconstruction outcomes in the Madras Gazette. Later, in the October 1794 issue of the Gentleman’s Magazine of London, Cruso and Findlay published an illustrated report describing a forehead pedicle-flap rhinoplasty that was a technical variant of the free-flap graft technique that Sushruta had described some twenty-three centuries earlier.

In Great Britain, Joseph Constantine Carpue (1764–1846) published the Account of Two Successful Operations for Restoring a Lost Nose (1815), which described two rhinoplasties: the reconstruction of a battle-wounded nose, and the repair of an arsenic-damaged nose. In Germany, rhinoplastic technique was refined by surgeons such as the Berlin University professor of surgery Karl Ferdinand von Gräfe (1787–1840). He published Rhinoplastik (Rhinoplasty, 1818) in which he described fifty-five historical plastic surgery procedures (Indian rhinoplasty, Italian rhinoplasty, etc.) He also added his technically innovative free-graft nasal reconstruction, a technique with a tissue-flap, harvested from a patient’s arm. Von Gräfe’s protégé, Johann Friedrich Dieffenbach (1794–1847), who was among the first surgeons to anaesthetize patients before performing nose surgery, published Die Operative Chirurgie (Operative Surgery, 1845), which became a foundational medical surgical text.

From this moment on refinements of techniques which mainly focused on improving
esthetics were developed. In the United States, in 1887, the otolaryngologist John Orlando Roe (1848–1915) performed the first, endonasal rhinoplasty (closed rhinoplasty) and reported about his management of saddle nose deformities in the article *The Deformity Termed “Pug Nose” and its Correction, by a Simple Operation* (1887) ⁵. The Prussian Jacques Joseph (1865–1934) published *Nasenplastik und sonstige Gesichtsplastik* (Rhinoplasty and other Facial Plastic Surgeries, 1928), which described refined surgical techniques for performing nose-reduction rhinoplasty using internal incisions ².

In the early twentieth century, Freer, in 1902, and Killian, in 1904, respectively pioneered the submucous resection septoplasty (SMR) procedure for correcting a deviated septum. In 1921, Rethi introduced the open rhinoplasty approach featuring an incision to the columella to facilitate modifying the tip of the nose. In 1929, Peer and Metzenbaum performed the first manipulation of the caudal septum. In 1921, Rethi introduced the open rhinoplasty approach featuring an incision to the columella to facilitate modifying the tip of the nose. In 1929, Peer and Metzenbaum performed the first manipulation of the caudal septum. In 1921, Rethi introduced the open rhinoplasty approach featuring an incision to the columella to facilitate modifying the tip of the nose. In 1929, Peer and Metzenbaum performed the first manipulation of the caudal septum. In 1947, Maurice H. Cottle (1898–1981) endonasally resolved a septal deviation with a minimal incision, which conserved the septum. He advocated for the closed rhinoplasty approach. In 1957, Sercer advocated the “decoration of the nose” (Dekortikation der Nase) technique which featured a columellar-incision open rhinoplasty that allowed for greater access to the nasal cavity and nasal septum ⁶. At mid–twentieth century, despite such refinement of the open rhinoplasty approach, the endonasal rhinoplasty was the usual approach to nose surgery until the 1970s, when Padovan ⁷ presented his technical refinements, advocating the open rhinoplasty approach; he was seconded by Wilfred S. Goodman in the late seventies, and by Jack P. Gunter in the nighties. Goodman ⁸ described technical and procedural progress with the article *External Approach to Rhinoplasty* (1973), in which he reported about his technical refinements, so popularizing the open rhinoplasty approach. In 1982, Jack Anderson ⁹ reported his refinements of nose surgery technique in the article *Open Rhinoplasty: An Assessment* (1982). In 1987, in the article *External Approach for Secondary Rhinoplasty* (1987), Jack P. Gunter ¹⁰ reported the technical effectiveness of the open rhinoplasty approach for performing a secondary rhinoplasty; his improved techniques advanced the management of a failed nose surgery.

1.3 Imaging of the nose

Pre- and postoperative standard and uniform (digital) color photographs are important and essential for postoperative evaluation of the (long-term) results of all kinds, but certainly of facial surgery. In addition, these photographs can also be used for teaching and research purposes. Most studies describing objective changes after surgical nose procedures are based on two-dimensional (2D) standardized photographs. This poses several potential problems. First, the pre- and postoperative pictures must be made in exactly the same way, i.e. from the same distance and with the head in an identical position to prevent over- or underestimation of absolute changes in for instance tip projection/rotation or width of the alar base. This problem may be overcome using relative measurements ¹¹, ¹², but this method is more time-consuming and still liable to the second disadvantage of using normal pictures: the complex three-dimensional (3D) appearance of the nose is studied on 2D pictures. Nowadays, advances in technology have generated
several 3D techniques to capture facial topography and overcome the deficiencies and problems encountered with conventional photographs. One of these techniques is 3D stereophotogrammetry. 3D stereophotogrammetry is a technique that uses two or more cameras configured as pairs to capture multiple views of the face from different angles. These different views are used to form a 3D photograph. An early disadvantage of 3D stereophotogrammetry has been its inaccuracy, but recently the technique has been improved resulting in high-quality, realistic 3D photographs. Pre- and postoperative 3D photographs can now be superimposed and the differences between the two surfaces can be compared to provide information about the results of facial surgery.

1.4 The 3D project

This thesis is part of a larger 3D project of which the main objective is to enhance the accuracy of 3D imaging, especially with regard to image fusion of the facial soft tissue surface, the facial skeleton and the dentition and to implement these techniques in daily clinical practice. In order to reach these goals a “3D lab” has been setup in the Radboud University Nijmegen Medical Centre, Nijmegen, the Netherlands (RUNMC) in 2005. To achieve the main objective of the 3D project, four keystones were found to be essential. They have been discussed in previous theses and are therefore only summarized here.

- A close cooperation between technical engineers, medical researchers and clinicians is mandatory to consider a clinical problem from different viewpoints and to think and act beyond the regular path.
- The use and upgrading of high tech hardware and up-to-date software is necessary to enable acquisition, composition, analysis and improvement of 3D data.
- A considerable patient population undergoing surgery is required to enable the set-up of a databank with a large amount of pre- and postoperative patient data.
- There is a need to develop methods to transfer preoperative virtual planning into the operative theatre.

An infrastructure was developed which made it possible to think and act beyond the regular path. In this way other medical and dental specialities and hospitals were also involved in collaboration projects. During the past years use and implementation of 3D imaging techniques became routine use in the various subspecialties of oral and maxillofacial surgery. In the fields of implantology and orthognathic surgery, a shift from conventional 2D imaging and planning towards the 3D alternative took place. In the oncology field more and more preoperative 3D imaging and reconstruction planning took place the past years.

3D Imaging techniques that have been available and clinically used throughout the past few years are:
General introduction

- Cone beam computed tomography (CBCT) (to acquire bone and soft tissue information of the viscerocranium)
- 3D stereophotogrammetry (to acquire textured information of the skin surface)
- Digital dental models (to acquire accurate dental tissue information)

These imaging techniques have been used as single modalities in the early years of the 3D Lab. With increasing technological advancements it became possible to combine these different imaging modalities and fuse them into an augmented 3D dataset.\textsuperscript{18, 19}

Considering the various subspecialties of oral and maxillofacial surgery, three major research fields have been defined within the 3D Lab:

1. Dento-alveolar surgery, especially implantology
2. Facial surgery, especially orthognathic surgery and patient with congenital deformities (e.g. cleft lip and palate) as well as patients with craniofacial deformities.
3. Oncology, especially head and neck reconstructive surgery

This thesis is part of the second major research theme. It is concerned with assessment of nasal changes in cleft lip and palate treatment, after orthognathic surgery and in patients undergoing isolated rhinoplasty procedures.

1.5 Aim and objectives

The aim of this thesis is to study the effects of various surgical interventions on the appearance of the nose itself, using three dimensional techniques. To make this possible 3D imaging hard- and software modalities have been used.

The main objectives of this thesis are twofold. In the first part the focus is on the validity of 3D stereophotogrammetry in imaging the face. The combination of several 3D photographs is investigated in different ways. Secondly the possibilities of integrating 3D photogrammetric datasets is discussed in several clinical studies. The following questions had to be answered:

- Is it possible to compare multiple 3D photographs acquired using 3D stereophotogrammetry on different moments and is this method accurate and reliable? (chapter 2 and 3)
- Is 3D stereophotogrammetry useful to acquire quantitative data from the nasal region and can this be used to evaluate surgical outcome? (chapter 4)
• How does the nose change due to rhinoplastic surgical interventions? (chapter 5, 6, 7)

• Does the nose change due to surgery of the maxillary complex? (chapter 8, 9)

1.6 Overview of the thesis

In 2005 the hardware of the 3D lab consisted of a 3D stereophotogrammetrical camera setup (3dMDface™ System, 3d MD Ltd, Atlanta, USA), which was used to collect 3D photographs of the facial soft tissue surface. Besides 3D software environments to view and analyse the 3D photographs (3dMD patient™ Software Platform version 1.0, 3dMD Lts, Atlanta, USA) a virtual software package in the form of Maxilim® (Medicim NV, Mechelen, Belgium) was available to view, combine, analyse and edit various 3D imaging modalities such as .OBJ, .STL, and dicom data.

The Maxilim® software made it possible to combine multiple 3D modalities such as 3D photographs and Cone Beam CT dicom data. An alternative to this, when no CBCT dicom data were available, was to use multiple 3D photographs for evaluation of changes over time or evaluation of surgery. The performed research to evaluate the accuracy of registering 3D photographs for clinical use is presented in chapter 2 and chapter 3.

In chapter 4 the use of 3D stereophotogrammetry was evaluated for patients who underwent rhinoplastic surgery, specifically in patients who underwent a correction for the “hump” deformity. This study actually first implemented the registration of 3D photographs for evaluation of rhinoplastic results. Although mainly a visual study, some preliminary quantitative information was already collected.

In chapter 5, pre- and postoperative 3D photographs were registered using the method described in chapter 2. The effects of rhinoplastic surgery on patients with a cleft lip and palate deformity was evaluated using a method to calculate partial volumes from the nose after registering 3D photographs. This made a quantitative evaluation of the nose pre- and postoperatively possible. The symmetry of the nose was measured pre- and postoperatively and compared.

In chapter 6 the Afroze cleft-lip incision technique and its influence on the lip and nose was evaluated postoperatively using the volumetric measurements presented in chapter 5 as well as using various linear measurements. The measurements were compared to a group of healthy controls.

Chapter 7 compares the use of two different nasal osteotomy techniques to evaluate swelling caused by these techniques. The percutaneous perforating and the endoanasal continuous techniques are compared using pre- and postoperatively volumetric measurements of the paranasal area using a method comparable to the one described in chapter 5.
In chapter 8 the influence of bone or tooth borne maxillary expansion on the external nose volume, alar width and the airway volume of the nose was evaluated using CBCT and 3D photographs. Airway volume was acquired from the CBCT data pre- and postoperatively. The 3D photographs were used to calculate volumes and alar width measurements pre- and postoperatively.

In chapter 9 the influence of maxillary movement on the soft tissues of the nose and lip was evaluated. Both CBCT and 3D photographs were acquired pre- and postoperatively and fused into one 3D model. Translations and rotations of the maxilla, and volumetric and linear measurements from the nose and lip were acquired and correlated.

In chapter 10 the related implications are discussed.
1.7 References

Registration of three-dimensional facial photographs for clinical use

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Chapter 2

Introduction
To objectively evaluate treatment outcomes in oral and maxillofacial surgery, pre- and post-treatment three dimensional (3D) photographs of the patient’s face can be registered. For clinical use, it is of great importance that this registration process is accurate (1 mm). The purpose of this study was to determine the accuracy of different registration procedures.

Methods
Fifteen volunteers (7 males, 8 females; mean age, 23.6 years; range, 21 to 26 years) were invited to participate in this study. Three dimensional photographs were captured at 3 different times: baseline ($T_0$), after 1 minute ($T_1$), and 3 weeks later ($T_2$). Furthermore, a 3D photograph of the volunteer laughing ($T_L$) was acquired to investigate the effect of facial expression. Two different registration methods were used to register the photographs acquired at all different times: surface-based registration and reference-based registration. Within the surface-based registration, 2 different software packages (Maxilim [Medicim NV, Mechelen, Belgium] and 3dMD Patient [3dMD LLC, Atlanta, GA]) were used to register the 3D photographs acquired at the various times. The surface-based registration process was repeated with the preprocessed photographs. Reference-based registration (Maxilim) was performed twice by 2 observers investigating the inter- and intraobserver error.

Results
The mean registration errors of the surface-based method are small for the 3D photographs at rest (0.39 mm for $T_0$-$T_1$ and 0.52 mm for $T_0$-$T_2$). The mean registration error increased to 1.2 mm for the registration between the 3D photographs acquired at $T_0$ and $T_L$. The mean registration error for the reference-based method was 1.0 mm for $T_0$-$T_1$, 1.1 mm for $T_0$-$T_2$, and 1.5 mm for $T_0$ and $T_L$. The mean registration errors for the preprocessed photographs were even smaller (0.30 mm for $T_0$-$T_1$, 0.42 mm for $T_0$-$T_2$, and 1.2 mm for $T_0$ and $T_L$). Furthermore, a strong correlation between the results of both software packages used for surface-based registration was found. The intra- and interobserver error for the reference-based registration method was found to be 1.2 and 1.0 mm, respectively.

Conclusion
Surface-based registration is an accurate method to compare 3D photographs of the same individual at different times. When performing the registration procedure with the preprocessed photographs, the registration error decreases. No significant difference could be found between both software packages that were used to perform surface-based registration.
Registration of three-dimensional facial photographs for clinical use

2.1 Introduction

In the past few years, three dimensional (3D) technology has evolved with high speed in oral and maxillofacial surgery. The evolution of the cone beam computed tomography scanner made accurate imaging of the hard tissues or bony structures of the face possible with a relatively low radiation dose. Apart from hard tissue imaging, 3D photogrammetry cameras (3D stereophotogrammetry) can be used to capture the soft tissue surface of the face with correct geometry and texture information.

To evaluate the results of surgical interventions in oral and maxillofacial surgery, pre- and postoperative 3D photographs of the patient’s face can be matched. In medical imaging, this matching procedure is referred to as registration. After registration of the 3D photographs, the differences between them can be visualized by a color scale or distance map. In this way, results of surgical\(^2\)-\(^7\) and nonsurgical treatment\(^8\)-\(^10\) can be evaluated quantitatively and objectively. Other useful applications comparing different 3D photographs are the evaluation of different types of swelling over time (eg, phlegmon, abscess, tumor growth), cross-sectional growth changes\(^11\), and establishment of databases for normative populations.\(^12\) Various clinical examples are illustrated in Figure 1.

Because the imaging systems are affected by changes in muscle tone, facial expression, and head posture, reliability and reproducibility of these systems have to be validated. Most reliable studies have referred to linear measurements to validate their systems.

For clinical use, it is of great importance that the registration process of the pre- and postoperative 3D photographs is accurate (1 mm).\(^13\) This is important because any changes in facial morphology could be due to inherent errors of the technique or to actual growth or treatment changes. With the validity of the scanning system already evaluated, the purpose of this study was to quantify the reproducibility of obtaining 3D photographs over time and to evaluate the different registration procedures.

2.2 Materials and Methods

2.2.1 Data acquisition

In this prospective study 15 volunteers (7 males, 8 females; mean age, 23.6 years; range, 21-26 years) were invited to participate. 3D photographs of the volunteers were captured using a 3D stereophotogrammetric camera setup and the software program Modular System (3dMDfaceSystem; 3dMD LLC, Atlanta, GA). During acquisition, the volunteers were asked to bite in maximum intercuspitation, swallow, relax their lips, and keep their eyes open. For every volunteer, a 3D photograph was acquired on 3 different points of time:
- TO (the first 3D photograph)
- T1 (1 minute after the first 3D photograph)
- T2 (3 weeks after the first 3D photograph)
Figure 1. Clinical application of registering different 3D photographs. The images on the top row illustrate the evaluation of a treatment of masseter hypertrophia using Botulin toxin. The images on the bottom row illustrate the use of mirroring and surface registration to investigate the amount of soft tissue loss.
Furthermore, a 3D photograph of the volunteers laughing (TL) was acquired shortly after TO to investigate whether different facial expression affects the registration error. Two different types of registration were performed: surface-based registration and reference-based registration.

### 2.2.2 Surface-based registration

Surface-based registration of 2 different 3D photographs was performed using 2 different software packages: Maxilim v.2.2.1 (Medicim NV, Mechelen, Belgium) and 3dMD Patient v3.0 (3dMDpatient Software Platform; 3dMD LLC, Atlanta, GA). Both software packages use an adapted version of the Iterative Closest Point algorithm to perform surface-based registration.\(^1\)\(^,\)\(^1\)\(^4\)

First, the original 3D photographs were registered using both software packages. A surface-based registration was performed between the 3D photograph acquired at TO and T1. Second, the 3D photographs acquired at time TO and T2 were registered. Finally, the 3D photographs of time TO and TL were registered to investigate the influence of facial expression. All these registrations result in several distance maps that were used to analyze the accuracy of the registration.

After registration of the original 3D photographs, a second registration procedure was performed in which the 3D photographs were preprocessed. By removing the hair and neck regions from the 3D photographs, obvious error regions were excluded during registration (Fig 2).

The registration procedures and preprocessing were performed on a Dell Precision M70 (Intel Pentium IV 2.62-GHz processor speed, 2.0 Gbp RAM, NVIDIA Quadro Fx Go 1400, 256 Mbp, graphics card).

### 2.2.3 Reference-based registration

After the surface-based registration procedure, a second, but different registration procedure was performed. This method is called reference-based registration. The 3D software program Maxilim allows a step-by-step setup of a frame based on the Cartesian coordinate system.\(^1\)\(^5\) It involves the following consecutive steps (Fig 3):

1. Selecting the 3D photograph the frame would be setup on
2. Selecting the right and left exocanthion (this is a part of the vertical plane setup)
3. Defining the line crossing the right exocanthion and sup aur al
4. Indicating the pupil reconstructed point landmark. This landmark is defined as the point in the middle of the line through the pupils. This is part of the median plane setup.

After finalizing these steps, the software computes the position of each plane, which forms the reference frame (Fig 3).

After setting the reference frames for all the 3D photographs (TO, T1, T2, and TL), the
Figure 2. Illustration of the different registration procedures. Two different registration methods were used to register the 3D photographs acquired at all different time points: surface-based registration (illustrated in the orange frame) and reference-based registration (illustrated in cyan frame). Within the surface-based registration, 2 different software packages (Maxilim and 3dMD Patient) were used to register the 3D photographs acquired at the various time points. The surface-based registration process was repeated with the preprocessed photographs. Reference-based registration (Maxilim) was performed twice by 2 observers investigating the inter- and intraobserver error.
Figure 3. 3D photograph-based reference frame. The horizontal plane of the reference frame is automatically computed as a plane 6.6 degrees below the cantion-superaurale line, along the horizontal direction of the natural head position. The plane goes through the pupil reconstructed point (the center point between the left and right eyes). The vertical plane is a plane perpendicular to the horizontal plane and along the horizontal direction of the natural head position. The median plane is a plane perpendicular to the horizontal and vertical planes.¹⁵
3D photographs could be superimposed by overlying all reference planes. In this way the 3D photograph acquired at TO and T1, TO and T2, and finally TO and TL were registered. After performing the reference-based registration, several distance maps were computed and the registration errors were analyzed. Two observers performed the setup of the reference frame for this method because placement of the landmarks is observer dependant. In this way an intra- and inter observer analysis of the reproducibility could be calculated.

2.2.4 Validation

To validate the accuracy of the different methods, the difference between the corresponding surfaces was calculated as a distance or error map. This distance map computes the difference (Euclidean distance) between the 3D photographs on a large number of points (∓20,000). The 50th, 90th, and 95th percentile of the registration error were computed in millimeters. Using these measurements, the differences between surface-based registration and reference-based registration could be evaluated. Within the surface-based registration procedure, the influence of preprocessing the 3D photographs could be investigated as well as the use of different software systems. To visualize these differences, a graph of the mean, box plots, and correlation graphs were computed.

The intra- and interobserver error for the surface-based registration method was evaluated in previous studies. In the current study, the inter- and intraobserver error for registration using the reference-based method was investigated.

2.3 Results

The mean registration errors are small for the 3D photographs at rest at different points of time (0.39 mm for T0-T1 and 0.52 mm for T0-T2). The mean registration error increases to 1.2 mm for the registration between the 3D photographs acquired at T0 and TL (Table 1). The mean registration error for the reference-based method was 1.0 mm for T0-T1, 1.1 mm for T0-T2, and 1.5 mm for T0 and TL.

To visualize not only the mean registration error but also the variance in the registration error, box plots were computed for the different time points and methods (Fig 4). Within the surface-based registration method, a distinction between the original and preprocessed 3D photographs can be made. The mean registration errors for the preprocessed photographs were less obvious than for the original photographs (0.30 mm for T0-T1, 0.42 mm for T0-T2, and 1.2 mm for T0 and TL) (Fig 5).

The registration error for the surface-based registration is smaller if compared with the reference-based registration (Fig 6). Within the reference-based registration, a mean error of 1.2 mm (interobserver) and 1.0 mm (intraobserver), respectively, was found. Concerning the used software for the surface-based registration, both software packages showed a very similar registration error (Fig 7).
Figure 4. Box plots illustrating the median, 25th, and 75th percentiles of the registration error for all surface- and reference-based registration methods.
Figure 5. Illustration of the differences in the registration error (mm) between using the original 3D photographs or the preprocessed 3D photographs. The top image illustrates the errors in a Bar graph. The bottom image illustrates the correlation of registration errors for using the original and preprocessed 3D photographs.
Figure 6. Illustration of the differences in the registration error (mm) between surface-based registration and reference-based registration. The top image illustrates the errors in a Bar graph. The bottom image illustrates the correlation between the surface-based registration method and the reference-based registration method.
Figure 7 Comparison between the 2 different software packages (Maxilim and 3dMD Patient). The results showed a large correlation between both registration algorithms as illustrated in the bottom image. The top image illustrates the registration errors as a Bar graph.
Registration of three-dimensional facial photographs for clinical use

2.4 Discussion

In this prospective study, the accuracy of 3D stereophotogrammetry was evaluated in a clinical setting using 3D photographs of 15 individuals at different times. After registration of the different 3D photographs of the same individuals, different registration errors were analyzed to investigate the accuracy.

In 1838, the first portfolio of stereoscopic photographs was created.\textsuperscript{16,17} Since that time, stereography evolved from the crude dual camera systems of the past to the modern 3D digital photographic systems, nevertheless still using the same principle: offset images are merged together to create a stereoscopic image.

With the advent of digital technology, digital photography has become an increasingly important tool in facial surgery.\textsuperscript{17} Nowadays many commercial systems are available on the market (eg, 3dMDface System [3dMD LLC], Di3D [Dimensional Imaging, Glasgow, UK], 3D-Sensoren FaceSCAN [3D Shape GmbH, Erlangen, Germany]).

Earlier studies were performed to investigate the accuracy of 3D stereophotogrammetry. These studies mostly focused on reliably measuring distances between typical anthropometric points on the 3D reconstructed images against corresponding points on live subjects or phantom models (eg, plaster casts) as a form of validation.\textsuperscript{2,18-24} Some other studies use more complex methods to obtain and analyze 3D shapes.\textsuperscript{25-27} Also, the accuracy of other surface acquisition systems, eg, laser scanning, has been evaluated in several studies.\textsuperscript{28-35} Kau et al investigated the accuracy of capturing laser scans of the same individual at different time points using a commercially available Minolta Vivid 900 laser scanner system.\textsuperscript{36} The results showed a mean registration error of below 0.4 mm; the error was within a range of 0.85 mm for 90% of the registration. Ma et al\textsuperscript{18} investigated the accuracy of a structured light technique to capture the geometry of the face and investigated the accuracy of structured light scans by capturing the same individual at different moments in time. A reliability of 0.2 mm was found in this study.

To the best of our knowledge, no studies have been performed to investigate the accuracy of 3D stereophotogrammetry (3dMD) in a clinical setting.

<table>
<thead>
<tr>
<th></th>
<th>T0-T1 Mean</th>
<th>T0-T2 Mean</th>
<th>T0-TL Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>SD</td>
<td>SD</td>
<td>SD</td>
</tr>
<tr>
<td>3dMD (original)</td>
<td>0.3977</td>
<td>0.5228</td>
<td>0.5304</td>
</tr>
<tr>
<td>Maxilim (original)</td>
<td>0.3913</td>
<td>0.4871</td>
<td>0.5122</td>
</tr>
<tr>
<td>3dMD (preprocessed)</td>
<td>0.2855</td>
<td>0.3391</td>
<td>0.4212</td>
</tr>
<tr>
<td>Maxilim (preprocessed)</td>
<td>0.3291</td>
<td>0.3496</td>
<td>0.4222</td>
</tr>
<tr>
<td>Reference-based (Obs1)</td>
<td>0.9844</td>
<td>0.7997</td>
<td>1.2690</td>
</tr>
<tr>
<td>Reference-based (Obs2)</td>
<td>1.0069</td>
<td>0.7570</td>
<td>1.2453</td>
</tr>
</tbody>
</table>
All 3D photographs used in the current study were acquired in a similar way. The 3D photographs of the patients are acquired in daily practice. The same specialized photographer was responsible for acquiring the 3D photographs. To investigate the influence of time more profoundly, 3D photographs were acquired in a way that short-term as well as long-term varieties could be evaluated. The differences in mean registration error between TO-T1 (0.39 mm) and TO-T2 were diminutive, which illustrated that the 3D photograph acquired 1 minute (T1) after the first photograph (TO) could be reproduced 3 weeks later (T2) with high accuracy. The 3D photograph of the patient laughing was captured to study the influence of different facial expression. After registration of the 3D photograph of the individual laughing with a 3D photograph of the individual in rest (TO), the expected large registration error, especially in the mouth region, was confirmed by the results.

The mean registration error is partially caused by the system error of the acquisition system. This error was described by Boehnen and Flynn and found to be ± 0.1 mm. Apart from the system error and registration error, there are several other factors that might influence the accuracy of the registration. One of those is the ability to capture the face in the same facial expression every time. Because a 3D photograph is a static picture, captured only in one moment, facial expression sometimes can be of great influence to reproducibility. Therefore, much attention was paid to acquire the face in the same facial expression. Apart from facial expression, positioning of the individual might also influence the accuracy of registration. To minimize this influence, the head was carefully positioned in the natural head position every single time. Other influencing factors could be loss of weight of the individual, tiredness of the facial skin, and maybe even the monthly hormonal cycle for females included in a study.

When comparing the results of registering the original and preprocessed 3D photographs, it could be noticed that the mean registration error was significantly reduced (P = .0097, 1-way ANOVA test) for the preprocessed photographs (Fig 5). This overall effect was expected; however, for the 3D photographs of the individuals laughing (TO-TL), the registration error increased for the registration of the preprocessed 3D photograph. In the first instance, this result seemed to be unexpected. Nevertheless, the registration error was already estimable in the original 3D photograph of the individual laughing. The regions removed by preprocessing had a smaller registration error than the regions in which obvious differences in facial expression occurred. The ratio between these regions became smaller, which finally resulted in a larger overall registration error.

Furthermore, the analysis of the results between the surface-based and reference-based method illustrated that surface-based registrations produced more accurate results. A significant difference between both methods was found (P = .00, 1-way ANOVA test). Surface-based registration was ideal in this study because 3D photographs of identical individuals were registered. On the contrary, reference-based registration is expected to give better results for registration of different individuals. Also, other complex methods like Procrustes Analysis or Active Appearance Models might be useful for this type of registration problems.

Finally, the results of both the surface-based registration methods (Maxilim and 3dMD Patient) could be compared. Both software packages use an adapted version of the It-
operative Closest Point registration. No significant difference was found between both registration algorithms (P = .86, 1-way ANOVA test), which illustrates that both algorithms are robust and give correct results. When comparing the results from the present study with similar studies, the accuracy of the 3dMD Face system is equal. The reliability found by Kau et al\textsuperscript{33} (± 0.4 mm) and Ma et al\textsuperscript{18} (± 0.2 mm) was performed on scans without the neck and hair region and therefore can be compared with the results of the preprocessed 3D photographs of the present study (0.39 mm). It can be concluded that surface-based registration is an accurate method to compare 3D photographs of the same individual at different time points. Therefore, 3D stereophotogrammetry is an accurate tool to evaluate facial changes (surgical or nonsurgical) over time. The results from the reference-based registration method showed a larger registration error compared with the results of the surface-based registration method. When performing the registration procedure with preprocessed photographs, the registration error decreased. No significant difference could be found between both software packages that were used to perform surface-based registration.
2.5 References


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31. Bush K, Antonyshyn O: Three-dimensional facial anthropometry using a laser sur-


3

Variation of the face in rest using 3D stereophotogrammetry

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Verhamme LM
Van Loon B
Plooij JM
Rangel FA
Kho A
Bronkhorst EM
Bergé SJ

Chapter 3

Introduction
To evaluate treatment outcomes following oral and maxillofacial surgery, pre- and post-treatment three-dimensional (3D) photographs of the patient’s face can be assessed, but this procedure is accurate only if the face is captured with the same facial expression every time. The purpose of this prospective study was to determine variations in the face at rest.

Methods
100 3D photographs of the same individual were acquired at different times. Initially, 50 3D photographs were obtained; 25 using a wax bite to ensure similar occlusion between subsequent photographs and 25 without wax bite. This procedure was repeated 6 weeks later. Variation of the face at rest was computed. The influence of time and wax bite was investigated. Different anatomical regions were investigated separately.

Results
A mean variation of 0.25 mm (0.21-0.27 mm) was found (standard deviation 0.157 mm). No large differences were found between different time points or use of wax bite. Regarding separate anatomical regions, there were small variations in the nose and forehead regions; the largest variations were found in the mouth and eyes.

Conclusion
This study showed small overall variation within the face at rest. In conclusion, different 3D photographs can be reproduced accurately and used in a clinical setting for treatment follow-up and evaluation.
3.1 Introduction

To evaluate the results of surgical interventions in oral and maxillofacial surgery, preoperative and postoperative three dimensional (3D) photographs of the patient’s face can be registered using surface-based registration\(^{16,21}\). 3D photographs of the patient are acquired at different moments in time and compared after aligning them using a surface-based registration method. After registration of the facial surfaces the differences can be visualized using a color scale or distance map. In this way, results of a surgical intervention can be evaluated quickly, quantitatively and objectively. A 3D photograph results in a static picture of the patient, therefore the accuracy of the evaluation depends on the ability to capture the patient’s face in rest reproducibly on multiple occasions. The purpose of this study was to determine the variation of the face at rest using 3D photographs.

3.2 Materials and methods

In this prospective study, 100 3D photographs of the same volunteer were acquired. During acquisition, special attention was addressed to positioning the volunteer and relaxing the facial musculature. The volunteer was placed in a natural head position and was asked to bite in maximum intercuspitation, swallow, relax his lips and keep both eyes open. All 3D photographs were taken by a trained photographer using a five-point 3D stereophotogrammetrical camera setup (3dMD CranialTM System, 3dMD LLC, Atlanta, USA). At the first time point, 50 3D photographs were acquired. In between, sub-

![Diagram](image)

**Fig. 1.** 100 3D photographs of the same individual were acquired. At the first time point, 50 photographs were obtained. They were divided into two groups, 25 normal 3D photographs and 25 3D photographs in which a wax bite was used to assure similar occlusion. This procedure was repeated 6 weeks later, resulting in four different groups.
sequent 3D photographs a rest moment of 1 min was incorporated. To investigate the influence of the position of the mandible, the first 25 3D photographs were acquired without a wax bite (group A1) and the subsequent 25 3D photographs with a wax bite in place (group A2). The wax bite used in this study was acquired in maximal occlusion. To evaluate the influence of time, the procedure was repeated 6 weeks later, resulting in another 50 3D photographs, 25 without a wax bite (group B1) and 25 with a wax bite in place (group B2). In this way, four separate groups were acquired (Fig. 1). For every group, one 3D photograph was selected randomly to be the reference photograph. All other 3D photographs in the group were registered with this reference 3D photograph using surface-based registration. Surface-based registration of the different 3D photographs was performed using Maxilim v.2.3.01 (Medicim NV, Mechelen, Belgium) software. The registration procedure was repeated for all four groups. The 3D photographs of time point 2 (groups B1 and B2) were registered with the reference 3D photograph of time point 1 (groups A1 and A2) so investigating the influence of time. The groups with a wax bite during acquisition (groups A2 and B2) were registered and compared with the 3D photographs of the group without a wax bite (groups A1 and B1). To investigate the regions of variation within the face, the 3D photographs were classified into several anatomical facial regions (forehead, eyebrows, eyes, nose, cheeks, mouth and chin) (Fig. 2). The variation was computed for each region. To compute the variation between all registered 3D photographs in a group Matlab was used. The reference 3D photographs were divided into 20,000 points. From

Fig. 2. The face was divided into several anatomical regions: forehead, eyebrows, eyes, nose, cheeks, mouth and chin.

Fig. 3. A cumulative distribution plot was generated to illustrate the variance of the separate groups.
each of these points the closest distance to all the other 3D photographs was computed. From these calculations, the variation between the different registered 3D photographs could be computed and statistical analysis could be performed. The root-mean-square (RMS) error, standard deviation and 90th and 95th percentile were computed for the 3D photographs. To visualize the RMS error and the distribution of the variance, a cumulative distribution was plotted. For the different anatomical regions, the RMS error, standard deviation and 90th and 95th percentile of the registration error were calculated. To illustrate the variation of all separate regions, a cumulative distribution plot was generated.

3.3 Results

The results for the different groups are illustrated in Table 1. The mean error (RMS) of all four groups ranged from 0.21 mm to 0.27 mm. The standard deviation ranged from 0.20 mm to 0.26 mm. For the registration between time point 1 and time point 2 the RMS error increased to 0.36 mm. For the difference between the use of a wax bite or no wax bite, the RMS error was 0.35 mm.

The 90% error was below 0.60 mm for all four groups and the 95% error was below 0.78 mm. The cumulative distribution (Fig. 3), illustrated that a large amount of error was situated between 0.0 and 0.15 mm. The lines on the x-axis illustrate the 0.5 mm and 1.0 mm margin (Fig. 3). From this plot it was clear that for 85–92% of all points the error was smaller than 0.5 mm. For an error of 1.0 mm this percentage is 98–100%.

Table 1. The RMS error, standard deviation and 90th and 95th percentile were computed for all 4 separate groups. These results were also calculated to investigate the difference between time point 1 and time point 2 and to investigate the use of a wax bite during acquisition of the 3D photographs.

<table>
<thead>
<tr>
<th></th>
<th>RMS error</th>
<th>Std</th>
<th>90th percentile</th>
<th>95th percentile</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Time point 1</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Without wax bite (A1)</td>
<td>0.2365 mm</td>
<td>0.2487 mm</td>
<td>0.5280 mm</td>
<td>0.696 mm</td>
</tr>
<tr>
<td>With wax bite (A2)</td>
<td>0.2148 mm</td>
<td>0.2003 mm</td>
<td>0.4579 mm</td>
<td>0.5904 mm</td>
</tr>
<tr>
<td><strong>Time point 2</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Without wax bite (B1)</td>
<td>0.2689 mm</td>
<td>0.2599 mm</td>
<td>0.5880 mm</td>
<td>0.7735 mm</td>
</tr>
<tr>
<td>With wax bite (B2)</td>
<td>0.2663 mm</td>
<td>0.2475 mm</td>
<td>0.5988 mm</td>
<td>0.7529 mm</td>
</tr>
<tr>
<td><strong>Other measurements</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time point 1 vs. Time point 2</td>
<td>0.3632 mm</td>
<td>0.3431 mm</td>
<td>0.8058 mm</td>
<td>1.0232 mm</td>
</tr>
<tr>
<td>Wax bite vs. no wax bite</td>
<td>0.3498 mm</td>
<td>0.4500 mm</td>
<td>0.7219 mm</td>
<td>1.0302 mm</td>
</tr>
</tbody>
</table>

The results for the different anatomical regions are illustrated in Table 2. The RMS error ranged from 0.16 mm to 0.37 mm. The 90th percentile error ranged from 0.33 mm to
0.78 mm and the 95th percentile error ranged from 0.40 mm to 1.01 mm. The cumulative distribution plot depicting the variance in all anatomical regions is illustrated in Fig. 4.

Table 2. The mean (RMS), standard deviation and 90th and 95th percentile were computed for all specific anatomical regions.

<table>
<thead>
<tr>
<th>Region</th>
<th>RMS error</th>
<th>Std</th>
<th>90th percentile</th>
<th>95th percentile</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forehead</td>
<td>0.1691</td>
<td>0.1258</td>
<td>0.3345</td>
<td>0.4027</td>
</tr>
<tr>
<td>Nose</td>
<td>0.1895</td>
<td>0.1764</td>
<td>0.4012</td>
<td>0.5129</td>
</tr>
<tr>
<td>Mouth</td>
<td>0.3777</td>
<td>0.3030</td>
<td>0.7609</td>
<td>0.9385</td>
</tr>
<tr>
<td>Cheeks</td>
<td>0.2118</td>
<td>0.1957</td>
<td>0.4801</td>
<td>0.5947</td>
</tr>
<tr>
<td>Eyes</td>
<td>0.3773</td>
<td>0.3380</td>
<td>0.7833</td>
<td>1.0159</td>
</tr>
<tr>
<td>Eyebrows</td>
<td>0.1890</td>
<td>0.1855</td>
<td>0.3784</td>
<td>0.4942</td>
</tr>
<tr>
<td>Chin</td>
<td>0.2329</td>
<td>0.1940</td>
<td>0.4880</td>
<td>0.6023</td>
</tr>
</tbody>
</table>

Fig. 4. A cumulative distribution plot was generated to illustrate the variance in all anatomical regions.

3.4 Discussion

The ability to reproduce the face at rest is a highly important factor for preoperative and postoperative evaluation of treatment changes. If the variation within the face at rest is large, the evaluation of surgery based on preoperative and postoperative 3D photographs is inaccurate.

With the advent of digital technology, digital photography has become an increasingly important tool in facial surgery. With the introduction of systems such as the 3dMDfaceTM System (3dMD LLC, Atlanta, USA), Di3DTM (Dimensional Imaging, Glasgow, UK) and 3D-Sensors FaceSCAN3D (3D Shape GmbH, Erlangen, Germany), the applicability of 3D photography in daily practice has become reality. 3D stereophotogrammetry is safe, noninvasive and able to capture superior quality ‘external surface’ 3D
photographs in less than 10 ms\textsuperscript{17}. these techniques are ideal for collecting 3D data even from the faces of young children or babies. After processing the data, an accurate digital model of the patient’s face is created, which can be used immediately in a clinical setting.

Earlier studies were performed to investigate the accuracy of 3D stereophotogrammetry. Most of these studies focused on reliably measuring distances between typical anthropometric points on the 3D reconstructed images against corresponding points on live subjects or phantom models (e.g. plaster casts) as a form of validation\textsuperscript{1,2,14,15,19,28}. Other studies used more complex methods to obtain and analyse 3D shapes\textsuperscript{7,12,13,19,21}. KAU et al.\textsuperscript{13}, MAAL et al.\textsuperscript{21} and MA et al.\textsuperscript{19} investigated the reproducibility of several 3D acquisition systems. KAU et al. found an accuracy of 0.4 mm (RMS error) using a Minolta Vivid 900 laser scanner. MAAL et al. used 3D stereophotogrammetry and assessed the reproducibility and found an accuracy of 0.4 mm. MA et al. found the reproducibility of their structured light system was 0.2 mm.

The reproducibility of different facial expressions has been studied. Some older studies used two dimensional (2D) photography\textsuperscript{11,25,30}, others used a 3D video tracking system to track facial landmarks during facial expression\textsuperscript{10,26,27,29}. 3D stereophotogrammetry has been used in several studies to investigate facial expression\textsuperscript{12}. Most of these studies were performed to investigate facial expression in patients with facial neuromuscular deficits or in children with cleft lip and palate\textsuperscript{9,26}. In some of these studies, the reproducibility of the face at rest is described. STRAUSS et al.\textsuperscript{25} acquired 2D photographs of 20 different subjects on 5 days. All photographs were acquired in a standardized way and analysed for 18 landmarks and linear and angular measurements. They found that the face at rest was reproduced accurately in 2D photographs. JONHSTON et al.\textsuperscript{12} assessed the reproducibility of five facial expressions using a 3D photography system. 3D photographs of 30 healthy Caucasian volunteers were acquired at three different moments in time; 15 min after the first 3D photograph a second 3D photograph was acquired. A third 3D photograph was taken 2 weeks after the first photograph. JONHSTON et al. found a reproducibility of 0.74 mm for the face at rest.

The focus of the current study was on the variation of the face at rest rather than facial expression or reproducibility of the acquisition system. In the current study, no landmarks were used, all 3D photographs were aligned using surface-based registration. The software package used in this study uses an adapted version of the Iterative Closest Point algorithm to perform surface registration\textsuperscript{4,20}. When the purpose of image registration is to combine several 3D photographs of the same individual, surface-based registration is perfectly suitable. The advantage of surface-based registration compared with landmark based registration in this type of study is that the result of surface-based registration is more accurate. In landmark based registration, the landmarks have to be indicated first, which immediately introduces a small error. The reproducibility of robust landmarks was described by JONHSTON et al.\textsuperscript{12} and was found to be 0.5 mm.

The results of the current study show small variation for the face at rest. Important factors investigated in this study were the influence of time and the use of a wax bite. The effect of both of these factors turned out to be very small. The slight differences of acquiring 3D photographs at different points in time illustrate that the face at rest is accurately reproducible.
The mouth is a region of large mobility, therefore the hypothesis was that the use of a wax bite might give better reproducibility of the face at rest. The results of the current study do not prove this hypotheses. A possible explanation is that the face at rest is accurately reproducible, but when movement occurs, these movements are within the soft tissues (especially cheek and mouth region) due to muscular activity, whereas the wax bite only fixates the mandibular bone on the maxilla. The volunteer in this study had a stable occlusion. The effect of using a wax bite might be more important in patients with an unstable occlusion, most certainly in patients with a severe Class III and overclosure of the mandible, patients with a Class II and a ‘Sunday bite’, and patients with a severe anterior open bite or lateral cross-bites in facial asymmetry. In this study, the individual was captured in maximal intercuspidation, but in maximal intercuspidation or centric relation the posture of the lips and the morphology are modified and the face is not at rest, certainly in Class II, Class III and asymmetric patients. Capturing the patient in natural head position with first tooth contact and in ‘centric relation’ does not always reproduce a face at rest. This issue remains controversial.

Within the different anatomical units, the most accurate values were found in the region of the forehead (RMS error: 0.17 mm) and the nose (RMS error: 0.19 mm). The most obvious variations were peri-oral (RMS error: 0.38 mm) and peri-ocular (RMS error: 0.37 mm). The large variation in the region of the eyes can be explained by the inability to capture the eyes correctly using 3D stereophotogrammetry.

It is difficult to compare the results of this study with earlier studies, because the focus of the current study is on variation within the face at rest while the focus of earlier studies was mainly on reproducibility. JOHNSTON et al. only acquired one 3D photograph of every individual at different moments in time and used landmark based registration. KAU et al. and MA et al. used surface-based registration, which was also used in the current study, but they also acquired one photograph at three time points. KAU et al. used laser scanning and MA et al. used a structured light system.

The results in the current study are useful for a number of clinical applications. One of these applications is combining cone beam computed tomography (CBCT) scans with 3D stereophotogrammetry. For the registration of different image modalities with each other, it is important that stable regions (where the smallest variation occurs) are registered with each other; regions where large variation occurs should be excluded from the registration process. From the results of the current study it can be concluded that the best regions to match these different datasets are the forehead and nasal region. It is important that these robust regions should not be modified during image acquisition, for example by a forehead fixation strap, which is regularly used in CBCT scanning. When the purpose of a CBCT scan is to combine it with 3D stereophotogrammetry one can decide not to use the strap around the forehead to fix the patient.

When focussing on variation within the face at rest, another factor that needs to be taken into account is the system error of the acquisition system. For the system used in the current study, this error was described by Boehnen and Flynn and found to be 0.1 mm. Other factors that might influence the accuracy of registration include positioning of the individual. To minimize this, the head was carefully placed in the natural head position every time. The procedure for acquiring 3D photographs of the volunteer...
Variation of the face in rest using 3D stereophotogrammetry

used in this study is similar to the regular clinical procedure. Other factors affecting accuracy could be loss of weight, tiredness of the facial skin, and perhaps the monthly hormonal cycle for females\textsuperscript{8,23}.

For clinical use, it is important that the registration process for the 3D photographs is accurate (<1 mm)\textsuperscript{22}, because any change in facial morphology could be due to inherent errors of the technique or to growth or treatment changes. The variation of the face at rest, found in the current study, is within these margins.

The results of this study show that the variation within the face at rest is small, indicating that 3D photographs of the face at rest can be reproduced accurately. This study illustrates that the influence of time is not obvious and has no clinical relevance. Using a wax bite did not increase accuracy in this study, but it is expected to have a greater influence in orthognathic patients. The most important variation was found in the mouth and eye regions. The lowest variation was found in the nose and forehead regions, making these regions the most robust regions to be used in aligning different 3D photographs or combining 3D photographs with other imaging modalities such as CBCT.
3.5 References


Three dimensional measurement of rhinoplasty results

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Plooij JM
Bergé SJ

Chapter 4

Introduction
Pre- and postoperative imaging is important and essential for evaluation of the results of rhinoplasty surgery. Two-dimensional photographs are used routinely for this purpose, but have several disadvantages as opposed to three-dimensional imaging techniques, such as 3D stereophotogrammetry. This study is the first to describe the measurement of rhinoplasty results using 3D stereophotogrammetry. The aim of this study was to evaluate the ability of 3D imaging to measure and objectify rhinoplasty results.

Methods
During a 6-month period all consecutive hump reduction patients were included in this prospective study. Pre- and postoperative 3D photographs were taken and compared.

Results
Twelve patients were studied. In ten of these twelve patients a significant volume reduction in the area of the nasal dorsum was found with 3D stereophotogrammetry. The maximum decrease (i.e. lowering) of the nasal dorsum ranged from 0.8 to 4.4 mm. In two patients no reduction of the nasal dorsum was found. In both patients this was due to additional changes made to the nose during surgery. These changes, increased tip rotation and dorsal augmentation respectively, were also documented with 3D stereophotogrammetry.

Conclusion
Both pronounced as well as subtle postoperative changes of rhinoplasty surgery can be objectified and measured with 3D stereophotogrammetry. This tool can be used to study whether surgical techniques have the desired effect on the nose, and to compare different techniques with each other.
4.1 Introduction

Pre- and postoperative standard and uniform (digital) color photographs are important and essential for postoperative evaluation of the (long-term) results of rhinoplasty surgery. In addition, these photographs can be used for teaching and research purposes. Thus far, all studies describing objective changes after rhinoplasty are based on two-dimensional (2D) standardized photographs. This poses several potential problems. First, the pre- and postoperative pictures must be made in exactly the same way, i.e. from the same distance and with the head in an identical position to prevent over- or underestimation of absolute changes in for instance tip projection/rotation or width of the alar base. This problem may be overcome using relative measurements, but these methods are more time-consuming and still liable to the second disadvantage of using normal pictures: the complex three-dimensional (3D) appearance of the nose is turned into 2D-pictures.

Recent advances in technology have generated several 3D techniques to capture facial topography and overcome the deficiencies and problems encountered with conventional photographs. One of these techniques is 3D stereophotogrammetry. 3D stereophotogrammetry is a technique that uses two or more cameras configured as pairs to capture multiple views of the face. These different views are used to form a 3D-photograph. An early disadvantage of 3D stereophotogrammetry has been its inaccuracy, but recently the technique has been improved resulting in high-quality, realistic 3D-photographs. Nowadays pre- and postoperative 3D-photographs can be superimposed and the differences between the two surfaces can be compared to provide information about the results of surgery on facial appearance. This study is the first to describe the measurement of rhinoplasty effects using 3D stereophotogrammetry. The aim of this study was to evaluate the ability of 3D-imaging to measure and objectify rhinoplasty results.

4.2 Materials and methods

4.2.1 Surgical procedure

Between September 2006 and April 2007 all rhinoplasty patients undergoing hump reduction were included in this prospective study. In all patients the operation was performed by one of the authors (KI or NvH). A detailed surgical report was kept to register if other surgical techniques (such as tip refining, septoplasty, et cetera) were used as well.

All rhinoplasty procedures were performed through an open approach. The open approach was chosen because both surgeons prefer this approach when more than just a hump reduction has to be performed, which was the case for all patients. The nasal dorsum was exposed immediately supraperichondrically and subperiostally. After the triangular cartilages had been detached from the nasal septum extramucosally and the nasal mucosa had been removed from the inner side of the nasal bones, a cartilaginous
and/or bony hump reduction was done, followed by medial oblique osteotomies. Subsequently the lateral osteotomies were performed. Finally the nasal bones were infractured to close the open roof. The nasal dorsum was positioned in the midline and if necessary one or two spreader grafts were used to further align the nasal dorsum. After finishing the remainder of the procedure nasal packing and an adhesive thermoplastic nasal splint were applied.

4.2.2 3D-imaging (i.e. 3D stereophotogrammetry)

3D digital photographs were taken 1 day preoperatively and 6 months postoperatively in all patients. The 3D-photographs of the face were captured with a 3D stereophotogrammetrical camera setup and the Modular System v1.0 (3dMDface™ System, 3dMD Ltd, Atlanta, GA, USA) software program. The camera setup consists of two pods, each equipped with 3 digital cameras and a flash. Both pods acquire 2 sets of photos simultaneously: 2 photos with a pattern projected and a full-color photo, resulting in a total of 6 facial pictures. The pattern is needed for the 3D surface reconstruction. As a result, a polygonal mesh with true color texture information is obtained. Capture time was 2 milliseconds, which limited the risk of movement artefacts. Prior to its use, the camera was calibrated to define a 3D coordinate system for the 3D-photograph, which was referred to as the original 3D coordinate system. The obtained 6 facial pictures were reconstructed into one 3D stereophotogrammetrical photograph and automatically saved as a ‘three-dimensional surface binary’ file (.tsb file). The 3D photographs were taken in natural head position with eyes open. Subsequently, the .tsb file was opened using the 3dMDpatient v2.0 (3DMDeat™ Software Platform, 3dMD Ltd) software program and directly exported as a ‘wavefront object’ file (.obj file) to enable import of the 3D-object into Maxilim® version 2.0.1 (Medicim NV, Mechelen, Belgium). Without any editing the .obj file was saved as ‘maxilim’ file (.mxm file) for further use. The surface-based matching tool of the Maxilim® software was used to superimpose the pre- and postoperative 3D-photographs. A four step matching process was performed (Table 1).

Table 1. Step-by-step approach to matching the textured and untextured surfaces.

<table>
<thead>
<tr>
<th>Step</th>
<th>Task Description</th>
<th>Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Step 1</td>
<td>Initial positioning of the 3D photographs by indicating landmarks on both images</td>
<td>Semi-automatic</td>
</tr>
<tr>
<td>Step 2</td>
<td>Excluding error regions</td>
<td>Manual</td>
</tr>
<tr>
<td>Step 3</td>
<td>Registration of the 3D photographs</td>
<td>Automatic</td>
</tr>
<tr>
<td>Step 4</td>
<td>Computation of distance map between superimposed 3D photographs</td>
<td>Automatic</td>
</tr>
</tbody>
</table>

First, four easily reproducible, corresponding landmarks that were well spread over the facial surface were indicated on the pre- and postoperative 3D surfaces / 3D photographs. These landmarks were a base for surface matching and minimized the need for further initial translation and rotation of the surfaces. Second, the accuracy of the registration was improved by excluding regions that were obviously different, such as the nose itself, border of the hair, the neck, the eyes and eyelids and the mouth. Subse-
Three dimensional measurement of rhinoplasty results

sequently, rigid registration was used to register the pre- and postoperative skin surfaces with a 3D surface matching algorithm (Iterated Closest Point (ICP) algorithm). Finally, a distance map was calculated between both surfaces. This resulted in a color-based image indicating unchanged (white areas), decreased (red discoloration) and increased (green discoloration) facial volumes. A higher intensity of discoloration corresponds with a larger change in facial volume. At the point of maximal reduction, indicated by the highest intensity of discoloration, the reduction of the nasal dorsum was calculated.

4.3 Results

Between September 2006 and April 2007 a hump reduction was performed in thirteen patients. One of these thirteen patients was lost to follow-up. The final study group consisted of five female and seven male patients with a mean age of 32.2 years (range 18.4 - 45.8). In all patients the hump reduction was combined with at least one other technique, e.g. placement of a strut or spreader graft, refinement of the tip or septoplasty. In ten out of our twelve patients a significant volume reduction in the area of the nasal dorsum was found after surgery. The decrease (i.e. lowering) of the nasal dorsum at the point of maximum reduction ranged from 0.8 to 4.4 mm with a median of 2.2 mm. Figure 1 shows an example of the color-based image that is the result of the virtual subtraction of the preoperative photograph from the postoperative photograph. In white the areas are shown where no changes in volume had occurred. Red areas, such as the nasal dorsum, represent areas with reduced volumes 6 months after surgery. Green discoloration indicates an increase in volume. Green discoloration in the nasal area can be the result of additional techniques performed during rhinoplasty surgery, such as upward rotation of the tip. Discoloration, either green or red, in the remaining facial regions is considered to be the result of differences in facial posture at the moment of pre- and postoperative imaging. For instance, if a patient has even a slight difference in the position of the mandible pre- and postoperatively, this is immediately detected as a change in volume in the region of the chin, neck and lips. The intensity, i.e. the degree, of redness and greenness corresponds with the amount of change in facial volume. The color scale in Figure 1 displays these intensities together with the corresponding millimetres of increase or decrease. In two patients no reduction of the nasal dorsum was found. In one patient with a saddle nose deformity a small bony hump was removed before a large cartilaginous dorsal onlay implant was placed. As expected and intended, a distinct increase in volume was found in the nasal dorsum region. This is shown as green discoloration of the nasal dorsum in Figure 2. The other patient without reduction of the nasal dorsum had a polly beak deformity prior to surgery. A very small cartilaginous pseudo hump was removed and subsequently the tip rotation was increased. In this patient no volume change was found in the dorsal region, probably due to the fact that the combination of these techniques led to straightening rather than lowering of the skin of the nasal dorsum. In addition, the increased rotation was shown as a volume increase in the supratip region and a volume decrease in the infratip region, shown in Figure 3.
In aesthetic rhinoplasty, patients' indications can be roughly divided into: reduction rhinoplasty, in which the nose is made smaller, and augmentation rhinoplasty, in which the nose is enlarged. In addition, both reduction as well as augmentation techniques can be performed on the tip (e.g., removal of cephalic margin or suturing techniques).

4.4 Discussion

In aesthetic rhinoplasty, patients' indications can be roughly divided into: reduction rhinoplasty, in which the nose is made smaller, and augmentation rhinoplasty, in which the nose is enlarged. In addition, both reduction as well as augmentation techniques can be performed on the tip (e.g., removal of cephalic margin or suturing techniques).
Three dimensional measurement of rhinoplasty results

Rhinoplasty is one of the most challenging facial surgical procedures. A clear understanding of nasal anatomy is critical in order to provide an aesthetic result that does not compromise nasal function. Thorough analysis of the nose is vital for proper diagnosis and for determining the most appropriate treatment plan. This treatment plan often consists of numerous techniques. Each technique has a certain goal, e.g. placement of a strut to increase rotation or hump reduction to reduce the nasal dorsum. It is therefore very important to verify postoperatively whether a certain technique did as planned result in its matching result.

Several surgical techniques and their effects have been studied in the past. Many of these studies have tried to establish objective methods to measure changes made to the nose. However, all these measurements were based on 2D-photographs. The nose is an outstanding example of a three-dimensional structure and changes made to the nose are hardly ever limited to two dimensions. These conclusions emphasize the need for a method of 3D-measurement of rhinoplasty results. With the development of 3D stereophotogrammetry such a method has become available. In the present study 3D stereophotogrammetry was used to capture 3D-photographs (3dMDface™System) and a surface-based matching tool (Maxilim®) to analyze the nasal changes between pre- and postoperative 3D-photographs. Several studies have been reported describing the accuracy and reliability of 3D-imaging techniques to measure facial appearance. They showed that the accuracy, reproducibility and reliability of the technique are high. The accuracy was found to be 0.5 mm. However, no study has yet been performed to determine the usefulness of 3D-imaging to measure and visualize rhinoplasty results.

This study describes that 3D stereophotogrammetry is capable of, and useful for, measuring changes made to the nose by rhinoplasty surgery. In ten hump reduction patients a significant reduction of the nasal dorsal volume was found. The maximum reduction ranged from 0.8 to 4.4 mm. In two patients no reduction of the nasal dorsal volume was found. According to the surgical report both patients had undergone a hump reduction, but in one patient this concerned the reduction of a very small pseudo-hump combined with upward rotation of the tip and in the other patient a cartilaginous onlay graft was placed after the hump reduction. In addition to the distinct visualisation of the hump reduction in the other patients, these changes (i.e. rotation of the tip and augmentation of the nasal dorsum, respectively) were both also detected with 3D stereophotogrammetry. This shows that the clinical postoperative findings can be objectified and measured with 3D stereophotogrammetry and that the changes found correspond with the techniques performed. Even smaller changes made to the nose can be measured with 3D stereophotogrammetry. 3D stereophotogrammetry can therefore be used to further objectify, measure and compare rhinoplasty results and to study whether certain surgical techniques indeed provide the desired effect on the appearance of the nose, especially in

niques and shield graft, respectively) and the nasal dorsum (e.g. hump reduction and dorsal onlay graft, respectively). As a general rule, changes made to the nasal dorsum are more distinct than changes made to the tip. Since the goal of this study was to determine whether rhinoplasty results can be measured with 3D stereophotogrammetry, only patients with a more pronounced effect, i.e. patients with a hump reduction as part of their rhinoplasty procedure, were included in this study.

Rhinoplasty is one of the most challenging facial surgical procedures. A clear understanding of nasal anatomy is critical in order to provide an aesthetic result that does not compromise nasal function. Thorough analysis of the nose is vital for proper diagnosis and for determining the most appropriate treatment plan. This treatment plan often consists of numerous techniques. Each technique has a certain goal, e.g. placement of a strut to increase rotation or hump reduction to reduce the nasal dorsum. It is therefore very important to verify postoperatively whether a certain technique did as planned result in its matching result.

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the long term. We are presently conducting a study to evaluate 3D stereophotogrammetry for the comparison of the outcomes of different surgical techniques.
4.5 References

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Three dimensional measurement of rhinoplasty results
3D Stereophotogrammetric assessment of pre- and postoperative volumetric changes in the cleft lip and palate nose.

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Chapter 5

Introduction
In cleft lip and palate patients the shape of the nose invariably changes in three dimensions (3D) due to rhinoplastic surgery. The purpose of this study was to evaluate 3D stereophotogrammetry as a 3D method to document volumetric changes of the nose in patients with a cleft lip (CL) or cleft lip and palate (CLP) after secondary open rhinoplasty.

Methods
Twelve patients with unilateral CL or CLP were enrolled in the study prospectively. 3D facial images were acquired using 3D stereophotogrammetry preoperatively and three months postoperatively. A 3D cephalometric analysis of the nose was performed and volumetric data were acquired. The reliability of the method was tested by performing an intra- and interobserver analysis. Left, right and total nasal volumes and symmetry were compared.

Results
No statistical significant differences (p<0.05) were found within and between observers for the measured volumes and symmetry. Postoperatively the total volume of the nose increased significantly, especially the volume at the cleft side. No significant volume difference pre- and postoperatively was found for the non-cleft side. The symmetry of the nose improved significantly.

Conclusion
3D stereophotogrammetry is a sensitive, quick and non-invasive method to evaluate volumetric changes of the nose in patients with a cleft lip or cleft lip and palate.
5.1 Introduction

The nose is known to be aberrant in both appearance and function in patients with a cleft lip (CL) or a cleft lip and palate (CLP). Distortions of the nose can vary from almost invisible to catastrophic, mostly dependent on the severity and type of cleft. To correct the nasal deformity in CL or CLP patients is a challenge. In the Netherlands a primary rhinoplasty correction is performed at the time of primary lip closure in unilateral CL or CLP patients since the last 25 years. This usually comprises of reducing the asymmetry by undermining and rotation of the nose without altering bony tissue. Nevertheless, as the children grow older, nasal shape remains deformed. There usually is an underprojection of the dome at the cleft side and surgery therefore mainly focuses on correcting this asymmetry by increasing the projection (which enhances the volume of the nasal pyramid) on the cleft side. Various studies have been undertaken to evaluate the result of different rhinoplastic procedures. However, quantification of surgical changes remains difficult. Besides direct anthropometric measurements traditionally, two dimensional (2D) photographs and radiographs are used to document and calculate changes after surgery. Up to now, studies comparing pre- and postoperative nasal changes in patients with clefts are limited to these techniques. The human body however, is a three dimensional (3D) entity and any change, whether from movement during facial expression or from surgery, happens in three dimensions. Various 3D imaging techniques have been developed to overcome the shortcomings of conventional 2D imaging. These include 3D cephalometry, Moiré topography, 3D laser scanning, 3D optoelectronic digitizers and 3D stereophotogrammetry. The latter method has gained popularity over the last years as digital 3D data sets of the face can be acquired rapidly and non-invasively, while simultaneously being archived for future analysis. Recent studies have shown 3D cephalometric measurements acquired with a 3D stereophotogrammetrical camera setup to be valid and reproducible.

To the best of our knowledge no 3D stereophotogrammetry studies have been performed on the volumetric 3D changes of the nose after secondary rhinoplasty in CL and CLP patients. Therefore the purpose of this study was to evaluate the value of 3D stereophotogrammetry for volumetric documentation of the nose in CL and CLP patients who underwent secondary rhinoplastic surgery.

5.2 Materials and Methods

5.2.1 Patients

The study sample comprised of CL and CLP patients from the Cleft Palate Craniofacial Unit of the Radboud University Nijmegen Medical Centre, Nijmegen, The Netherlands, operated between June 2007 and December 2007. Inclusion criteria were: unilateral CL or unilateral CLP, age above 12 years and signed informed consent. Exclusion criteria were: associated craniofacial deformities, syndromes and earlier secondary rhinoplastic surgery.
5.2.2 Operative procedure

All operative procedures were performed by one surgeon (PS). An open rhinoplasty (Rethi incision: rim incision traversing the columella) was performed in all patients. Depending on the deformity, the following nasal surgery components were employed: a septal deviation was corrected by remodeling the deviating septum and trimming of the base. The lower lateral cartilages were reduced and sutured together in order to narrow the dome. A columnellar strut was placed for nasal tip support. For this purpose a part of the septal cartilage was used or cartilage was acquired from the auricular concha. Furthermore dome sutures, shield, tip or dorsal grafts were implemented if required. When correction of the nasal bone was mandatory a medial and lateral osteotomy including efracture and infracture was performed.

5.2.3 Pre- and postoperative 3D documentation

A 3D stereophotogrammetrical camera setup with an integrated software program modular system V 1.0 (3dMDface” System, 3dMD LLC, Atlanta, GA, USA) was used to capture 3D photographs of the face. The 3D photographs were generated from six 2D photographs taken simultaneously (four grey-scale photographs and two full color photographs). A polygon light pattern was projected onto the four grey-scale photographs. Based on this pattern and its deformed image, a 3D photograph was reconstructed. These 3D photographs were automatically saved as ‘three-dimensional surface binary’ files (.tsb file) and were visualized and analyzed using 3D editing software (3dMDpatient V3.0.1. 3dMDpatientTM Software Platform, 3dMD LLC). With this system it was possible to capture 180 degrees of the subjects face, which concurred with an ear to ear 3D photograph. The 3D photographs were taken in natural head position and habitual occlusion. Patients were asked to relax their facial musculature, swallow and keep their molars in occlusion after swallowing. 3D photographs were acquired preoperatively as well as at the clinical control visit three months postoperatively. The preoperative surgical deformities of the nose were recorded by using criteria proposed by Nakamura et al.

5.2.4 3D Measurements

To isolate the region of interest on the 3D photographs, the neck and parts of the hair were trimmed using 3dMDpatient V3.0.1 software. The 3D photograph was exported as a wavefront object file (.obj) and imported into Maxilim® version 2.2.2.1 (Medicim NV, Mechelen, Belgium). A surface-based matching procedure of the pre- and postoperative 3D photographs was performed in five steps as described by our group. On the matched 3D photographs a distance map was created giving an indication of the soft tissue changes (figure 1). A modified 3D cephalometric analysis, based on 3D cephalometric soft tissue analysis on CT data (table 1), was performed to outline the region of interest for the volumetric measurements. This resulted in the matched 3D photographs
3D stereophotogrammetric assessment of pre- and postoperative volumetric changes in the cleft lip and palate nose

Fig. 1. 3D distance map of the pre- and postoperative soft tissue changes in patient 6. Decrease (red) of volume on the non-cleft side; increase (green) in volume on the cleft side.

on a Cartesian coordinate system with the nose lined by various planes (figure 2). These planes defined the borders of the volume of the nose and were used for further circumscriptio of the 3D photograph. Finally, only the nose was left and a virtual volume could be computed. To compare left and right volumes, the nose was divided into a left and right part using the cephalometric based median plane (table 1). The left and right volumes of the pre- and postoperative nose were then measured (mm$^3$).

To determine intra- and interobserver reliability all measurements were performed twice by two observers (BL and TM), independently of each other, with a time interval (8 weeks for BL and 2 weeks for TM), so preventing memory effects.

Table 1. Definitions of landmarks and planes used based on the 3D cephalometric soft-tissue analysis according to Swennen$^{27}$.

<table>
<thead>
<tr>
<th>Landmark and planes</th>
<th>Abbreviation</th>
<th>Description</th>
<th>View</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alare (left)</td>
<td>al(l)</td>
<td>Left alare, most lateral point on the left alar contour.</td>
<td>Base view</td>
</tr>
<tr>
<td>Alare (right)</td>
<td>al(r)</td>
<td>Right alare, most lateral point on the right alar contour.</td>
<td>Base view</td>
</tr>
<tr>
<td>Cheilion (left)</td>
<td>ch(l)</td>
<td>Left cheilion, point located at the left labial commissure.</td>
<td>Frontal</td>
</tr>
<tr>
<td>Point</td>
<td>Description</td>
<td>Plane</td>
<td></td>
</tr>
<tr>
<td>------------------------------</td>
<td>-----------------------------------------------------------------------------</td>
<td>------------------------</td>
<td></td>
</tr>
<tr>
<td>Cheilion (right) ch(r)</td>
<td>Right cheilion, point located at the right labial commissure.</td>
<td>Frontal</td>
<td></td>
</tr>
<tr>
<td>Cheilion (middle) ch(m)</td>
<td>Soft tissue point automatically computed as the midpoint of the right cheilion and left cheilion.</td>
<td>Frontal</td>
<td></td>
</tr>
<tr>
<td>Endocanthion (left) en(l)</td>
<td>Left endocanthion, soft tissue point located at the inner commissure of the left eye fissure.</td>
<td>Frontal</td>
<td></td>
</tr>
<tr>
<td>Endocanthion (right) en(r)</td>
<td>Right endocanthion, soft tissue point located at the inner commissure of the right eye fissure.</td>
<td>Frontal</td>
<td></td>
</tr>
<tr>
<td>Exocanthion (left) ex(l)</td>
<td>Left exocanthion, soft tissue point located at the outer commissure of the left eye fissure.</td>
<td>Frontal</td>
<td></td>
</tr>
<tr>
<td>Exocanthion (right) ex(r)</td>
<td>Right exocanthion, soft tissue point located at the outer commissure of the right eye fissure.</td>
<td>Frontal</td>
<td></td>
</tr>
<tr>
<td>Exocanthion (middle) ex(m)</td>
<td>Soft tissue point automatically computed as the midpoint of the right exocanthion and left exocanthion.</td>
<td>Frontal</td>
<td></td>
</tr>
<tr>
<td>Pupil reconstructed p''</td>
<td>Pupil reconstructed point, midpoint between the endocanthi and pupils, located on the level of the exocanthi.</td>
<td>Frontal</td>
<td></td>
</tr>
<tr>
<td>Subnasale sn</td>
<td>Subnasale, midpoint on the nasolabial soft tissue contour between the columella crest and the upper lip.</td>
<td>Lateral right</td>
<td></td>
</tr>
</tbody>
</table>

**Plane**

**Posterior Nasal Plane**

A plane through landmarks ex(l), ex(r) and ch(m).

**Lateral left Nasal Plane**

A plane through landmarks en(l) and al(l) and perpendicular to the vertical plane.

**Lateral Right Nasal Plane**

A plane through landmarks en(r) and al(r) and perpendicular to the vertical plane.

**Median Plane**

The Median (z) 3D Reference Plane is computed through the Pupil Reconstructed Point and as a plane perpendicular to the horizontal (x) and the vertical (y) 3D Reference Planes.

**Upper Nasal Plane**

A plane through landmark ex(m) and parallel to the horizontal plane.

**Lower Nasal Plane**

A plane through landmark sn and parallel to the horizontal plane.

**Horizontal Plane**

The horizontal (x) 3D Reference Plane is automatically computed as a plane 6.6 degrees below the Cantion - Superaurale line, along the horizontal direction of the natural head position and through the Pupil Reconstructed Point translated 77.2 mm more posteriorly.

**Vertical Plane**

The vertical (y) 3D Reference Plane is computed as a plane perpendicular to the Horizontal (x) 3D Reference Plane and along the horizontal direction of the natural head position.
5.2.5 Statistical analysis

Means and standard deviations were calculated and comparisons were made between:

1. the pre- and postoperative total volumes of the nose,
2. the pre- and postoperative cleft side nasal volumes,
3. the pre- and postoperative non-cleft side nasal volumes,
4. the pre- and postoperative volumetric symmetry calculated by dividing the volume of the cleft side and the non-cleft side. A ratio of 1.00 means perfect symmetry.

Pre- and postoperative differences were analyzed using Paired Student’s t–tests with a p-value of 0.05 indicating statistical significant differences.

Paired Student’s t-tests were used to calculate the intra- and interobserver reproducibility of the volumes for repeated measurements (mean difference) and to test for statistical significant differences. The measurement error was calculated as the standard deviation (SD) of the mean difference divided by $\sqrt{2}$. Reliability coefficients between first and second measurement were calculated as Pearson correlation coefficients.

The statistical data analysis was performed with the SPSS software program, version 16.0 (SPSS Inc, Chicago, USA).
5.3 Results

5.3.1 Patients and controls

Eight male and four female patients aged 13 to 40 years (median, 18 years) met the inclusion criteria and had various deformities of the nose (table 2). There were two patients with an isolated CL and 10 with a CLP. There were eight left and four right sided clefts.

5.3.2 Operative procedure

Twelve secondary open rhinoplasty procedures were performed (table 2). Interdomal sutures were used in all patients. In two patients no further surgical procedures were performed. In the remaining 10 patients one or two of the following surgical procedures were used in order to achieve more symmetry and increase the volume of the tip on the cleft side: a columellar strut was used in seven patients (five using septal cartilage and two using auricular cartilage), three patients underwent an alar wing graft (two using auricular cartilage, one using septal cartilage), a tip graft was performed in one patient

Table 2. Surgical characteristics for the 12 patients.

<table>
<thead>
<tr>
<th>Patient</th>
<th>CL/CLP side</th>
<th>Deformity of the nose</th>
<th>Columellar strut</th>
<th>Alar graft</th>
<th>Tip graft</th>
<th>Nasal bone osteotomy</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>right*</td>
<td>A,B,C,D</td>
<td>no</td>
<td>yes(^1)</td>
<td>no</td>
<td>no</td>
</tr>
<tr>
<td>2</td>
<td>left</td>
<td>A,D</td>
<td>no</td>
<td>yes(^2)</td>
<td>no</td>
<td>no</td>
</tr>
<tr>
<td>3</td>
<td>left</td>
<td>B,C,D</td>
<td>yes(^1)</td>
<td>no</td>
<td>no</td>
<td>no</td>
</tr>
<tr>
<td>4</td>
<td>right</td>
<td>A,B,C,D</td>
<td>no</td>
<td>no</td>
<td>no</td>
<td>no</td>
</tr>
<tr>
<td>5</td>
<td>left</td>
<td>A,D</td>
<td>yes(^1)</td>
<td>yes(^2)</td>
<td>no</td>
<td>no</td>
</tr>
<tr>
<td>6</td>
<td>left</td>
<td>A,B,C,D</td>
<td>yes(^1)</td>
<td>no</td>
<td>no</td>
<td>yes</td>
</tr>
<tr>
<td>7</td>
<td>right</td>
<td>A,B,C,D</td>
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<tr>
<td>11</td>
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</tbody>
</table>

\(^{A}(A)\) Deviated columella; \(B)\) depressed and deviated nasal tip; \(C\) wide nasal ala on the cleft side; \(D\) flat and v-shaped nostril.

* CL only.

\(^{1}\) Nose septal cartilage.

\(^{2}\) Auricular cartilage.
3D stereophotogrammetric assessment of pre- and postoperative volumetric changes in the cleft lip and palate nose

(using septal cartilage) and a transcuhaneous nasal bone osteotomy was performed in two patients.

5.3.3 Reliability of the method

No statistical significant differences (p<0.05) were found within and between observers for the measured volumes and symmetry (table 3). The reliability coefficients for all volumes ranged from 0.96 to 1.00; Duplicate measurement errors ranged from 55.68 mm$^3$ to 147.40 mm$^3$.

<p>| Table 3. Mean volume differences (mm$^3$) with 95% confidence intervals and p-value, reliability coefficients (Pearson's correlation coefficient), and measurement error (mm$^3$) within and between observers. |
|-------------------------------------------------|-------------|-------|---------|-------------|-------------|</p>
<table>
<thead>
<tr>
<th>Mean difference (mm$^3$)</th>
<th>95% Confidence interval of the difference</th>
<th>Lower</th>
<th>Upper</th>
<th>Sig. (2-tailed)</th>
<th>Reliability coefficient</th>
<th>Measurement error (mm$^3$)</th>
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</thead>
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<tr>
<td>Cleft side volume</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Intra 1</td>
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<td>131.41</td>
<td>.79</td>
<td>.98</td>
<td>129.86</td>
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<td>55.51</td>
<td>.81</td>
<td>1.00</td>
<td>55.68</td>
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<tr>
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<td>.00</td>
<td>.01</td>
<td>.36</td>
<td>.99</td>
<td>.00</td>
</tr>
</tbody>
</table>

5.3.4 Volume Measurements

The volumes of the total nose pre- and postoperatively were computed. A mean volume increase of 1228.36 mm$^3$ was found (95% Confidence Interval (CI): 570.20 mm$^3$ – 1886.52 mm$^3$). This increase was statistically significant (p=0.002). The pre- and
postoperative volumes of the cleft and non-cleft side of the nose are shown in table 4. A mean pre- and postoperative volume difference of 966.29 mm$^3$ was found for the cleft side which was significant (95% CI: 437.43 mm$^3$ – 1495.16 mm$^3$; $p=0.002$). For the non-cleft side the mean pre- and postoperative volume difference was 262.07 mm$^3$, which was not significant (95% CI: -47.40 mm$^3$ – 571.54 mm$^3$; $p=0.09$). Almost all patients had an augmentation of the nasal volume as a result of the operation as is shown by the increase of volume on the cleft side (table 4). However, patients four and nine show a decrease in volume.

The results of the ratio cleft side / non-cleft side are depicted in table 5. There was significant improvement of the symmetry (mean difference 0.03, 95% CI: 0.002 – 0.062; $p=0.03$).

<table>
<thead>
<tr>
<th></th>
<th>Cleft side volume (mm$^3$)</th>
<th>Non-cleft side volume (mm$^3$)</th>
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<td></td>
<td>Preoperative</td>
<td>postoperative</td>
</tr>
<tr>
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<td>17350.31</td>
</tr>
<tr>
<td>2</td>
<td>21688.17</td>
<td>22389.93</td>
</tr>
<tr>
<td>3</td>
<td>14807.19</td>
<td>15858.85</td>
</tr>
<tr>
<td>4</td>
<td>13061.27</td>
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<td>20595.76</td>
<td>21344.01</td>
</tr>
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<td>6</td>
<td>19689.99</td>
<td>21370.49</td>
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<tr>
<td>12</td>
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<td>14477.66</td>
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</table>

5.4 Discussion

To the best of our knowledge, this is the first study to evaluate volumetric changes after rhinoplasty using 3D stereophotogrammetry in patients with clefts. Various methods to assess cleft related facial deformities have been described. Traditionally studies comparing pre- and postoperative nasal changes in CL or CLP patients were limited to radiographs, anthropometry and 2D photogrammetry. As summarized in the introduction, various 3D imaging techniques have been developed to overcome the shortcomings of conventional 2D imaging.

During recent years, 3D stereophotogrammetry has evolved immensely. With the introduction of systems such as the 3dMDfaceTM System (3dMD LLC, Atlanta, USA),
Di3DTM (Dimensional Imaging, Glasgow, UK) and 3D-Sensoren FaceSCAN3D (3D Shape GmbH, Erlangen, Germany), the applicability of 3D photographs in daily practice has become reality. 3D stereophotogrammetry is safe, noninvasive and able to capture superior quality ‘external surface’ photographs in less than 2 milliseconds. These characteristics make it ideal to collect 3D data of faces even in children or babies. After processing the data, an accurate digital model of the patient’s face is created which immediately can be used in a clinical setting. Disadvantages of the system are the need for carefully controlled lighting conditions and the use of four to six high resolution cameras, making it currently a relatively non-portable system, while the cost of the setup can reach € 50.000 or more.

The accuracy of these newly developed 3D imaging systems in recording facial morphologic features has recently been validated. Several recent studies have focused on determining the reproducibility of identifying landmarks by using various 3D modalities including 3D stereophotogrammetry. The results of these studies indicate the 3dMD system to be accurate and precise for facial purposes. Furthermore, the small error in placing landmarks doesn’t lead to statistical significant different volumetric or symmetry measurements, as is seen in the intra- and interobserver validation (table 3).

Nevertheless, several sources of error can be identified using this system. Firstly, an error might occur when the 3D photographs are reconstructed. The 3D hard- and software has its limitations in the reconstruction of for example the nostrils, because of the complex anatomy and the inability of the cameras to capture dark holes perfectly. As a consequence, the nostrils are a region of error. However, this error is expected to be of minimal influence for this study since special attention was given to positioning the patient in a standardized manner while acquiring the pre- and the postoperative 3D pho-

<table>
<thead>
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<th>Patient</th>
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<td>0.89*</td>
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<td>0.87</td>
<td>0.97*</td>
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<tr>
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<td>0.87*</td>
</tr>
<tr>
<td>12</td>
<td>0.82</td>
<td>0.83*</td>
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</table>

Table 5. Pre- and postoperative ratio of the cleft and non-cleft side volume. A ratio of 1.00 means perfect symmetry. (*) Indicates improvement of symmetry.
tographs. An alternative to minimize this problem is using a Cone Beam CT (CBCT) 3D reconstruction of the nose. However, because of the radiation side effect, CBCT is not applicable for longitudinal follow up whereas 3D photographs are harmless. Secondly, surface matching of the pre- and postoperative 3D photographs can result in minimal errors. Recently, our group published about the error of matching 3D photographs onto skin surfaces derived from CBCT data\textsuperscript{17}. Results of matching two different 3D photographs shows to be even more reliable\textsuperscript{18}. In this way, a mean registration error of less than 0.6 mm is expected which is clinical acceptable and valuable\textsuperscript{18}. A third possible error exists in the definition of the midline. In this study the midline is dictated by the median plane, which is based on the pupil reconstructed point. This landmark is indicated as the middle of the inter-endocanthal line. Literature illustrates that identification of landmarks can be difficult and lead to a small error\textsuperscript{7,9,27}. However, since just one and the same midline plane was used for the pre- and postoperative 3D photographs the amount of volume increase as well as the symmetry ratio could not be affected.

For every patient the best operative technique was chosen by one experienced surgeon. The shape of the CL or CLP nose varied widely and as a consequence the surgical correction depended on the deformity of the nose on one hand and the wishes of the patient on the other hand, making every rhinoplasty unique. Nevertheless, changes of the nasal region were obvious in all patients using the 3D photographs of the pre- and postoperative soft tissues (e.g. figure 1).

Since the main goal for surgery was to acquire more symmetry and tip projection, it was expected that the cleft side of the noses would increase in volume. In 10 out of 12 patients more volume was seen and measured on the cleft side. The results of the volumetric measurements were in accordance with the operative techniques performed. For example alar wing volume increased in patients who acquired an alar wing graft. Furthermore, there was a decrease in volume of the complete nose in two patients. The decrease of volume in patient number four was mostly caused by reduction of fibrous and connective tissue. Aside from this, there was no augmentation. In this patient the symmetry did not improve. In patient number nine, both alar wings were mobilized and reinserted more medially in combination with a columellar strut and reduction of fibrous and connective tissue. This caused an overall reduction of volume and more symmetry. Patient number six (figure 1) showed a decrease of volume on the non-cleft side which was attributed to the nasal osteotomy he underwent because of a deviation of the nasal bone to the non-cleft side. On the cleft side the volume increased partly because of a columellar strut and dome sutures. His nose became more symmetrical.

Although this study represents a small sample, significant statistical changes in the volume of the noses could be proved after three months of follow-up using 3D stereophotogrammetry. The Student’s t-test statistical analysis was used because of the small group with paired data. Using this test, the mean difference of the pre- and postoperative data could be analyzed taking into account the within-subject variability.

The main purpose of this study was to investigate the applicability of 3D stereophotogrammetry to measure short term changes in nasal volumes after operation. However, in future studies changes over a longer period of time will be assessed as postoperative swelling might influence short term results. In this way, it will also be possible to com-
pare different operative techniques in patients with a CL or CLP deformed nose. In conclusion 3D stereophotogrammetry is a sensitive, quick and non-invasive method to capture and evaluate the changes of the nose after rhinoplasty in CL or CLP patients.
5.5 References

3D stereophotogrammetric assessment of pre- and postoperative volumetric changes in the cleft lip and palate nose


3D stereophotogrammetric assessment of pre- and postoperative volumetric changes in the cleft lip and palate nose
3D stereophotogrammetric analysis of lip and nasal symmetry after primary cheiloseptoplasty in complete unilateral cleft lip repair

Van Loon B
Reddy SG
Van Heerbeek N
Ingels KJ
Maal TJ
Borstlap WA
Reddy RR
Kuijpers-Jagtman AM
Bergé SJ

Rhinology. 2011 Dec;49(5):546-53
Chapter 6

Introduction
The aim of this study was to evaluate symmetry of the lip and nose in patients with complete unilateral cleft lip, alveolus and palate (CUCLP) after primary cheiloseptoplasty (Afroze technique), in comparison to non-cleft controls.

Methods
In this prospective study forty-four patients with operated non-syndromic CUCLP were included. The control group consisted of 44 volunteers without cleft defects of approximately the same age and sex. Primary septrpasty was performed in conjunction with the cleft lip (CL) repair using the Afroze technique. 3D facial images were acquired using 3D stereophotogrammetry. After a 3D cephalometric analysis of the lip and nose was performed in both groups, linear and volumetric data were acquired. Lip and nose symmetry were calculated and compared using Student’s t-tests as well as the Chi square test.

Results
For all measurements the control group was up to 36% closer to perfect symmetry compared to the CUCLP group after primary surgery. This difference was statistically significant.

Conclusion
After primary cheiloseptoplasty according to the Afroze technique in patients with CUCLP, asymmetry in the nose and lip area still exists as compared to non-cleft controls. Although non-cleft individuals also show some degree of asymmetry the results of this study stress the difficulty in obtaining near normal symmetrical relations.
6.1 Introduction

The ultimate goal for repair of the complete unilateral cleft lip, alveolus and palate (CUCLP) deformity is to create normal oronasal form and function. This aim has resulted in a plethora of techniques and innovations to optimize the esthetic and functional results. However, the management of CUCLP deformities, especially that of the nose, remains a challenge.

Various studies\textsuperscript{1-8} have been undertaken to evaluate the results of different operative procedures to correct the CUCLP nose deformity. However, quantification of rhinoplastic procedures remains difficult. Besides direct anthropometric measurements\textsuperscript{9}, studies comparing pre- and postoperative nose and lip changes in patients with clefts are limited to two dimensional (2D) photographs and radiographs\textsuperscript{10,11}. Nevertheless the human face is a three dimensional (3D) structure and various 3D imaging techniques have been developed to overcome the shortcomings of conventional 2D imaging. These include 3D cephalometry\textsuperscript{12}, Moiré topography\textsuperscript{13}, 3D laser scanning\textsuperscript{14}, 3D optoelectronic digitizers\textsuperscript{15} and 3D stereophotogrammetry\textsuperscript{16-18}. The latter method has gained popularity over the last years as digital 3D data sets of the face can be acquired rapidly, non-invasively, and simultaneously be stored digitally for future analysis\textsuperscript{19}. Recent studies have shown 3D facial measurements acquired with a 3D stereophotogrammetric camera setup to be valid, reproducible\textsuperscript{19,20} and clinically useful\textsuperscript{21-23}.

The Afroze technique, described by Reddy et al.\textsuperscript{24}, is performed in conjunction with a primary functional septoplasty to achieve close to normal symmetry of the nose. However data of the achieved symmetry and the comparison to healthy volunteers are still lacking. To the best knowledge of the authors, so far just one study evaluated facial symmetry in infants, including symmetry of the nose, after Millard lip and McComb nose repair\textsuperscript{25}. Therefore, the aim of this study was to assess the outcome of lip and nasal symmetry with the help of 3D stereophotogrammetry in a group of patients with CUCLP after complete cleft lip correction in combination with a primary septoplasty using the Afroze incision\textsuperscript{24} and to compare these data with a group of healthy control subjects.

6.2 Materials and Methods

6.2.1 Subjects

This prospective study was performed at a high volume cleft center (the GSR Institute of Craniofacial Surgery, Hyderabad, India). Forty-four one year postoperative patients (18 female, 26 male; mean age 3.1 years, range 12 to 96 months) with non-syndromic CUCLP defects were included in this study, of which 29 had a left sided cleft and 15 a right sided cleft. The control group consisted of 44 healthy coeval volunteers (19 female, 25 male; mean age 3.6 years, range 12 to 72 months) taken randomly from a larger prospective study of individuals of the same population without cleft defects.
6.2.2 Surgery

Left lip correction was performed using the Afroze technique. Primary septoplasty was carried out simultaneously with the cleft lip repair. The septoplasty procedure involved muscle dissection after which the perichondrium on both sides was reflected. The septum was then lifted off the nasal spine and repositioned in its anatomical centre with the nasalis muscle from both sides approximated to form a sling around the septum. In this new position the septum has no bony support and is not associated with the nasal spine immediately postoperatively, but does get bony support as the palatal and alveolar shelves move closer together late postoperatively.

6.2.3 3D stereophotogrammetry

A 3D stereophotogrammetrical camera setup with integrated software program modular system V 1.0 (3dMDface™ System, 3dMD LLC, Atlanta, GA, USA) was used to capture 3D photographs of the face. The 3D photographs were generated from six 2D photographs taken simultaneously (four grey-scale photographs and two full color photographs). A polygon light pattern was projected onto the four grey-scale photographs. Based on this pattern and its deformed image, a 3D photograph was reconstructed. With this system it was possible to capture 180 degrees of the subjects face, which concurred with an ear to ear 3D photograph. 3D photographs of the control group and for the CUCLP group were acquired one year postoperative. Before 3D documentation parental consent was obtained.

To isolate the region of interest on the 3D photographs, the neck and parts of the hair were trimmed using 3dMDpatient V3.0.1 software. The 3D photograph was imported into Maxilim® version 2.2.2.1 (Medicim NV, Mechelen, Belgium). To acquire linear measurements a modified 3D cephalometric analysis was performed resulting in 3D photographs in a Cartesian coordinate system. The linear and volumetric measurements of the nose and lip (nostril sagittal length, nostril transversal length, vertical philtrum length, horizontal philtrum length and volume) are depicted in Table 1 and figure 1. For the volumetric measurements of the nose the region of interest was lined by various planes based on the cephalometric analysis that was performed for the linear measurements. These planes defined the area of interest of the volume of the nose. Finally, the nose was divided into a left and a right half based on the median plane and a virtual volume could be computed.

6.2.4 Statistical analysis

To calculate the error of the method, 25 random 3D photographs were measured twice by two independent observers (TM and BvL). Correlation between both observers and within observers was evaluated using Pearson correlation. Furthermore the
Figure 1. Linear and volumetric volumes used in this study. (a) Linear measurements used in this study as part of the cephalometric analysis. (b) The creation of the volumes for symmetry measurements. First the cephalometric analysis is performed after which the nose is lined by various planes. These planes are then used to cut the 3D photo and the two halves of the nose can be measured.
intra- and interobserver reliability was tested using Student’s t-test with a p-value of < 0.05 indicating a statistically significant difference. This was done for each variable separately. The volumetric measurements that were used in this study, have been validated previously for the same observers 23.

For two sided measurements, the asymmetry can be expressed as the percentual difference between the two sides. The asymmetry percentage was calculated for each patient and control and these results were then divided into ≤0.5%, >0.5 and ≤ 5%, > 5 and ≤ 10%, >10 and ≤ 15%, and >15% deviation from perfect symmetry. The mean and standard deviation for all measurements were calculated and the Student’s t-test and Chi square test (Fisher’s exact test) were performed. The statistical data analysis was performed with the SPSS software program, version 16.0 (SPSS Inc, Chicago, USA).

6.3 Results

Table 2 shows the intra- and interobserver analysis. The mean difference, 95% confidence interval, Pearson correlation coefficient, measurement error and p-value for the intra- and interobserver reliability showed no statistical significant differences (p<0.05) between and within the observers.

For all five measurements (nostril sagittal length, nostril transversal length, vertical philtrum length, horizontal philtrum length and volume) the Student’s t-test showed a statistical significant difference for the asymmetry score (table 3) between the two groups. The control group was found to be up to 36 % closer to perfect symmetry compared to the operated CUCLP group.

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<tr>
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<th>Description</th>
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</thead>
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<td>Distance between landmarks Anterior Nostril (left) and Posterior Nostril (left)</td>
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<td>Nostril transverse left</td>
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<td>Distance between landmarks Medial Nostril (right) and Lateral Nostril (right)</td>
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</table>
3D stereophotogrammetric analysis of lip and nasal symmetry after primary cheiloseptoplasty in complete unilateral cleft lip repair

Table 2 Intra- and interobserver analysis. The mean difference between the measurements with a 95% confidence interval and p-value, Pearson reliability coefficient and measurement error are given. No statistical significant differences were found.

<table>
<thead>
<tr>
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<td>0.95</td>
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<tr>
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<td>Intra 1 0.08</td>
<td>-0.22</td>
<td>0.39</td>
<td>0.58</td>
<td>0.91</td>
</tr>
<tr>
<td></td>
<td>intra 2 -0.07</td>
<td>-0.24</td>
<td>0.1</td>
<td>0.38</td>
<td>0.97</td>
</tr>
<tr>
<td></td>
<td>inter 1 -0.02</td>
<td>-0.26</td>
<td>0.23</td>
<td>0.89</td>
<td>0.95</td>
</tr>
<tr>
<td></td>
<td>inter 2 -0.13</td>
<td>-0.54</td>
<td>0.29</td>
<td>0.28</td>
<td>0.94</td>
</tr>
<tr>
<td>Nostril transverse left</td>
<td>intra 1 0.16</td>
<td>-0.23</td>
<td>0.56</td>
<td>0.4</td>
<td>0.81</td>
</tr>
<tr>
<td></td>
<td>intra 2 0.01</td>
<td>-0.28</td>
<td>0.29</td>
<td>0.79</td>
<td>0.87</td>
</tr>
<tr>
<td></td>
<td>inter 1 -0.17</td>
<td>-0.37</td>
<td>0.03</td>
<td>0.1</td>
<td>0.95</td>
</tr>
<tr>
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<td>-0.33</td>
<td>0.25</td>
<td>0.81</td>
<td>0.91</td>
</tr>
<tr>
<td>Nostril transverse right</td>
<td>intra 1 -0.16</td>
<td>-0.73</td>
<td>0.41</td>
<td>0.57</td>
<td>0.7</td>
</tr>
<tr>
<td></td>
<td>intra 2 0.01</td>
<td>-0.18</td>
<td>0.19</td>
<td>0.59</td>
<td>0.97</td>
</tr>
<tr>
<td></td>
<td>inter 1 -0.12</td>
<td>-0.35</td>
<td>0.1</td>
<td>0.27</td>
<td>0.96</td>
</tr>
<tr>
<td></td>
<td>inter 2 0.22</td>
<td>-0.3</td>
<td>0.75</td>
<td>0.17</td>
<td>0.77</td>
</tr>
<tr>
<td>Vertical philtrum length left</td>
<td>intra 1 0.1</td>
<td>-0.44</td>
<td>0.64</td>
<td>0.7</td>
<td>0.72</td>
</tr>
<tr>
<td></td>
<td>intra 2 -0.07</td>
<td>-0.41</td>
<td>0.27</td>
<td>0.52</td>
<td>0.89</td>
</tr>
<tr>
<td></td>
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<td>-0.09</td>
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<td>0.93</td>
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<tr>
<td></td>
<td>inter 2 -0.38</td>
<td>-0.87</td>
<td>0.11</td>
<td>0.09</td>
<td>0.77</td>
</tr>
<tr>
<td>Vertical philtrum length right</td>
<td>intra 1 0.33</td>
<td>-0.37</td>
<td>1.03</td>
<td>0.34</td>
<td>0.73</td>
</tr>
<tr>
<td></td>
<td>intra 2 -0.01</td>
<td>-0.37</td>
<td>0.36</td>
<td>0.95</td>
<td>0.93</td>
</tr>
<tr>
<td></td>
<td>inter 1 -0.02</td>
<td>-0.33</td>
<td>0.29</td>
<td>0.9</td>
<td>0.95</td>
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<tr>
<td></td>
<td>inter 2 -0.38</td>
<td>-1.12</td>
<td>0.36</td>
<td>0.27</td>
<td>0.82</td>
</tr>
<tr>
<td>Horizontal philtrum length left</td>
<td>intra 1 0.01</td>
<td>-0.5</td>
<td>0.52</td>
<td>0.96</td>
<td>0.9</td>
</tr>
<tr>
<td></td>
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<td>-0.65</td>
<td>0.21</td>
<td>0.53</td>
<td>0.95</td>
</tr>
<tr>
<td></td>
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<td>0.42</td>
<td>0.48</td>
<td>0.93</td>
</tr>
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<td>-0.82</td>
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<td>0.35</td>
<td>0.86</td>
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<td>Horizontal philtrum length right</td>
<td>intra 1 0.40</td>
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<td>0.12</td>
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<td>0.96</td>
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<td>-0.8</td>
<td>0.51</td>
<td>0.74</td>
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</table>
In figure 2 and table 4 the distribution of the degree of deviation from perfect symmetry is given. The Chi square for the nostril sagittal length (p<0.001), nostril transverse length (p<0.001), vertical philtrum length (p<0.001), horizontal philtrum length (p<0.001) and volume measurement (p<0.001) indicated a statistically significant different distribution between the control and cleft group.

Table 3. Group statistics with mean and standard deviation of the asymmetry as a percentage from perfect symmetry for the control and CUCLP group. Mean difference (percentage), standard deviation, standard error, 95% confidence interval and p-value (Student's t-test) between the control group and the CUCLP group are given for the deviation from perfect symmetry. All measurements show statistical significant difference between the CUCLP group and the control group.

<table>
<thead>
<tr>
<th>Group</th>
<th>Mean (%) and SD</th>
<th>Mean Diff (%)</th>
<th>Std Error Diff</th>
<th>95% Confidence interval of the Difference</th>
<th>Sign 2-tailed)</th>
</tr>
</thead>
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<tr>
<td>Nostril sagittal length</td>
<td>Control 4.88 ± 4.16</td>
<td>-36.45</td>
<td>11.22</td>
<td>-58.76 -14.14</td>
<td>0.002</td>
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<tr>
<td></td>
<td>CUCLP 41.34 ± 74.34</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Nostril transversal length</td>
<td>Control 4.46 ± 3.02</td>
<td>-23.36</td>
<td>3.59</td>
<td>-30.51 -16.23</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td></td>
<td>CUCLP 27.83 ± 23.62</td>
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<td></td>
<td></td>
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</tr>
<tr>
<td>Vertical philtrum length</td>
<td>Control 2.94 ± 2.61</td>
<td>-20.96</td>
<td>2.79</td>
<td>-26.51 -15.39</td>
<td>&lt;0.001</td>
</tr>
<tr>
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<td>CUCLP 23.89 ± 18.36</td>
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<td>Horizontal philtrum length</td>
<td>Control 1.85 ± 1.54</td>
<td>-12.82</td>
<td>2.52</td>
<td>-17.83 -7.82</td>
<td>&lt;0.001</td>
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<td>CUCLP 14.68 ± 16.63</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Volume</td>
<td>Control 4.76 ± 4.24</td>
<td>-12.77</td>
<td>2.11</td>
<td>-16.98 -8.57</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td></td>
<td>CUCLP 17.54 ± 13.37</td>
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<td></td>
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</table>
3D stereophotogrammetric analysis of lip and nasal symmetry after primary cheiloseptoplasty in complete unilateral cleft lip repair

Table 4. Asymmetry distribution for the control group and CUCLP group. The patients and controls are distributed over 5 categories ranging from 0% to >15% deviation from perfect symmetry.

<table>
<thead>
<tr>
<th>Deviation from 0</th>
<th>Control group (N=44)</th>
<th>CUCLP (N=44)</th>
</tr>
</thead>
<tbody>
<tr>
<td>≤0.5 and ≤5</td>
<td>4</td>
<td>25</td>
</tr>
<tr>
<td>&gt;0.5 and ≤10</td>
<td>10</td>
<td>3</td>
</tr>
<tr>
<td>&gt;10 and ≤15</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>&gt;15 and &gt;5</td>
<td>6</td>
<td>10</td>
</tr>
<tr>
<td>&gt;10 and &gt;15</td>
<td>4</td>
<td>24</td>
</tr>
</tbody>
</table>

Nostril Sagittal length

Nostril Transverse length

Vertical Philtrum length

Horizontal Philtrum length

Volume

Figure 2. graphs showing the distribution of the deviation from perfect symmetry for both the control (a) and cleft (b) group for every measurement.
6.4 Discussion

Using 3D stereophotogrammetry it was possible to assess the outcome of cleft lip surgery in combination with primary septoplasty using the Afroze incision for symmetry of lip and nose. Comparison of the CUCLP and control group revealed, even after corrective surgery, a significant difference concerning symmetry for both lip and nose measurements.

The first portfolio of stereoscopic photographs was created in the 1850’s. From that point on, stereography evolved to modern 3D digital photographic systems. With the advent of digital technology, the applicability of 3D photographs in daily practice has become reality. The accuracy of various 3D imaging systems in recording facial morphologic features has been validated for various 3D modalities including the 3dMD system used in this study.7,19,20,29-33. The results of these studies indicated the 3dMD system to be accurate and precise for facial purposes. Nevertheless several drawbacks of using 3D photographs can be identified for this study. Firstly, an error might occur when the 3D photographs are reconstructed. The 3D hard- and software has its limitations, especially in the reconstruction of for example the nostrils, because of the complex anatomy and the inability of the cameras to capture dark holes perfectly. As a consequence, the nostrils are a region of error and therefore identification of landmarks in this region can be difficult. A way to minimize this problem would be to use a Cone Beam CT (CBCT) 3D reconstruction of the nose. However, because of the radiation dose and long acquisition time, CBCT is not applicable for longitudinal follow up whereas 3D photographs are harmless.

Secondly, an error may occur during placement of the landmarks used in this study. In this study landmarks were used to compute linear measurements and to dictate the planes lining the right and left half of the nose for volumetric measurements. Earlier studies showed that identification of landmarks on 3D photographs can be difficult and lead to a small error.20,29,31. The analysis of the measurement error of the present study showed that the intra- and interobserver reliability were adequate.

Another drawback of this study is the lack of preoperative 3D patient data. Therefore the amount of improvement or impairment of the symmetry of the lip and nose as a direct effect of surgery cannot be measured. By comparing the result to a non-cleft control group, however, we can estimate to which extend a close to normal symmetry was reached. In a previous study volumetric changes of the nose in patients with a CUCLP were documented before and after secondary rhinoplasty.23. Despite improvements, perfect symmetry could not be achieved.

Several studies used 3D techniques to evaluate the soft tissues of the face of patients with orofacial clefts in comparison to controls. Hood et al.25 used the C3D stereophotogrammetry system to assess facial symmetry in 20 patients with orofacial clefts, after Millard lip, McComb nose and palate repair, and compared the results with non-cleft age-matched controls. Pre- and postoperative facial asymmetry was evaluated by calculating distances between landmarks and their mirror images and expressing the result as an asymmetry score for each area of interest. The unilateral CLP group was more
asymmetric than the unilateral CL group and these again were more asymmetric than the control group.

Bilwatsch et al. \textsuperscript{34} assessed the degree of facial symmetry in patients with CUCLP with an optical 3D sensor which implied that textured information was not available. Twenty-two ten-year-old patients with CUCLP, who underwent lip repair using the Tennison–Randall technique without primary rhinoplasty and did not undergo further revision surgery were included. After establishing a plane of symmetry differences were determined between landmarks, surface areas and virtual volumes of various areas of interest. Statistically significant differences could be found between cleft and non-cleft sides. They concluded that complete nasal symmetry was difficult to achieve with Tennison–Randall’s lip repair without revision surgery.

The various linear and volumetric measurements in the present study indicated the symmetry of the patient group with CUCLP to differ significantly from the control group. For all measurements the control group was up to 36\% (table 3) closer to perfect symmetry compared to the postoperative CUCLP group. The nostrils seemed to be the area where most deviation existed. The volumetric measurements, which give an indication of symmetry for the whole nose, indicated the control group to be mostly symmetric with 75\% of controls having a symmetry score within five percent deviation from perfect symmetry. For the group with CUCLP this was just 18\%, which indicated a significant difference. This shows that the Afroze technique in combination with a functional repair of the nose is not able to achieve near normal symmetry. Whether other techniques are performing better remains to be investigated and asks for a randomized clinical trial design with direct comparison of different techniques and 3D analysis of the outcome.

6.5 Conclusions

After primary cheiloseptoplasty according to the Afroze technique in patients with CUCLP asymmetry in the nasal and lip area still exists as compared to non-cleft controls. Although non-cleft individuals also show some degree of asymmetry the results of this study stress the difficulty in obtaining near normal symmetrical relations.
6.6 References


3D stereophotogrammetric analysis of lip and nasal symmetry after primary cheiloseptoplasty in complete unilateral cleft lip repair
Postoperative volume increase of facial soft tissue after percutaneous versus endonasal osteotomy technique in rhinoplasty using 3D stereophotogrammetry

Van Loon B
Van Heerbeek N
Maal TJ
Borstlap WA
Ingels KJ
Schols JG
Bergé SJ

Rhinology. 2011 Mar;49(1):121-6
Chapter 7

Introduction
When lateral osteotomies are performed as part of a rhinoplasty the nose and paranasal region invariably change in three dimensions. The purpose of this study is to compare the effect of the percutaneous perforating and endonasal continuous osteotomy techniques concerning the degree of postoperative swelling using three dimensional (3D) stereophotogrammetry.

Methods
A prospective follow-up study was conducted. Patients requiring bilateral osteotomies were included and randomly underwent a percutaneous osteotomy on one side and an endonasal osteotomy on the other side. Pre- and postoperative 3D photos were acquired using 3D stereophotogrammetry. Volumetric measurement data were acquired from the paranasal region using 3D software. Measurements were compared using Student’s t-test and Wilcoxon signed rank test statistics.

Results
20 patients were included. A percutaneous osteotomy was performed on the right side in nine patients and on the left side in 11 patients. The total volume, the volume of the right paranasal and left paranasal region were significantly larger postoperative. No difference was found between the sides (mean volume difference = 59.95 mm³, 95% CI: -269.77 mm³ to 389.67 mm³ p=0.708). The Wilcoxon test confirmed this (p=0.601).

Conclusion
No difference concerning swelling is found between the percutaneous and endonasal osteotomy technique sides. With 3D stereophotogrammetry volumetric data can be acquired and compared to evaluate soft-tissue changes.
7.1 Introduction

Lateral osteotomies are frequently performed as part of a rhinoplasty for various purposes: to close an open roof after hump removal, to narrow a broad nasal pyramid or to correct an asymmetric lateral nasal wall contour. Although several techniques using different kinds of osteotomes and chisels have been described, the lateral osteotomy can be divided into two basic techniques: the percutaneous/perforating/external osteotomy on one hand and the endonasal/continuous/internal osteotomy on the other hand. Both osteotomy techniques can be used in combination with an open approach as well as with a closed rhinoplasty technique.

The ideal lateral osteotomy should be precise, reproducible and safe with minimal postoperative sequelae such as edema, ecchymosis or scar formation. Critics of the percutaneous technique suggest that visible scars will be a result of using this technique, while advocates of the percutaneous technique suggest that the endonasal technique causes much more mucosal and periosteal disruption including subsequent bleeding and edema. Since few studies address this discussion using only clinical assessment as outcome measure, a randomized study to objectively assess both techniques was designed.

With the advent of three dimensional (3D) imaging techniques, such as 3D stereophotogrammetry, it is possible to capture and acquire measurements from the nose rapidly and non-invasively. Specifically precise volumetric measurements concerning changes of the nose can now be calculated from 3D data.

The aim of this study is to compare the effect of the percutaneous perforating and endonasal continuous osteotomy techniques with regard to the degree of postoperative swelling using 3D stereophotogrammetry.

7.2 Materials and Methods

7.2.1 Patients

The study sample comprised of patients from the department of Otorhinolaryngology of the Radboud University Nijmegen Medical Centre, The Netherlands. Inclusion criteria were the need for a bilateral osteotomy as well as a signed informed consent. Exclusion criteria were patients who required a dorsal augmentation as well as patients with associated craniofacial deformities or syndromes and earlier rhinoplasty surgery. Permission for the study was obtained from the ethical committees. After written informed consent was obtained, all participating patients were randomly assigned into two groups. In group one a percutaneous perforating osteotomy was performed on the right side and an endonasal continuous osteotomy was performed on the left side. In group two the endonasal continuous technique was performed on the right side and the percutaneous perforating technique on the left. The author (BvL) performing the measurements was blinded concerning the technique used on each side.
7.2.2 Operative procedure

All procedures were performed by the same surgeons (KI or NvH). A primary open rhinoplasty was performed in all patients. The right sided osteotomy was always performed before the left sided osteotomy and when paramedian osteotomies, a hump reduction, oblique or transversal osteotomies were necessary, these were performed before the lateral osteotomies. To delineate the lateral osteotomy, lines were drawn on the skin of the patient. The percutaneous osteotomy was performed through a three millimeter (mm) skin incision halfway the osteotomy to be made, without applying a local anesthetic. A three mm osteotome was used to scratch away the supraperiosteal tissue containing the angular artery. Then five to six separate perforations through the nasal bone were made just a few millimeters apart using a two mm osteotome. The first perforation was made halfway the nasal bone, followed by perforations towards the piriform aperture. Furthermore, the superior part of the nasal bone was perforated. Finally, the nasal bone was infractured.

The endonasal osteotomy was performed with a four mm, guided osteotome. First, a local anesthetic was injected at the entry site just above the inferior turbinate followed by an incision just above the inferior turbinate so visualizing the edge of the piriform aperture. Secondly, a submucosal tunnel was created on the medial side of the nasal bone, the osteotome was inserted and the osteotomy was performed while the tip of the osteotome was palpated continuously through the skin. Finally the nasal bone was infractured to complete the osteotomy. Great care was taken in both procedures to preserve a distal triangle of bone at the piriform aperture to prevent narrowing of the vestibule at the head of the inferior turbinate.

After the osteotomies had been completed the nasal bones were shaped into the right position. Subsequently, local pressure was applied to the nasal pyramid during the remaining of the procedure until nasal packing was complete. Standard internal nasal packing was applied at the end of surgery. An adhesive thermoplastic external nasal splint was used in all cases. The nasal packing was removed after four to five days and the external splint was removed after 14 days.

7.2.3 Pre- and postoperative 3D documentation

A 3D stereophotogrammetrical camera setup with an integrated software program modular system V 1.0 (3dMDface™ System, 3dMD LLC, Atlanta, GA, USA) was used to capture 3D photos of the face. The 3D photos were generated from six 2D photos taken simultaneously (four grey-scale photos and two full color photos). A polygon light pattern was projected onto the four grey-scale photos. Based on this pattern and its deformed image, a 3D photo was reconstructed. With this system it was possible to capture 180 degrees of the subjects face, which concurred with an ear to ear 3D photo.

The 3D photos were taken in natural head position and habitual occlusion. Patients were asked to relax their facial musculature, swallow and keep their molars in occlusion after swallowing. 3D photos were acquired preoperatively as well as at the first clinical
Postoperative volume increase of facial soft tissue after percutaneous versus endonasal osteotomy technique in rhinoplasty using 3D stereophotogrammetry control visit postoperatively.

7.2.4 3D Measurements

To isolate the region of interest on the 3D photos, the neck and parts of the hair were trimmed using 3dMDpatient V3.0.1 software. After this the 3D photo was imported into Maxilim* version 2.2.2.1 (Medicim NV, Mechelen, Belgium) and a surface-based matching procedure of the pre- and postoperative 3D photos was performed in five steps as described by our group. After registration, a distance map could be calculated, which gave an indication of the soft tissue changes (figure 1). A modified 3D cephalometric analysis was performed to outline the region of interest for the volumetric measurements. This analysis was based on the 3D cephalometric soft tissue analysis for CT data. This resulted in the matched 3D photos on a Cartesian coordinate system with the regions of interest confined by various planes (figure 2). These planes defined the borders of the volume of the paranasal swelling and were used for further circumscription of the 3D photo. Finally, only the paranasal regions were left and a virtual volume could be computed. The left and right paranasal volumes of the pre- and postoperative 3D photos were then measured.

7.2.5 Statistical analysis

The pre- and postoperative volume differences were calculated for the percutaneous and endonasal side for each patient. Pre- and postoperative differences were analyzed using paired Student’s t–tests and the Wilcoxon signed rank test statistics, with a p-value of < 0.05 indicating statistical significant differences. The statistical data analysis was performed with the SPSS software program, version 16.0 (SPSS Inc, Chicago, USA).

7.3 Results

7.3.1 Patients

Twenty patients (10 male and 10 female) aged 20 to 55 years (median 35 years) were included in this study. Nine patients (five male, four female) underwent a percutaneous osteotomy on the right side and an endonasal osteotomy on the left side, whereas 11 patients (five male, six female) underwent a percutaneous osteotomy on the left side and an endonasal osteotomy on the right side.

7.3.2 Pre- and postoperative 3D documentation

Preoperative 3D photos were acquired 0-7 days prior to surgery (median two days) and postoperatively 3D photos were acquired after 4-5 days (median four days).
The volumes of the preoperative and postoperative paranasal regions are presented in table 1. The preoperative volumes of the paranasal regions vary from 3,132 mm$^3$ to 10,638 mm$^3$ and the postoperative volumes vary from 3,993 mm$^3$ to 13,857 mm$^3$. The

7.3.3 3D measurements

The volumes of the preoperative and postoperative paranasal regions are presented in table 1. The preoperative volumes of the paranasal regions vary from 3,132 mm$^3$ to 10,638 mm$^3$ and the postoperative volumes vary from 3,993 mm$^3$ to 13,857 mm$^3$. The
Postoperative volume increase of facial soft tissue after percutaneous versus endonasal osteotomy technique in rhinoplasty using 3D stereophotogrammetry

Paired differences between the 3D photo’s are given in Table 2 and illustrated in Figure 3. The total volume (mean volume difference = 3,149 mm$^3$, 95% CI: 2,339 mm$^3$ to 3,959 mm$^3$ $p=0.000$) as well as the volume of the right paranasal (mean volume difference = 1,639 mm$^3$, 95% CI: 1,223 mm$^3$ to 2,053 mm$^3$ $p=0.000$) and left paranasal region (mean volume difference = 1,510 mm$^3$, 95% CI: 1,053 mm$^3$ to 1,967 mm$^3$ $p=0.000$) was significantly larger postoperative. No significant difference was found between the percutaneous and endonasal side (mean volume difference = 60 mm$^3$, 95% CI: -270 mm$^3$ to 390 mm$^3$ $p=0.708$). The Wilcoxon signed rank test also indicated no statistical significant difference between the percutaneous and endonasal side ($p=0.601$).

Table 1. Volumetric measurements of the 20 patients. Preoperative, postoperative and volume increase are given for the endonasal and percutaneous side. * indicates statistical significant increase between preoperative and postoperative.

<table>
<thead>
<tr>
<th>Patient</th>
<th>Preoperative</th>
<th>Postoperative</th>
<th>Volume increase</th>
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</thead>
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<tr>
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<td>Preop volume (mm$^3$)</td>
<td>Postop volume (mm$^3$)</td>
<td>Volume increase (mm$^3$)</td>
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<tr>
<td>Right</td>
<td>Perc side</td>
<td>Endonasal side</td>
<td>Percutaneous side</td>
</tr>
<tr>
<td>1</td>
<td>8654</td>
<td>9234</td>
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<td>5845</td>
<td>6650</td>
<td>805</td>
</tr>
<tr>
<td>14</td>
<td>9386</td>
<td>10672</td>
<td>1285</td>
</tr>
<tr>
<td>15</td>
<td>8558</td>
<td>8911</td>
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<tr>
<td>16</td>
<td>4159</td>
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<td>7045</td>
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</tr>
<tr>
<td>18</td>
<td>7329</td>
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<td>1587</td>
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<td>5561</td>
<td>7172</td>
<td>1612</td>
</tr>
<tr>
<td>20</td>
<td>5604</td>
<td>7133</td>
<td>1529</td>
</tr>
<tr>
<td>Mean</td>
<td>7351</td>
<td>8895</td>
<td>1544*</td>
</tr>
</tbody>
</table>
In this study, using 3D stereophotogrammetry, the degree of postoperative swelling was obvious in all patients (e.g. Figure 1). However no difference was found concerning postoperative swelling when comparing the percutaneous perforating and endonasal osteotomy side.

![Boxplots of the percutaneous and endonasal osteotomie. The percutaneous and endonasal volumes are shown indicating no statistical difference.](image)

**Table 2. Paired Samples Test between the groups. Mean, SD and 95% Confidence intervals are given for the comparison of the difference between the percutaneous osteotomy and endonasal osteotomy side.**

<table>
<thead>
<tr>
<th>Paired Differences</th>
<th>Mean difference (mm³)</th>
<th>Std. Deviation</th>
<th>Std. Error Mean</th>
<th>95% Confidence Interval of the Difference</th>
<th>Sig. (2-tailed)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Percutaneous pre - Percutaneous post</td>
<td>1604</td>
<td>871</td>
<td>195</td>
<td>1197 - 2012</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Endonasal pre - Endonasal post</td>
<td>1544</td>
<td>994</td>
<td>222</td>
<td>1079 - 2010</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Percutaneous – Endonasal</td>
<td>60</td>
<td>705</td>
<td>158</td>
<td>-270 - 390</td>
<td>0.708</td>
</tr>
</tbody>
</table>

7.4 Discussion

In this study, using 3D stereophotogrammetry, the degree of postoperative swelling was obvious in all patients (e.g. Figure 1). However no difference was found concerning postoperative swelling when comparing the percutaneous perforating and endonas-
Postoperative volume increase of facial soft tissue after percutaneous versus endonasal osteotomy technique in rhinoplasty using 3D stereophotogrammetry

sal continuous osteotomy technique. Previous studies that compared a variety of lateral nasal osteotomy techniques used various methods to analyze their results. Rohrich et al.\(^8\) compared the results of both percutaneous perforating and endonasal continuous techniques endoscopically in fresh cadavers. They found that the percutaneous technique resulted in a more controlled fracture with less intranasal trauma measured by the occurrence of mucosal tears. In their clinical experience the percutaneous technique provides excellent control, is direct, and minimizes hemorrhage, edema, and ecchymosis postoperatively.

Gryskiewicz and Gryskiewicz studied several osteotomy techniques using clinical evaluation to compare them \(^9\). They compared the endonasal continuous osteotomy with the endonasal perforating osteotomy and percutaneous perforating osteotomy in different groups of patients and with different sides in the same patient. They used two mm osteotomes for the perforating osteotomies and four mm guarded osteotomes for continuous osteotomies. Three examiners determined whether a difference in ecchymosis and edema was present between the left and right side at two, seven and 21 days postoperatively. They demonstrated that the perforating technique performed through an endonasal approach caused less edema and ecchymosis than the continuous technique performed endonasally. Although they conclude that their study confirms the clinical impression that percutaneous perforating lateral osteotomies with a two mm straight osteotome reduces postoperative ecchymosis and edema compared with the endonasal continuous method, no statistical difference was found between these techniques. Concerning the comparison of the endonasal perforating and the percutaneous perforating technique, where the endonasal perforating osteotomy was superior to the percutaneous perforating method, also no statistical difference was found.

In another randomized study using clinical evaluation, Yücel \(^10\) compared the percutaneous perforating technique in a group of patients with a group who underwent an endonasal continuous osteotomy by using a scoring diagram for edema and ecchymosis. Two blinded surgeons made the comparisons. Yücel found that ecchymosis was less on the second postoperative day in patients with the endonasal continuous osteotomy compared to the percutaneous perforating osteotomy group. However, on the seventh postoperative day ecchymosis had already partly resolved and no difference was found anymore. During the postoperative period no difference was found in degree of edema.

In the 1850’s the first portfolio of stereoscopic photographs was created \(^11\). From that point on, stereography evolved from the crude dual camera systems of the past to modern 3D digital photographic systems, although both use the same principles. Offset images were merged together to create a stereoscopic image. With the advent of digital technology, digital photography has become an increasingly important tool in facial surgery \(^12\). The accuracy of these newly developed 3D imaging systems in recording facial morphologic features has recently been validated \(^13-15\). Several recent studies have focused on determining the reproducibility of identifying landmarks by using various 3D modalities including 3D stereophotogrammetry \(^2, 13, 14, 16-20\). The results of these studies indicate the 3dMD system to be accurate and precise for facial purposes. Furthermore, the small error in placing landmarks doesn’t lead to statistical significant different
volumetric or symmetry measurements, as was found in a recent study by our group in which the pre- and postoperative volumes of the nose in cleft lip and palate patients was measured using 3D stereophotogrammetry 3. Nevertheless, several errors can be identified using this system. Firstly, surface matching of the pre- and postoperative 3D photographs can result in minimal errors. Recently, our group published about the error of matching 3D photographs onto skin surfaces derived from CBCT data 6. Results of matching two different 3D photos shows to be even more reliable 22. In this way, a mean registration error of less than 0.6 mm was found which is clinical acceptable and valuable 13,22. A second possible error exists in the definition of the planes and whether these define a representative area. The planes are based on the cephalometric analysis and define the region of interest and therefore the volume measured in this region. Volumes outside of these planes aren’t measured and therefore, if the region of interest isn’t sufficient, data are missed. However since the same planes are used for the pre- and postoperative 3D photographs, the volume difference measured gives a reliable indication of the volume in- or decrease caused by the osteotomy. Also we don’t know the influence of the two osteotomy techniques on the contralateral side. However if one of the two techniques would have influenced the contralateral side more than the other technique we would have found a difference in volume.

Although this study represents a small sample, significant statistical changes in the volume of the paranasal region could be proved postoperatively using 3D stereophotogrammetry. The power of this study is reflected in table 2. A statistical significant difference would have been found if the difference between both techniques would be 330 or more (half the width of the confidence interval). The mean swelling for both techniques is about 1,600 mm$^3$ (table 1) indicating that a statistical significant difference would have been found when one of both techniques would reduce or increase swelling with 21% (330/1,600). In this study the mean difference between both techniques is just 60 mm$^3$ (4%). The Student’s t-test statistical analysis was used because of the small group with paired data. The Wilcoxon signed rank test was used as the group cannot be assumed to be normally distributed. Using these tests, the mean difference of the pre- and postoperative data could be analyzed.

The above mentioned studies comparing the percutaneous and endonasal osteotomy technique all used clinical assessment as outcome measure. Although both the percutaneous as well as the endonasal technique are widely accepted and practiced, no studies have found statistical evidence of either the percutaneous osteotomy or the endonasal osteotomy resulting in differences concerning swelling. With the use of 3D digital images the rather qualitative outcome from the few studies that have been performed, is replaced by a quantitative outcome. Based on these data it is apparent that the suggested damaging of the mucosa by using the endonasal route doesn’t lead to more or less swelling if compared to the percutaneous method. A tear in the mucosa on the inner side of the nasal bone at the level of the osteotomy, might even have a favorable effect on blood drainage.
7.5 Conclusions

The purpose of this study was to investigate and compare the degree of swelling caused by the percutaneous and endonasal osteotomy technique with the help of 3D stereophotogrammetry. No statistical significant difference was found between the percutaneous osteotomy and the endonasal osteotomy sides. With 3D stereophotogrammetry volumetric measurement data can be acquired from 3D photo’s and these measurements can be compared to evaluate soft-tissue changes.
7.6 References


14. Weinberg SM, Scott NM, Neiswanger K, Brandon CA, Marazita ML. Digital three-dimensional photogrammetry: evaluation of anthropometric precision and accu-
Postoperative volume increase of facial soft tissue after percutaneous versus endonasal osteotomy technique in rhinoplasty using 3D stereophotogrammetry.


Volumetric changes of the nose and nasal airway two years after tooth-borne and bone-borne surgically assisted rapid maxillary expansion

Nada RM
van Loon B
Schols JG
Maal TJ
de Koning MJ
Mostafa YA
Kuijpers-Jagtman AM

Chapter 8

Introduction
This study aimed to assess the effects of bone-borne and tooth-borne surgically assisted rapid maxillary expansion (SARME) on the volume of the nose and nasal airway two years post-surgically.

Methods
Thirty two patients with transverse maxillary hypoplasia were included in this prospective cohort study. In 19 patients, a tooth-borne distractor (Hyrax) was used for expansion, in the remaining 13 a bone-borne distractor (Transpalatal Distractor, TPD) was used. Cone beam computed tomography scans and 3D photographs of the face acquired prior to treatment and 22 ±7 months later were used to evaluate the volume of the nose and nasal airway.

Results
Nasal volume increased by 1.01 ± 1.6 % in the Hyrax group and by 2.39 ± 2.4 % in the TPD group. Nasal airway volume increased by 9.7 ± 5.6 % in the Hyrax group and 12.9 ± 12.7 % in the TPD group. The changes in the nose and nasal airway volume between the pre- and post-treatment measurements were statistically significant (p < 0.05). the differences between treatment groups were not statistically significant (p > 0.05).

Conclusion
Twenty-two months after SARME, the increase in the volume of the nose, and nasal airway was comparable between tooth-borne and bone-borne devices.
8.1 Introduction

Surgically assisted rapid maxillary expansion (SARME) has long been used as a method for correction of transverse maxillary deficiency in adult patients. While the procedure aims to expand the constricted maxilla to coordinate the upper and lower arches; the transversal enlargement of the maxillary apical base simultaneously alters the dimensions of the nose and the nasal cavity. The skeletal and dental effects of SARME with either tooth-borne or bone-borne expansion have been thoroughly described in the literature. However, traditional 2D cephalograms provided limited information on the effects of expansion devices on the dimensions of the nose and nasal airway. With the introduction of three dimensional (3D) imaging modalities like 3D stereophotogrammetry and cone beam computed tomography (CBCT) a more detailed and accurate evaluation of the changes in soft tissues and airway volumes became feasible. Compared with conventional radiography, CBCT allows a more detailed visualization and quantification of the airway space. Consequently, the past few years have seen an increasing number of publications using CBCT for upper airway analysis following maxillary expansion. These studies have mainly investigated the effects of each expansion device separately or focused on the oropharyngeal airway. The effects of tooth-borne and bone-borne SARME on the volume of the nose and the nasal airway have not yet been directly compared.

The aim of the present study was therefore to evaluate the long term effects of bone-borne and tooth-borne SARME on the volume of the nose and nasal airway using 3D imaging software. The null hypothesis to be tested was that the choice of tooth-borne or bone-borne devices does not result in different volumetric changes of the nose and nasal airway.

8.2 Materials and Methods

This study included 32 patients seeking orthodontic treatment at the Department of Orthodontics and Craniofacial Biology of the Radboud University Nijmegen Medical Centre, Nijmegen (the Netherlands). Inclusion criteria were skeletal maturity, skeletal transverse maxillary deficiency combined with another skeletal discrepancy that required orthognathic surgical intervention, and no developmental deformity. Exclusion criteria were presence of developmental deformity, signs of fluid accumulation in the maxillary sinuses on the CBCT images, and absence of more than 4 teeth in the posterior maxillary arch. Nineteen patients underwent tooth-borne expansion, while the remaining 13 patients underwent bone-borne expansion. The study protocol was approved by the Medical Ethics Committee of the Radboud University Nijmegen Medical Centre, Nijmegen, The Netherlands (#181/2005). All patients gave written informed consent.
8.2.1 Surgical Procedure

The same surgical procedure was applied in all patients and was thoroughly described in a previous study. Briefly, osteotomy at the level of Le Fort I with additional midline osteotomy and pterygo-maxillary disjunction was performed under general anesthesia. In 19 patients, a tooth-borne distractor (Hyrax; Dentaurum, Ispring, Germany) was cemented and fitted on orthodontic bands on the first premolars and first molars. In the remaining 13 patients, a bone-borne distractor (the transpalatal distractor TPD; Surgi-Tec, Bruges, Belgium) was fixed to the palatal bone during the operation by means of two screws at the level of the second premolars. The type of distractor used was chosen following agreement between the orthodontist and the surgeon; this decision was generally based on the periodontal condition of the anchor teeth and the degree of palatal constriction. All operations were performed by the same surgeon (MdK). Following a latency period of one week, the appliances were activated at a rate of 1 mm per day. The expansion was continued until the palatal cusps of the maxillary teeth touched the buccal cusps of the lower dentition. When the desired expansion was achieved, the distraction device was blocked by inserting a blocking screw in one of the boreholes of the TPD, and was left in place for a three-month consolidation period. Orthodontic treatment using straight wire fixed appliances was initiated 8-10 weeks after the end of active distraction.

For each patient, CBCT scans and 3D photographs of the face were taken prior to treatment (T0) and 22 ±7 months later, after completion of the presurgical orthodontic treatment and prior to the second orthognathic intervention (T1). The CBCT scans were acquired using the i-CAT® 3D Imaging System (Imaging Sciences International Inc, Hatfield, PA, USA) with a field of view of 22×16 cm and 0.4 mm voxel size. Data from the CBCT were exported in Digital Imaging and Communications in Medicine (DICOM) format. A 3D stereophotogrammetrical camera setup with an integrated software program modular system V 1.0 (3dMDface™ System, 3dMD LLC, Atlanta, GA, USA) was used to capture the 3D photographs of the face. All photographs were taken in natural head position and relaxed facial musculature. For further analysis, the captured images were exported as a wavefront object file (.obj) and imported into Maxilim® software version 2.2.2.1 (Medicim NV, Mechelen, Belgium).

8.2.2 Nasal Volume

The volume of the nose was measured as previously described by Van Loon et al. First, a surface-based matching procedure was performed for the pre- and post-treatment 3D photographs (fig. 1). This was followed by a modified 3D cephalometric analysis of the superimposed photographs to outline the region of the nose for volumetric measurements using the landmarks and planes as depicted in table 1. This resulted in the matched 3D photographs on a Cartesian coordinate system with the regions of interest lined by various planes. These planes defined the borders of the volume of the nose and were used for further circumscription of the 3D photograph (fig. 2). Finally, only the
nasal regions were left and a virtual volume could be computed. The left and right nasal volumes of the pre- and post-operative 3D photographs were then measured in cubic centimeters (cm$^3$). In addition to the volume, the greater alar cartilage width (AW) was obtained by measuring the distance between the right and left alar points. All measurements were performed by the same examiner (BvL), who was blinded for the type of device and was not involved in the patient treatment. The duplicate measurement error of this method was reported in a previous publication.$^{16}$

![Image of superimposed pre- and post-expansion 3D photographs.](image)

**Fig. 1.** Superimposed pre- and post-expansion 3D photographs. The green color indicates that the post-expansion photograph is in front of the original one and the red color indicates the opposite. Each color gradation is 1 mm.

![Image of untextured 3D photographs A, landmarks and planes to outline the nasal area; B cropped nasal area.](image)

**Fig. 2.** Untextured 3D photographs A, landmarks and planes to outline the nasal area; B cropped nasal area.
Table 1. Definitions of landmarks and planes used based on the 3D cephalometric soft-tissue analysis

<table>
<thead>
<tr>
<th>Landmarks and planes</th>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Landmarks</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alare (left)</td>
<td>al(l)</td>
<td>Left alare, most lateral point on the left alar contour.</td>
</tr>
<tr>
<td>Alare (right)</td>
<td>al(r)</td>
<td>Right alare, most lateral point on the right alar contour.</td>
</tr>
<tr>
<td>Cheilion (left)</td>
<td>ch(l)</td>
<td>Left cheilion, point located at the left labial commissure.</td>
</tr>
<tr>
<td>Cheilion (right)</td>
<td>ch(r)</td>
<td>Right cheilion, point located at the right labial commissure.</td>
</tr>
<tr>
<td>Cheilion (middle)</td>
<td>ch(m)</td>
<td>Soft tissue point automatically computed as the midpoint of the right cheilion and left cheilion.</td>
</tr>
<tr>
<td>Endocanthion (left)</td>
<td>en(l)</td>
<td>Left endocanthion, soft tissue point located at the inner commissure of the left eye fissure.</td>
</tr>
<tr>
<td>Endocanthion (right)</td>
<td>en(r)</td>
<td>Right endocanthion, soft tissue point located at the inner commissure of the right eye fissure.</td>
</tr>
<tr>
<td>Exocanthion (left)</td>
<td>ex(l)</td>
<td>Left exocanthion, soft tissue point located at the outer commissure of the left eye fissure.</td>
</tr>
<tr>
<td>Exocanthion (right)</td>
<td>ex(r)</td>
<td>Right exocanthion, soft tissue point located at the outer commissure of the right eye fissure.</td>
</tr>
<tr>
<td>Exocanthion (middle)</td>
<td>ex(m)</td>
<td>Soft tissue point automatically computed as the midpoint of the right exocanthion and left exocanthion.</td>
</tr>
<tr>
<td>Pupil reconstructed</td>
<td>p'</td>
<td>Pupil reconstructed point, midpoint between the endocanthi and pupils, located on the level of the exocanthi.</td>
</tr>
<tr>
<td>Subnasale</td>
<td>sn</td>
<td>Subnasale, midpoint on the nasolabial soft tissue contour between the columella crest and the upper lip.</td>
</tr>
<tr>
<td><strong>Planes</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Horizontal plane</td>
<td></td>
<td>The horizontal (x) 3D Reference Plane is automatically computed as a plane 6.6 degrees below the Cantion - Superaurale line, along the horizontal direction of the natural head position and through the Pupil Reconstructed Point translated 77.2 mm more posteriorly.</td>
</tr>
<tr>
<td>Vertical plane</td>
<td></td>
<td>The vertical (y) 3D Reference Plane is computed as a plane perpendicular to the Horizontal (x) 3D Reference Plane and along the horizontal direction of the natural head position.</td>
</tr>
<tr>
<td>Median plane</td>
<td></td>
<td>The median (z) 3D Reference Plane is computed through the Pupil Reconstructed Point and as a plane perpendicular to the horizontal (x) and the vertical (y) 3D Reference Planes.</td>
</tr>
<tr>
<td>Posterior nasal plane</td>
<td></td>
<td>A plane through landmarks ex(l), ex(r) and ch(m).</td>
</tr>
<tr>
<td>Upper nasal plane</td>
<td></td>
<td>A plane through landmark ex(m) and parallel to the horizontal plane.</td>
</tr>
<tr>
<td>Lower nasal plane</td>
<td></td>
<td>A plane through landmark sn and parallel to the horizontal plane.</td>
</tr>
<tr>
<td>Lateral left nasal plane</td>
<td></td>
<td>A plane through landmarks en(l) and al(l) and perpendicular to the vertical plane.</td>
</tr>
<tr>
<td>Lateral right nasal plane</td>
<td></td>
<td>A plane through landmarks en(r) and al(r) and perpendicular to the vertical plane.</td>
</tr>
</tbody>
</table>
8.2.3 Airway Volume

The nasal airway volume was measured on the CBCT scans using ITK-SNAP open-source software (http://www.itksnap.org). First, a square shaped area of interest was defined to outline the nasal airway on the mid-sagital slice. The upper anterior corner was defined by soft-tissue nasion, while the lower posterior border was defined by the posterior nasal spine (fig. 3). All axial slices were checked to ensure that the airway was included in the selected area. The nasal airway was then manually segmented by tracing the soft tissue air interface using user-guided 3D active contour segmentation in ITK-SNAP.17 Once the segmentation was completed, the software automatically computed the volume of the nasal airway in cubic centimeters (fig. 4). The most anterior coronal slice showing the entire palatal root of the first molars was used to measure the distance between the palatal root apices at T0 and T1. All segmentations were performed by the same examiner (RN) who was blinded to the type of device and was not involved in patient treatment. Eleven randomly selected CBCT scans were segmented twice, with a time interval of 2 weeks, to determine the intra-examiner reliability.

8.2.4 Statistical Analysis

Statistical analysis was performed using SPSS (Statistical Package Social Sciences 16.0, SPSS Company, Chicago, IL). Descriptive statistics were first calculated to give a rough outline of the results in addition to box plots. Pre- and post-treatment measurements were compared using paired t-test with significance set at p < 0.05. Independent t-test was used to compare the two groups (significance at p < 0.05). Pearson correlation coefficient test was used to test the relationship between the volumetric soft tissue changes in the nose and the nasal airway. The intra-observer reliability for repeated measurements was calculated by means of the Pearson correlation coefficient and paired sample t-test for the first and second measurements.
8.3 Results

The tooth-borne expansion group comprised 19 patients (5 males, 14 females). The mean age at the time of surgical intervention was 24.2 ± 7 years. The bone-borne group included 13 patients (6 males, 7 females) with a mean age of 31.9 ± 10 years. The average time between the CBCT scans taken at T0 and T1 was 21.7 ± 6.6 months for the Hyrax group and 22.6 ± 6.9 months for the TPD group. The amount of expansion at the level of the palatal root apices of the first molars was 5.46 ± 3.3 mm for the hyrax group and 3.4 ± 2.5 mm and the TPD group. This distance was not significantly different between the two groups (p = 0.13). The amount of dental expansion and its correlation to the skeletal changes have been thoroughly described in a previous study involving the same patients.9

8.3.1 Soft tissue changes of the nose

Intra-observer reproducibility of the nasal volume measurements was reported in a previous publication using the same protocol.16 Table 2 shows the nasal volume measured on the 3D photographs for both groups at T0 and T1. Baseline data prior to treatment was comparable between the two treatment groups (p = 0.11). Following expansion, the nasal volume only increased by 1.08 ± 1.62 % in the Hyrax group and by 2.39 ± 2.4 % in the TPD group. These changes were statistically significant between T0 and T1 (p = 0.008). The absolute and percentage increase in volume was slightly higher in the TPD group than in the Hyrax group; however, this difference was not statistically significant between the two groups (p = 0.12).
The alar width had increased in both groups at T1. The mean increase in alar width was 1.2 ± 0.9 mm in the Hyrax group and 1.4 ± 1.5 for the TPD group. There was no significant difference between the two groups (p = 0.7).

8.3.2 Nasal airway changes

Intra-observer reproducibility was high between the repeated segmentations, with a correlation coefficient of 0.93 between the first and second segmentations (p < 0.001). There was no statistically significant difference between the first and second measurements (standard error mean = 1.55 cm³, p = 0.52). Table 3 presents the changes in the nasal airway volume and the comparison between the two treatment groups. The airway volume increased by 9.7 ± 5.6% in the Hyrax group and 12.9 ± 12.7% in the TPD group, each representing a statistically significant increase between T0 and T1 (p < 0.001). The difference between the two treatment groups was not statistically significant (p = 0.35). The absolute and percentage changes in the airway volume were not correlated with the volume changes of the nose as measured on the stereophotogrammetric images (p = 0.41, r = 0.15).

Table 2. Changes in the nasal volume in cm³ measured on the 3D photographs.

<table>
<thead>
<tr>
<th>Nasal volume</th>
<th>Mean (SD)</th>
<th>Hyrax n=19</th>
<th>TPD n=13</th>
<th>Mean Diff.</th>
<th>Sig.2-tailed</th>
<th>95% Confidence Interval of Diff.</th>
</tr>
</thead>
<tbody>
<tr>
<td>T0</td>
<td>35.78 (6.20)</td>
<td>39.56 (6.26)</td>
<td>-3.78</td>
<td>0.11</td>
<td>-8.54 - 0.97</td>
<td></td>
</tr>
<tr>
<td>T1</td>
<td>36.14 (6.17)</td>
<td>40.59 (7.08)</td>
<td>-4.46</td>
<td>0.09</td>
<td>-9.62 0.71</td>
<td></td>
</tr>
<tr>
<td>Difference T1-T0</td>
<td>0.36 (0.53)</td>
<td>1.04 (1.13)</td>
<td>-0.67</td>
<td>0.07</td>
<td>-1.42 0.07</td>
<td></td>
</tr>
<tr>
<td>% Change</td>
<td>1.08 (1.62)</td>
<td>2.39 (2.40)</td>
<td>-1.31</td>
<td>0.12</td>
<td>-2.99 0.38</td>
<td></td>
</tr>
</tbody>
</table>

Table 3. Changes in the nasal airway volume (cm³) measured on the CBCT.

<table>
<thead>
<tr>
<th>Nasal airway volume</th>
<th>Mean (SD)</th>
<th>Hyrax n=19</th>
<th>TPD n=13</th>
<th>Mean Diff.</th>
<th>Sig.2-tailed</th>
<th>95% Confidence Interval of Diff.</th>
</tr>
</thead>
<tbody>
<tr>
<td>T0</td>
<td>54.05 (12.83)</td>
<td>54.75 (17.04)</td>
<td>-0.70</td>
<td>0.9</td>
<td>-12.71 11.30</td>
<td></td>
</tr>
<tr>
<td>T1</td>
<td>59.16 (13.80)</td>
<td>61.77 (16.01)</td>
<td>-2.60</td>
<td>0.64</td>
<td>-14.26 9.05</td>
<td></td>
</tr>
<tr>
<td>Difference T1-T0</td>
<td>5.11 (3.17)</td>
<td>7.01 (4.86)</td>
<td>-1.90</td>
<td>0.25</td>
<td>-5.24 1.43</td>
<td></td>
</tr>
<tr>
<td>% Change</td>
<td>9.74 (5.60)</td>
<td>12.95 (12.70)</td>
<td>-3.20</td>
<td>0.35</td>
<td>-10.06 3.66</td>
<td></td>
</tr>
</tbody>
</table>
The present study investigated the changes of the nose and nasal airway volume following bone-borne and tooth-borne expansion about 2 years after treatment. These volumetric changes were evaluated using CBCT scans and 3D photographs taken before treatment and at the end of presurgical orthodontics ~22 months post-SARME. The scans acquired at the end of the pre-surgical orthodontic stage were required for planning the second orthognathic intervention and thus did not subject the patients to additional X-ray exposure.

During the acquisition of CBCT scans, the temporomandibular joints are sometimes included in the limited FOV at the expense of including the entire nose. Due to this technical limitation, the tip of the nose was cut off in many scans, which prevented us from evaluating the changes of the nose on the CBCT data. Changes of the nose were instead evaluated by means of 3D photographs acquired on the same day. Retrospectively, the mean age of the patients in the TPD group was higher than in the Hyrax group. Since all patients included in the study were skeletally mature, this between-group age difference does not influence the airway changes described herein.

CBCT imaging proved to be a valuable diagnostic tool in the evaluation of airway shape and dimensions. Segmentation or post processing of the DICOM images using third-party software is generally required to allow the 3D visualization and quantification of the airway volume. This airway segmentation could be carried out either automatically or manually. Automatic segmentation by differentiating the densities between the airway and surrounding soft tissue by a threshold value is significantly faster and is considered more practical. Nevertheless, variations in the threshold value have been reported to result in different volume measurements. In the present study, segmentation of the airway was carried out manually by tracing the soft tissue air interface using user-guided 3D active contour segmentation in ITK-SNAP. Despite being more time consuming, manual segmentation offers the advantage of controlling the airway delineation slice by slice and has been shown to be more accurate.

At 22 months post expansion, a statistically significant increase in the nasal airway volume was observed in both groups (9.7 % and 12.9 % for tooth-borne and bone-borne expansion, respectively). This increase did not significantly differ between tooth-borne and bone-borne expansion, confirming the null hypothesis. Deeb et al. similarly used CT data to evaluate changes in nasal volume following bone-borne expansion using the Dresden bone-borne distractor, and reported only a 5.1 % increase of nasal airway volume as opposed to the 12.9 % increase in the present study. This difference between results could be attributed to the method of airway volume quantification, as they estimated the volume based on three cross-sectional areas in the front, middle, and posterior parts of the nose.

The majority of previous studies have relied on acoustic rhinometry (AR) to evaluate the airway volume. Doruk et al. found significant correlations between airway volume measurements using AR and CT. Compared to the present study, previous studies that used AR to evaluate the airway volume tended to report a larger percent increase in
Volumetric changes of the nose and nasal airway two years after tooth-borne and bone-borne surgically assisted rapid maxillary expansion

nasal airway volume. Babacan et al. found a 14.09% increase in nasal volume while Wriedt et al. reported a 21.2% increase at 6 months following tooth-borne SARME. A long term follow-up study by Seeberger et al. reported 23.25% enhancement of the nasal volume at 63 months post expansion.

The functional benefit of such increase in volume has not been fully determined in the literature. Magnusson et al. evaluated nasal cavity size, airway resistance, and the subjective sensation of nasal obstruction after SARME at 3 and 18 months post expansion. They reported that a subjective improvement in nasal function was not apparent in the total sample, and was only obvious in subjects with an initial nasal obstruction. Furthermore, they found no correlation between the objective increase in nasal cavity and the subjective sensation of improved nasal function.

Many studies have validated the accuracy of 3D stereophotogrammetry in capturing facial morphologic features. Van Loon et al. proved its applicability for measuring postoperative changes in nasal volumes following rhinoplasty. In the present study, the changes in the nose volume following expansion were minimal and were not correlated with the increase in nasal airway volume. The posterior region or the nasal airway showed greater dimensional changes than the anterior or soft tissue part of the nose. Similar findings have been previously reported, and were attributed to the nasal anatomy; because of the greater dimensions of the posterior region of the nasal cavity, the smallest amount of transverse expansion leads to a more pronounced change in the volume.

The increase in nasal base width following SARME is an aesthetic concern for many clinicians. In the present study the nasal width increase was limited to 1.2 mm and 1.4 mm in the Hyrax and TPD group, respectively. These findings correspond with the results of previous studies. Berger et al. reported a 2 mm increase in alar width that was maintained one year following tooth-borne expansion. Similarly Ramieri et al. found 1.4 mm increase in alar width one year following bone-borne expansion. From an aesthetic point of view, it would be difficult to judge how this limited increase would be perceived by the patient. There is no established threshold in the literature to determine the lay person’s and a professional’s perception of variations in the nasal width.

8.5 Conclusion

Twenty-two months following SARME, the increase in alar width, volume of the nose, and nasal airway was comparable between tooth-borne and bone-borne devices.
8.6 References


Volumetric changes of the nose and nasal airway two years after tooth-borne and bone-borne surgically assisted rapid maxillary expansion


Volumetric changes of the nose and nasal airway two years after tooth-borne and bone-borne surgically assisted rapid maxillary expansion
Three dimensional changes of nose and upper lip volume after orthognathic surgery.

Van Loon B
Van Heerbeek N
Bierenbroodspot F
Verhamme LM
Xi T
de koning M
Ingels, K
Bergé SJ
Maal TJ

Int J Oral Maxillofac Surg. accepted
Chapter 9

Introduction
Orthognathic surgery aims to improve both function and facial appearance of a patient. Translation of the maxillomandibular complex for correction of malocclusion is always followed by changes of the covering soft tissues, especially the nose and lips. The purpose of this study was to evaluate the changes of the nasal region and upper lip due to orthognathic surgery using combined CBCT and 3D stereophotogrammetric datasets.

Methods
Patients who underwent a Le Fort I osteotomy, with or without a bilateral sagittal split osteotomy, were included in this study. Pre- and postoperative documentation consisted of 3D stereophotogrammetry and CBCT scans. 3D measurements were performed on the combined datasets and analyzed.

Results
Anterior translation and clockwise pitching of the maxilla led to a significant volume increase of the lip. Cranial translation of the maxilla led to an increase in the alar width.

Conclusion
The combination of CBCT DICOM data and 3D stereophotogrammetry proved to be a helpful tool in the 3D analysis of the maxillary hard tissue changes as well as analyzing the soft tissues. Measurements could be acquired and compared to investigate the influence of maxillary movement on the soft tissues of the nose and the upper lip.
Three dimensional changes of nose and upper lip volume after orthognathic surgery

9.1 Introduction

Orthognathic surgery aims to improve function and aesthetic facial appearance of a patient. To achieve optimal results both aspects are crucial. Movement of the maxillomandibular complex for correction of malocclusion is always followed by changes of the covering soft tissues and therefore has its effect on esthetics.

Predicting the changes of the soft-tissue of the nose as a consequence of maxillomandibular surgery has been previously studied anthropometrically 1, two dimensionally (2D) by means of direct or indirect plaster cast 2, using photographs 3, lateral roentgencephalometry 4 and three dimensionally (3D) 5-10. The human body is a three dimensional entity and therefore any change, whether from movement during facial expression or from surgery, happens in three dimensions.

The purpose of this study was to three dimensionally evaluate the changes of the nasal region (inter-alar width and nose volume) and upper lip volume as a consequence of orthognathic surgery.

9.2 Materials and methods

9.2.1 Patients

Patients who underwent a Le Fort I osteotomy (with or without a simultaneous bilateral sagittal split osteotomy) between 2006 and 2010 were included. Exclusion criteria were: missing pre- or postoperative 3D photograph or CBCT scans, multi-segment Le Fort I osteotomy, mandibular setback, performed alar cinch procedure, rhinoplasty surgery during or within one year after the Le Fort I osteotomy, minimal facial growth potential (female age < 16 years, male age < 17 years), and patients with other accompanying craniofacial syndromes.

9.2.2 Pre- and postoperative 3D documentation

A Cone Beam CT scan (CBCT) (i-CAT* system, Imaging Sciences International, Hatfield, PA, USA) was used to capture bony tissue information. A 3D stereophotogrammetrical camera setup (3dMD™ System, 3dMD LLC, Atlanta, GA, USA) was used to capture 3D photographs of the face. The 3D photographs were generated from six 2D photographs taken simultaneously (four grey-scale photographs and two full color photographs). A polygon light pattern was projected onto the four grey-scale photographs. Based on this pattern and its deformed image, a 3D photograph was reconstructed 11.

A full field of view extended height CBCT scan was acquired preoperative and one year postoperative. 3D photographs were acquired direct preoperative as well as one year postoperative.
9.2.3 3D Measurements

**Hard tissue maxillary changes:** Both the CBCT and the 3D photographs were taken in natural head position and habitual occlusion. Patients were asked to relax their facial musculature, swallow and keep their molars in habitual occlusion after swallowing.\(^{12}\)

From the preoperative and postoperative CBCT scan a 3D reconstruction (3D model) was created in Maxillim (Maxilim®version 2.2.2.1 Medicim NV, Mechelen, Belgium). The postoperative 3D model was aligned with the preoperative model using a voxel based matching procedure as described by Nada et al.\(^ {13,14}\) The central incisor, right molar and left molar landmarks were indicated on the preoperative 3D model. These landmarks form a triangle on the preoperative maxilla. A Le Fort I osteotomy was performed digitally on the preoperative 3D model to separate the preoperative maxilla model from the skullbase. The separated preoperative maxilla model was aligned with the postoperative 3D model again using voxel based matching. In this way a second triangle was acquired consisting of exactly the same points. For the preoperative and postoperative triangles the center of mass was calculated and the difference between the two triangles resulted in the translations and rotations of the maxilla (fig 1a).

**Nasal and lip changes:** to isolate the region of interest on the 3D photographs, the neck and parts of the hair were trimmed using 3dMDpatient V3.1.0 software. A surface-based matching procedure of the pre- and postoperative 3D photographs was performed in five steps as described by our group.\(^ {15}\) On the matched 3D photographs a distance map was created indicating the soft tissue changes (fig. 1b). Finally a modified 3D cephalo-

![Fig 1a Preoperative (red) and postoperative (yellow) position of the maxilla.](image)

![Fig 1b. Distance kit indicating difference between preoperative and postoperative 3D soft tissues. The range of the color histogram is -6mm to 6 mm](image)
metric analysis, based on a previous described 3D cephalometric soft tissue analysis on CT data \(^{16}\) (table 1), was performed. From this analysis the inter-alar width and planes lining the nose and upper lip were acquired (fig 2). The planes indicate the region of interest (ROI) and from this ROI, the volumes of the nose and upper lip were calculated.

![Image](image_url)

**Fig 2. Landmarks used for the measurements**

A: Postoperative 3D photograph with the preoperative landmarks.

B: Postoperative 3D photograph with the used planes

C and D: volumes of the nose and upper lip preoperative (red) and postoperative (blue).

### 9.2.4 Operative procedure

All surgical operations were performed or supervised by one of the authors (MdK). After nasotracheal intubation the mucobuccal fold of the maxilla (and in bimaxillary cases also the mandible) was infiltrated with local anaesthetic Ultracain Ds - Forte. The Le Fort I procedure was started with an incision in the gingivobuccal sulcus from the canine on one side to the canine on the other side. After elevation of the mucoperiosteum and nasal mucosa the osteotomy line was designed with a fine burr after which the osteotomy cut was made with a reciprocal saw. The lateral nasal walls and nasal sep-
<table>
<thead>
<tr>
<th>Landmark</th>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alare (left)</td>
<td>al(l)</td>
<td>Left alare, most lateral point on the left alar contour.</td>
</tr>
<tr>
<td>Alare (right)</td>
<td>al(r)</td>
<td>Right alare, most lateral point on the right alar contour.</td>
</tr>
<tr>
<td>Cheilion (left)</td>
<td>ch(l)</td>
<td>Left cheilion, point located at the left labial commissure.</td>
</tr>
<tr>
<td>Cheilion (right)</td>
<td>ch(r)</td>
<td>Right cheilion, point located at the right labial commissure.</td>
</tr>
<tr>
<td>Cheilion (middle)</td>
<td>ch(m)</td>
<td>Soft tissue point automatically computed as the midpoint of the right cheilion and left cheilion.</td>
</tr>
<tr>
<td>Nasion</td>
<td>n</td>
<td>Nasion is the midpoint of the frontonasal suture.</td>
</tr>
<tr>
<td>Subnasale</td>
<td>sn</td>
<td>Subnasale, midpoint on the nasolabial soft tissue contour between the columella crest and the upper lip.</td>
</tr>
<tr>
<td>Christa Philtri (left)</td>
<td>cph(l)</td>
<td>The point at each crossing of the vermillion line and the elevated margin of the philtrum</td>
</tr>
<tr>
<td>Christa Philtri (right)</td>
<td>cph(r)</td>
<td>The point at each crossing of the vermillion line and the elevated margin of the philtrum</td>
</tr>
<tr>
<td>Christa Philtri (middle)</td>
<td>cph(m)</td>
<td>Soft tissue point automatically computed as the midpoint of christa philtri left and christa philtri right</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Plane</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Median Plane</td>
<td>The Median (z) 3D Reference Plane is computed through the Pupil Reconstructed Point and as a plane perpendicular to the horizontal (x) and the vertical (y) 3D Reference Planes.</td>
</tr>
<tr>
<td>Horizontal Plane</td>
<td>The horizontal (x) 3D Reference Plane is automatically computed as a plane 6.6 degrees below the Cantion - Superaurale line, along the horizontal direction of the natural head position and through the Pupil Reconstructed Point translated 77.2 mm more posteriorly.</td>
</tr>
<tr>
<td>Vertical Plane</td>
<td>The vertical (y) 3D Reference Plane is computed as a plane perpendicular to the Horizontal (x) 3D Reference Plane and along the horizontal direction of the natural head position.</td>
</tr>
<tr>
<td>Lateral left Nasal Plane</td>
<td>A plane through landmarks ch(l) and al(l) and perpendicular to the vertical plane.</td>
</tr>
<tr>
<td>Lateral Right Nasal Plane</td>
<td>A plane through landmarks ch(r) and al(r) and perpendicular to the vertical plane.</td>
</tr>
<tr>
<td>Upper Nasal Plane</td>
<td>A plane through landmark n and parallel to the horizontal plane.</td>
</tr>
<tr>
<td>Lower Nasal Plane</td>
<td>A plane through landmark sn and parallel to the horizontal plane.</td>
</tr>
<tr>
<td>Upper lip plane</td>
<td>A plane through landmark cph(m) and parallel to lower lip plane.</td>
</tr>
<tr>
<td>Lower lip plane</td>
<td>A plane through landmark ch(m) and parallel to plane HorizontalPlane.</td>
</tr>
</tbody>
</table>
tum were osteotomized with a nasal osteotome. The nasal spine was then rounded. After mobilisation of the maxilla it was positioned in the planned position using an acrylic wafer. Fixation was performed with four 1.5 mm miniplates (KLS Martin, Tuttlingen, Germany), one paranasal and one on the buttresses on each side. The mucosa was closed with a 4-0 Vicryl suture (Ethicon, Johnson and Johnson Medical Gmbh, Norderstedt, Germany), no alar cinch or v-y closure was performed. Intraoperative antibiotics were given (1000 mg Cefazoline and 500 mg Metronidazol).

9.2.5 Statistical analysis

An intra- and inter-observer analysis was performed to evaluate the reproducibility of the landmarks used in the soft tissue analysis. The paired Student’s t-test was used for statistical analysis with a p-value of 0.05 indicating statistical difference. The preoperative and postoperative measurements were compared using the Student’s t-test. The influence of the maxillary translations and rotations on the soft tissue variables was investigated using linear regression analysis with statistical significant differences indicated by a p-value of <0.05.

The statistical data analysis was performed with the SPSS software program, version 16.0 (SPSS Inc, Chicago, USA).

9.3 Results

9.3.1 Patients

Thirty-six patients were included in this study (12 men and 24 women). The mean age was 26.9 (range 17 – 55 years). Twelve (5 men, 7 women) underwent a Le Fort I osteotomy, the other 24 (7 men, 17 women) underwent a bimaxillary procedure.

9.3.3 Pre- and postoperative 3D documentation

CBCT and 3D photographs were acquired preoperatively and one year postoperatively (range 6 months to 24 months).

9.3.3 3D measurements

The intra- and inter-observer analysis (table 2) showed no statistical significant differences. The postoperative landmarks were statistically significantly different from the preoperative landmarks (P<0.001). In table 3 the hard tissue landmarks are split
up into their respective coordinates. The anterior translation changed statistically significantly while the other translations did not (Central incisor landmark: P< 0.001, left molar: P<0.001 and right molar: P< 0.001).

The soft tissue measurements in table 3 indicated a statistically significant change in the inter alar width (p<0.001). Postoperatively the nose widened. The volumetric measurements of the lip and nose also showed statistical significant increase postoperatively (P<0.001).

Regression analysis of the maxillary movement and its effect on the soft tissue measurements (table 4) indicated a positive correlation between cranial translation of the maxilla and an increase in the alar width. Anterior translation and clockwise pitching of the maxilla was associated with a statistical significant increases of lip volume. Anterior translation of the maxilla didn’t significantly influence nose volume.

### Table 2. Inter and intra observer analysis for the landmarks used in this study. A p-value < 0.05 indicates significant changes.

<table>
<thead>
<tr>
<th>Paired differences</th>
<th>Mean</th>
<th>Std. Deviation</th>
<th>Std. Error Mean</th>
<th>95% Confidence Interval of the Difference</th>
<th>Sig. (2-tailed)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inter observer</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vertical</td>
<td>-.062</td>
<td>.878</td>
<td>.074</td>
<td>-.209</td>
<td>.085</td>
</tr>
<tr>
<td>Horizontal</td>
<td>.083</td>
<td>.694</td>
<td>.059</td>
<td>-.033</td>
<td>.199</td>
</tr>
<tr>
<td>Median</td>
<td>-.017</td>
<td>.892</td>
<td>.075</td>
<td>-.166</td>
<td>.132</td>
</tr>
<tr>
<td>Euclidean Distance</td>
<td>-.077</td>
<td>.647</td>
<td>.055</td>
<td>-.185</td>
<td>.032</td>
</tr>
<tr>
<td>Intra observer</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vertical</td>
<td>.064</td>
<td>.663</td>
<td>.056</td>
<td>-.047</td>
<td>.175</td>
</tr>
<tr>
<td>Horizontal</td>
<td>.020</td>
<td>.554</td>
<td>.047</td>
<td>-.073</td>
<td>.112</td>
</tr>
<tr>
<td>Median</td>
<td>.047</td>
<td>.671</td>
<td>.057</td>
<td>-.065</td>
<td>.159</td>
</tr>
<tr>
<td>Euclidean Distance</td>
<td>.040</td>
<td>.478</td>
<td>.040</td>
<td>-.039</td>
<td>.120</td>
</tr>
</tbody>
</table>

9.4 Discussion

For a long time 2D techniques were the only techniques available to acquire measurements of 3D objects. To measure an object in three dimensions, 3D imaging techniques had to be developed. This was necessary to overcome the shortcomings of the various 2D methods such as overprojection, scaling problems and incorrect measurements. With the progress of (affordable) computer hard- and software, different 3D imaging methods have been developed and are increasingly used around the world. One of these imaging devices capable of capturing 3D data is 3D stereophotogrammetry.
### Three dimensional changes of nose and upper lip volume after orthognathic surgery

Table 3. Comparison of the pre- and postoperative measurements of the three hard tissue landmarks and the four soft tissue landmarks. The mean, standard deviation, standard error of the mean, 95% confidence interval and p-values are given. A p-value < 0.05 indicates significant changes.

<table>
<thead>
<tr>
<th>Paired Differences</th>
<th>Mean</th>
<th>Std. Deviation</th>
<th>Std. Error Mean</th>
<th>95% Confidence Interval of the Difference</th>
<th>Sig.2-tailed</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Hard tissue landmarks</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Central incisor</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Anterior translation (mm)</td>
<td>3.36</td>
<td>1.90</td>
<td>0.31</td>
<td>2.73 - 3.98</td>
<td>0.00</td>
</tr>
<tr>
<td>Cranial translation (mm)</td>
<td>0.99</td>
<td>3.96</td>
<td>0.66</td>
<td>-0.36 - 2.33</td>
<td>0.15</td>
</tr>
<tr>
<td>Lateral right translation (mm)</td>
<td>-0.17</td>
<td>1.41</td>
<td>0.24</td>
<td>-0.65 - 0.30</td>
<td>0.47</td>
</tr>
<tr>
<td>Left Molar</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Anterior translation (mm)</td>
<td>3.27</td>
<td>1.65</td>
<td>0.28</td>
<td>2.71 - 3.83</td>
<td>0.00</td>
</tr>
<tr>
<td>Cranial translation (mm)</td>
<td>0.46</td>
<td>2.33</td>
<td>0.39</td>
<td>-0.33 - 1.25</td>
<td>0.25</td>
</tr>
<tr>
<td>Lateral right translation (mm)</td>
<td>-0.11</td>
<td>0.90</td>
<td>0.15</td>
<td>-.41 - 0.19</td>
<td>0.47</td>
</tr>
<tr>
<td>Right Molar</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Anterior translation (mm)</td>
<td>3.23</td>
<td>1.84</td>
<td>0.31</td>
<td>2.61 - 3.86</td>
<td>0.00</td>
</tr>
<tr>
<td>Cranial translation (mm)</td>
<td>0.56</td>
<td>2.37</td>
<td>0.40</td>
<td>-0.24 - 1.37</td>
<td>0.16</td>
</tr>
<tr>
<td>Lateral right translation (mm)</td>
<td>-0.14</td>
<td>0.93</td>
<td>0.16</td>
<td>-0.46 - 0.17</td>
<td>0.36</td>
</tr>
<tr>
<td><strong>Soft tissue measurements</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nose volume (mm³)</td>
<td>1203.58</td>
<td>1113.86</td>
<td>185.64</td>
<td>1580.46 - 826.71</td>
<td>0.00</td>
</tr>
<tr>
<td>Lip volume (mm³)</td>
<td>2207.41</td>
<td>1979.52</td>
<td>329.92</td>
<td>2877.19 - 1537.64</td>
<td>0.00</td>
</tr>
<tr>
<td>Interallar Width (mm)</td>
<td>1.76</td>
<td>1.02</td>
<td>0.17</td>
<td>2.11 - 1.42</td>
<td>0.00</td>
</tr>
</tbody>
</table>
The first portfolio of stereoscopic photographs was created in the 19th century. From that point on, stereography evolved to modern 3D digital photographic systems in which offset images are merged together to create a stereoscopic image. 3D photography has become an increasingly important tool in facial surgery and nowadays a lot of 3D commercial systems are available on the market.

A non-invasive 3D method to capture the face, that has gained popularity over the last years, is 3D stereophotogrammetry. The data yielded with this method consist of textured 3D soft tissue data which can be used for various measurements. The accuracy of these newly developed 3D imaging systems in recording facial morphologic features has been validated previously. Several studies focused on determining the reproducibility of identifying landmarks by using various 3D modalities including 3D stereophotogrammetry. The results of these studies indicated the 3dMD system to be accurate and precise for facial purposes. Furthermore, the small error in placing landmarks did not lead to statistical significant different volumetric or symmetry measurements, as was seen in a recent study by our group. In this study the pre- and postoperative volumes of the nose in cleft lip and palate patients were measured using 3D stereophotogrammetry.

Invasive methods to acquire 3D datasets from the maxillomandibular region include roentgen methods such as Cone Beam CT (CBCT) and conventional CT. These scans consist of DICOM data which can be reconstructed into a 3D dataset in various software modalities. The 3D reconstruction itself consists of both bony and untextured soft tissue data usually lacking information of the soft tissues of the nose. The combination of both CBCT and 3D stereophotogrammetry produces a 3D dataset consisting of both bony and textured soft tissue information. This dataset can be used for planning and evaluation of surgery.

Changes of the nose and lip region could be objectified and correlated to the surgery performed using the aforementioned methods. In summary, translation or rotation of

Table 4. Linear regression analysis of alar width, lip volume and nose volume. A p-value < 0.05 indicates significant relation.

<table>
<thead>
<tr>
<th>model</th>
<th>B (mm)</th>
<th>Std. Error</th>
<th>95.0% Confidence Interval</th>
<th>Sig. 2-tailed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alar width</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Constant)</td>
<td>1.81</td>
<td>0.17</td>
<td>1.47</td>
<td>2.15</td>
</tr>
<tr>
<td>Cranial Translation</td>
<td>0.15</td>
<td>0.06</td>
<td>0.03</td>
<td>0.28</td>
</tr>
<tr>
<td>Lip volume</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Constant)</td>
<td>212.84</td>
<td>584.51</td>
<td>-976.35</td>
<td>1402.04</td>
</tr>
<tr>
<td>Anterior translation</td>
<td>572.12</td>
<td>164.30</td>
<td>237.85</td>
<td>906.40</td>
</tr>
<tr>
<td>Pitch (clockwise)</td>
<td>170.27</td>
<td>71.42</td>
<td>24.96</td>
<td>315.57</td>
</tr>
<tr>
<td>Nose volume</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Constant)</td>
<td>498.83</td>
<td>400.53</td>
<td>-315.14</td>
<td>1312.80</td>
</tr>
<tr>
<td>Anterior translation</td>
<td>214.40</td>
<td>109.08</td>
<td>-7.280</td>
<td>436.09</td>
</tr>
</tbody>
</table>

The first portfolio of stereoscopic photographs was created in the 19th century. From that point on, stereography evolved to modern 3D digital photographic systems in which offset images are merged together to create a stereoscopic image. 3D photography has become an increasingly important tool in facial surgery and nowadays a lot of 3D commercial systems are available on the market.

A non-invasive 3D method to capture the face, that has gained popularity over the last years, is 3D stereophotogrammetry. The data yielded with this method consist of textured 3D soft tissue data which can be used for various measurements. The accuracy of these newly developed 3D imaging systems in recording facial morphologic features has been validated previously. Several studies focused on determining the reproducibility of identifying landmarks by using various 3D modalities including 3D stereophotogrammetry. The results of these studies indicated the 3dMD system to be accurate and precise for facial purposes. Furthermore, the small error in placing landmarks did not lead to statistical significant different volumetric or symmetry measurements, as was seen in a recent study by our group. In this study the pre- and postoperative volumes of the nose in cleft lip and palate patients were measured using 3D stereophotogrammetry.

Invasive methods to acquire 3D datasets from the maxillomandibular region include roentgen methods such as Cone Beam CT (CBCT) and conventional CT. These scans consist of DICOM data which can be reconstructed into a 3D dataset in various software modalities. The 3D reconstruction itself consists of both bony and untextured soft tissue data usually lacking information of the soft tissues of the nose. The combination of both CBCT and 3D stereophotogrammetry produces a 3D dataset consisting of both bony and textured soft tissue information. This dataset can be used for planning and evaluation of surgery.

Changes of the nose and lip region could be objectified and correlated to the surgery performed using the aforementioned methods. In summary, translation or rotation of
the maxilla did not lead to a significant volume increase of the nose. Anterior translation and pitching of the maxilla did influence the lip volume. Cranial translation of the maxilla led to alar width increase. Lateral or medial translation or rotations did not have any effect on the measurements performed in this study.

Several sources of error have to be discussed when using fused datasets with multiple CBCT and 3D stereophotogrammetric datasets. Firstly, the reconstruction of CBCT Dicom data into a 3D model is known to cause a small error. In the study performed by Liang et al. the accuracy of the 3D model of a mandible was evaluated. The mean deviation of the gold standard (a laser scanned 3D model of the mandible) was found to be 0.28 mm for the 3D model reconstructed out of CBCT data whereas it was 0.14 for that of Multi Slice CT data. This deviation was for the complete mandible and is therefore very small. Secondly, the alignment method for the CBCT scans was based on the multimodal image registration technique by maximization of mutual information by Maes et al. This method allows for sub voxel accurate registration of medical images with a minimal error. Thirdly, since 3D photographs do not consist of voxels, they can only be registered using a surface-based matching procedure. Recently, our group published about the error of matching two 3D photographs and the results of this study illustrated that the registration procedure was reliable with a mean registration error of less than 0.5 mm. Fourth, the indication of landmarks can result in errors because of faulty indication of these landmarks between 3D models. However, since the maxillary movements were evaluated by using landmarks only indicated on the preoperative maxilla model, no indication error is expected here. The soft tissue landmarks were indicated on both the preoperative and postoperative 3D photo. The largest error can be expected to occur here since the landmarks are indicated twice. Previous studies showed the error of placing landmarks to be less than a millimeter. Fifth, it is possible that the volume of the upper lip is influenced by the position and inclination of the upper incisors. Since the data postoperatively were acquired one year after surgery, also orthodontic factors such as a changed inclination of the upper incisors or the presence of brackets might have influenced the upper lip volume after surgery.

In the 1970s first efforts to quantify nasal soft tissue changes due to bony manipulations were published using lateral cephalometrics. This article described that advancement of the maxilla led to advancement of the tip of the nose by approximately a third. They found this movement to be more marked in cleft lip and palate patients, when leaving the nasal spine intact and by displacing the maxilla upwards. Honrado et al. evaluated nasal changes after maxilla-mandibular surgery with a 3D camera. For their maxillary changes they relied on the postoperative notes which gave an estimation of the maxillary movements and not necessarily of the real movements. For soft tissue changes they also used landmarks. They found changes of the inter alar width and inter nostril width to occur with movement of the maxilla anteriorly with and without downward and upward rotation. They did not find any other significant changes. Even the use of an alar cinch did not seem to prevent alar widening.

The current study did not find a statistically significant correlation between anterior movements of the maxilla and volume increase of the nose. Cranial translation of the maxilla was related to an increase in the inter alar width. Rotations of the maxilla did
not show any correlated nose changes. There is a discrepancy between the findings in previous studies and the current one, which might be explained by various factors. First, the study by Honrado et al. did not have exact knowledge of the maxillary changes but relied solely on the notes of the surgeon. Although they gave a thorough report of the surgery, conclusive data on maxillary movements was absent. Secondly, in the Honrado study, the soft tissues were evaluated 3-6 months postoperatively. During this period swelling and/or soft tissue remodeling might still be present. Thirdly, in the current study group no alar cinching was performed. It would be interesting to compare two groups, one with and one without alar cinching to investigate a possible influence in more detail.

Altman et al. have discussed the role of rhinoplastic surgery during maxillomandibular surgery previously. They conclude that changes in nasal morphology after orthognathic surgery are difficult, if not impossible, to predict. Alar width changes and increased nose tip projection are the most obvious changes after maxillary surgery. Altman et al. argue that procedures on the nasal dorsum, including hump reduction and depression correction as well as deviation surgery, and those procedures aimed at correcting tip malformations, but not tip position, can be combined with orthognathic maxillary surgery. According to Altman et al. adjustment of tip position and alar base are more difficult to perform simultaneously because they are more affected by maxillary changes. This study also found changes to inter alar width and volume increase after maxillary surgery. Since maxillary surgery appears to have an influence on the nose, it might be sensible to perform rhinoplastic surgery separately from the orthognathic procedure in a two step approach, after (re)evaluating its necessity following the orthognathic procedure. Since the current study illustrated nasal changes when performing a Le Fort I osteotomy it remains debatable whether it is wise to combine orthognathic surgery with rhinoplastic procedures in one operative procedure.

To the best knowledge of the authors this study is the first to combine both 3D hard tissue information using CBCT data and 3D soft tissue information using 3D stereophotogrammetry to acquire clinical relevant information to evaluate the changes of the nasal region and the upper lip volume following orthognathic surgery.

With the introduction of these imaging modalities, the applicability of 3D photographs in daily practice has become reality. 3D stereophotogrammetry is ideal to collect 3D data of faces from newborn babies to elderly. After processing the data, an accurate digital model of the patient’s face is created which immediately can be used in a clinical setting. For scientific purposes the acquisition of multiple, preferably non-invasive, 3D datasets creates many opportunities to evaluate growth, physical adaptations and surgical interventions.

9.5 Conclusions

The main purpose of this study was to investigate the influence of maxillary movement on the soft tissues of the nose and lip with the help of CBCT DICOM data and 3D stereophotogrammetry. The combination of these techniques proved to be a
tool allowing maxillary hard tissue measurements and soft tissue measurements to be acquired and compared objectively.

This way of working will lead to a better and more accurate planning of orthognathic surgery, especially concerning the effects of hard tissue on facial soft tissues.
9.6 References


Three dimensional changes of nose and upper lip volume after orthognathic surgery


Three dimensional changes of nose and upper lip volume after orthognathic surgery
10 Discussion
10.1. Introduction

This thesis, as part of the Nijmegen 3D project, uses 3D imaging techniques to acquire measurements of the nose. This three dimensional way of documentation makes it possible to evaluate surgical outcome of this, small part of the viscerocranium. Assessment of nasal changes have been studied in the past\(^1\)–\(^{15}\). However, quantification of surgical changes remains difficult. Besides direct anthropometric measurements traditionally, two dimensional (2D) photographs and radiographs are used to document and calculate changes after surgery\(^{16, 17}\). Many of these studies have tried to establish objective methods to measure postoperative changes of the nose. However, all those studies were based on 2D measurements. But as a matter of fact, the nose is an outstanding example of a three dimensional structure and changes made to the nose are hardly ever limited to two dimensions. This fact emphasizes the need for a 3D measurement method of the results of rhinoplastic procedures. Three dimensional imaging techniques have been developing fast over the last 20 years and with their development, quality and quantity of medical applications evolved equally. Various 3D imaging techniques have been developed to overcome the shortcomings of conventional 2D imaging. These include 3D cephalometry\(^{18}\), Moiré topography\(^{19}\), 3D laser scanning\(^{20}\), 3D optoelectronic digitizers\(^{21}\) and 3D stereophotogrammetry\(^{22-24}\).

The 3D project and the 3D lab in Nijmegen focused initially on the various possibilities of using 3D imaging techniques, especially 3D stereophotogrammetry and Cone Beam CT. By using and experimenting with these imaging devices, a multitude of applications became more and more clear as well as applicable.

The first part of this thesis focused on the reproducibility and accuracy of 3D stereophotogrammetry (chapter 2 and 3). In chapters 4, 5, 6 and 7 3D stereophotogrammetry was used for evaluation of surgical procedures concerning the nose. In chapter 8 and 9 CBCT imaging was combined with 3D stereophotogrammetry to evaluate the effect of bony surgery on airway volume and on the soft tissues of the nose. The results of these studies will be discussed in “the address to the aims”. In the “future aspects” future research projects and the clinical applicability will be discussed.

10.2 Address to the aims

10.2.1 Is it possible to compare multiple 3D photographs acquired by using 3D stereophotogrammetry in time and is this method accurate and reliable? (chapter 2 and 3)

The 3D stereophotogrammetric system was the sole piece of hardware available for 3D evaluation of the face in the beginning years of the Nijmegen 3D lab\(^25\). One of the first studies performed using 3D stereophotogrammetry in the 3D project focused on soft tissue changes in orthognathic surgery\(^26\). A 3D cephalometric soft tissue analysis
was developed based on 3D photographs. Besides the use of 3D cephalometric analyses also surface-based registration techniques were used to evaluate the treatment outcome in orthognathic patients. Surface-based registration of 3D photographs proved to be possible and seemed to be an accurate way to compare various 3D photographs from one and the same patient captured throughout the follow up. Using this non-invasive surface-based technique, it was possible to evaluate facial changes in three dimensions. Postoperative treatment changes could be evaluated in an objective numeric way. However the reproducibility of the system and the method had not yet been studied in a clinical setting. Already in an early stage it became clear that the accuracy of registering 3D photographs was affected by differences in facial muscle tone, expression, growth and head posture. Therefore reliability and reproducibility of the system had to be validated and the first validation studies were conducted.

In a first study (chapter 2) 3D photographs of 15 volunteers were acquired at different moments in time. The 3D photographs were registered in two different ways: surface-based and reference-based. The results of this study proved that the reproducibility of acquiring these 3D photographs at different moments in time was high and in this way clinically acceptable. There was nevertheless a registration error, which was smaller for the surface-based registration method compared to the reference based method. However this registration error was so minimal that one had to conclude that 3D photographs, especially when using the surface-based registration method, could be used clinically to compare one and the same subject at different moments in time. After this study the question arose how the registration procedure could be further improved and which regions of the face would be most stable and could be best used for registration of two different 3D photographs of the same individual.

In chapter 3 the respective value of different facial units for the process of registration was studied. In this experiment, 100 3D photographs of one volunteer, 50 at time point t0 and 50 six weeks later at time point t1, were acquired. In both groups, half of the 3D photographs were performed with a wax bite in situ to stabilize the mandible. The photographs were surface-based registered and divided into several anatomical facial regions or units. The results of this study illustrated a small variation of registration for the face in rest. Within the different anatomical regions, the most accurate units proved to be forehead and nose. This was as expected since only a small layer of soft tissue overlies the bony structures in those areas. The regions with the largest registration variations were found to be perioral and periorbital. The larger variation in these regions could be explained by a range of different anatomical positions of the perioral and periorbital muscles in rest. A slightly different mandibular position or eye blinking at the moment of capture may have influenced the results significantly. Furthermore, in the region of the eyes, the 3D stereophotogrammetric system could not capture information from the cornea correctly. This imaging problem, due to cornea reflection resulting in a concave instead of a convex structure, is not solved yet. Nevertheless, since the results of this study have been published in 2010, the stereophotogrammetric systems improved. The camera system nowadays is equipped with higher resolution cameras, which improved image quality tremendously. However, up till today, still some regions are hard to capture using 3D stereophotogrammetry (especially eyes, teeth and hair).
From the studies in chapter 2 and 3, it could be concluded that surface-based registration is an accurate method to compare 3D photographs of one and the same individual, even if acquired at different points in time. The forehead and nose regions are the most appropriate regions to select and use during registration of two 3D photographs of a patient. Surface-based registration has now been used to a large extent in numerous clinical case studies to evaluate facial changes (surgical and non-surgical) over time. The use of 3D photographs omits the necessity to expose patients to any form of noxious radiation which is of course a great advantage.

10.2.2 Is 3D stereophotogrammetry useful to acquire quantitative data from the nasal region and can this be used to evaluate surgical outcome? (chapter 4)

Since this thesis focuses on the assessment of nasal changes after cleft lip and palate treatment, orthognathic surgery and rhinoplasty, it was necessary to evaluate the usefulness of 3D stereophotogrammetry especially for this facial unit. With the development of 3D stereophotogrammetry, such a method became available. In chapter 4 a first attempt to evaluate nasal changes with the help of 3D stereophotogrammetry after hump reduction rhinoplasty was made. In this study 12 patients were included. Based on the results of the research described in chapter 2 and 3, pre- and postoperative 3D photographs were surface-based registered and a pre-post-distance kit was calculated. This resulted in a color based image indicating unchanged, decreased and increased facial volumes. A higher intensity of discoloration corresponds with more change in volume. In this way the amount of reduction of the nasal dorsum could be calculated. This study proved that clinical postoperative findings could be objectified and measured with 3D stereophotogrammetry. A correlation between the 3D-changes and the surgical techniques performed was found. 3D stereophotogrammetry was capable of, and useful for measuring changes made to the nose by surgery. Even smaller changes made to the nose could be measured. This imaging technique could therefore be used to further objectify, measure and compare rhinoplasty results and to study whether certain surgical techniques indeed provide the desired effect on the appearance of the nose, especially in long term evaluation.

The study presented in chapter 4 qualitatively evaluated changes to the nose using the color based distance kit, and quantified the changes by measuring the maximal volume reduction. For future studies however a more quantitative reliable method was mandatory. During this study the idea blossomed to acquire volumetric measurements to evaluate surgically induced nasal changes. The problem however was that 3D photographs do not contain an absolute depth into the tissue. It is the surface shape that is captured and provides the data. Nevertheless, a single 3D photo can be used to acquire volumetric measurements from the nose. If one pre- and one postoperative 3D photograph of the nose could be aligned and/or superimposed (or matched perfectly), the volumetric differences between the two datasets, caused by the intervention, could be documented. In a next step, a method was developed to quantify the volumetric differences between
3D photographs. The developed method was based on a surface-based matching procedure of the 3D photographs, and worked out in five steps. This process involved the creation of a distance map of the pre-post matched 3D photographs, so giving an indication of the nasal soft tissue changes. A modified 3D cephalometric analysis, based on 3D cephalometric soft tissue analysis on CT data, was performed to outline the region of interest for the volumetric measurements. This resulted in the matched 3D photographs within a Cartesian coordinate system, with the nasal structures lined by various planes. These planes defined the borders of the volume of the nose and were used for further circumscript of the 3D photographs. Finally, only the nose was left and a virtual nasal volume could be computed.

The data acquired in this way gave an indication of the volume of the nose, but as a matter of fact this data did not represent the true nasal volume. Measurement errors were expected to be small since the landmarks used had to be indicated only once (on the pre-operative 3D photographs). The same landmarks were used to acquire the postoperative measurements. The most important disadvantage of these volumetric measurements was the absence of a vector, so no absolute indication of the direction of change was known. However by combining this information with the distance kit, a relative direction could be extrapolated.

10.2.3 How does the nose change due to rhinoplastic surgical interventions? (chapter 5, 6, 7)

After proving that clinical postoperative findings could be objectified and measured with 3D stereophotogrammetry, there was a need to acquire objective data. In chapter 5 the first attempt to quantify surgical interventions of the nose using 3D stereophotogrammetry was described. A group of unilateral cleft lip and palate (CLP) patients undergoing secondary open rhinoplasty procedures was documented pre- and postoperatively using 3D photographs. Twelve patients were included in this study and pre- and three months postoperative 3D photographs were acquired. Volumetric measurements were acquired from the total nose, the left side and the right side.

As this was the first experiment (a pilot study in fact) to use 3D stereophotogrammetry quantitatively, only 12 patients were included prospectively and results were evaluated after just three months. During this short evaluation time scar formation would still take place and oedema might still be present leading to different results when repeating the measurements for example one year postoperative. Ideally a larger patient group should have been included and followed for a longer period.

A second limitation was caused by the 3D hard- and software. The reconstruction of, for example the nostrils, was difficult because of the complex anatomy and the inability of the cameras to capture dark holes in a perfect way. As a consequence, nostrils were a region of error. However, this error was expected to be of minimal influence for this study since special attention was given to positioning the patient in a standardized manner while acquiring the pre- and the postoperative 3D photographs in the same position. An alternative to minimize this reconstruction problems would have been the
use of a CBCT 3D reconstruction of the nose. However, because of the radiation side effect, CBCT is not applicable for longitudinal follow up whereas 3D photographs are harmless.

A third limitation was the necessity to define a midline. In this study the facial midline was dictated by the median plane, which was based on the pupil-reconstructed point. This landmark was indicated as the middle of the inter-endocanthal line. Literature proved that identification of landmarks can be difficult and leads to small errors. However, since just one and the same midline plane was used for the pre- and postoperative 3D photographs, the amount of volume increase as well as the symmetry ratio could theoretically not be affected.

The fourth limitation was in fact also an advantage of this study design. Only one surgeon performed all rhinoplasties and used his standardized technique to improve symmetry. No information on the effect of other techniques or surgeons was therefore available. For future studies, other techniques and surgeons had to be included and a larger group of patients had to be studied. These shortcomings were corrected in the study presented in Chapter 6.

A collaboration with the Gosla S. Reddy (GSR) Institute of craniofacial surgery in Hyderabad, India, a high volume cleft centre, was set up. Around 1500 CLP patients are operated in the GSR Institute each year. For the study in chapter 6, the Nijmegen 3D stereophotogrammetry system was brought twice to the GSR Institute of craniofacial surgery in India to acquire pre- and one year postoperative 3D photos from unilateral CLP patients. The aim was to assess the one year postoperative surgical outcome of lip and nasal symmetry in a group of patients with complete unilateral CLP after cleft lip correction in combination with a primary septoplasty using the Afroze technique and to compare this with a healthy control group. Forty-four one-year postoperative complete unilateral CLP patients and 44 healthy control patients without cleft defects were included.

The main limitation of this study was the absence of enough follow-up data. 3D stereophotogrammetry data were acquired on two occasions with only one year in between. During the second visit it became clear that the follow up in India is hard to arrange since patients live far away from the GSR Cleft Center. Therefore, the methodology was adapted and a comparison of the patient population with a matched control group became reality. The amount of improvement or impairment of the symmetry of the lip and nose as a direct effect of surgery could not be evaluated. By comparing the results to a non-cleft control group, however, an estimation to which extend a close to normal symmetry was reached, could be investigated.

Another limitation was the placement of the landmarks used to compute the linear measurements and to dictate the planes lining the right and left half of the nose for the volumetric measurements. Again, the midline was defined as the middle of the inter-endocanthal line. The analysis of the measurement error of the present study proved that the intra- and interobserver reliability for this method were adequate. This study showed that the Afroze technique in combination with a functional repair of the nose was not able to achieve near normal symmetry. Whether other techniques are perform-
ing better remains to be investigated.

A first attempt to investigate the results of 2 different surgical techniques for one and the same indication in a 3D way was nevertheless already performed in chapter 7. Two lateral osteotomy techniques were compared using 3D stereophotogrammetry to study the degree of swelling caused by each of the techniques. Lateral osteotomies are frequently performed as part of a rhinoplasty for various purposes. Although different techniques use different kinds of osteotomes and chisels, the lateral nasal osteotomy can basically be divided into two techniques: the percutaneous/ perforating/external osteotomy on one hand and the endonasal/continuous/internal osteotomy on the other hand. To compare both techniques 3D photographs were acquired pre- and four days postoperatively.

The method presented in chapters 5 and 6 could be adapted for the rhinoplasty study and proved in this way its flexibility. A problem of the volumetric method however was the definition of the planes and whether these defined a representative area. The planes were based on a cephalometric analysis and defined the region of interest and therefore the volumes measured in this region. Volumes outside these planes were not measured and therefore, if the region of interest was not sufficient, data were probably missed. Since the same planes were used for the pre- and postoperative 3D photographs, the volume differences measured gave a reliable indication of the volume in- or decrease caused by the osteotomies. Furthermore the influence of each of the two osteotomy techniques on the contralateral side was not investigated. If one of the two techniques would have influenced the contralateral side more than the other technique, a difference in volume would however have been found.

From chapter 5 it could be concluded that improvement of symmetry could be achieved by rhinoplastic procedures in patient with a cleft lip and palate deformity and that this symmetry could be objectified with 3D stereophotogrammetry. However, chapter 6 made clear that normal symmetry was very difficult to achieve. These studies all used 3D photographs to compare pre – postoperative, patient – control, left – right measurements. After the previous studies focusing on nasal changes using 3D stereophotogrammetry, the question arose whether it was possible to evaluate the influence of maxillary surgical interventions on the volume of the nose.

10.2.4 Does the nose change due to surgery of the maxillary complex? (chapter 8, 9)

To evaluate the influence of maxillary surgical interventions bony information was necessary and therefore roentgen information was necessary. For this DICOM data from CBCT was used since it was already discovered earlier that 3D reconstructions from CBCT data could be combined with 3D stereophotogrammetry data in an accurate manner.

Chapter 8 focused on the effects of surgically assisted rapid maxillary expansion (SARME) on the alar width, volume of the nose and the nasal airway. Despite the grow-
ing attention among clinicians concerning the effects of various treatment modalities on
the overlying soft tissues, limited information is available concerning soft tissue changes
of the face \textsuperscript{42,43}. The use of 3D datasets consisting of multiple 3D modalities made it pos-
sible to simultaneously evaluate changes in the three dimensions of space for soft and
hard tissues using one single model \textsuperscript{33,44}. Transverse maxillary expansion was found to
result in an increase in the nose volume, alar width and nasal airway volume \textsuperscript{42,45-47}. To
which degree patients functionally benefit from an increase in volume remains unclear
\textsuperscript{48}. Despite the fact that a significant effect on nasal airway volume is observed, the cli-
nical benefit has yet to be determined.

After the transverse dimension was studied there was a need to study changes of the nose
and upper lip region caused by movement of the maxillary base. Therefore in Chapter 9
3D stereophotogrammetry was combined with 3D reconstructions of the bony tissues
acquired from CBCT data. Pre- and postoperative data were evaluated and the changes
of the nose due to maxillary surgery was evaluated. Since translation of the maxilloma-
ndibular complex for correction of malocclusion is always followed by changes of the
covering soft tissues, especially the nose and lip, the purpose of this study was to eval-
uate the changes of the nasal region and upper lip volume due to orthognathic surgery
using combined 3D datasets.

The main advantage of this study was the combined information from the bony changes
and the soft tissue changes in all dimensions of space. Because of the elaborate steps that
had to be taken to acquire all the results, several sources of error have to be discussed.
Firstly, the apparatus for acquisition of 3D stereophotogrammetric and CBCT data, in
the Nijmegen set up are located in different buildings. As a consequence, the data were
not acquired at exact the same moment possibly causing matching differences. Never-
theless, previous studies have proved registration of 3D photographs with CBCT data to
be reliable \textsuperscript{36}. Secondly, the follow up of one year might lead to registration difficulties
of the bony base if growth was involved. In this study growth is eliminated by working
with patients that did not grow anymore. Besides growth, changes in weight might also
lead to registration difficulties. Patients undergoing orthognathic surgery might change
weight, especially, in the first weeks after surgery \textsuperscript{49}. It is expected that one year postop-
eratively this was stable and the registered 3D photographs didn’t give an indication of
this occurring, however no weight data were acquired. Thirdly, landmarks and planes
defined the region of interest and volume changes outside this region are not measured.
Finally, the volumes that were measured did not give information about the direction of
change. It would be interesting to be able to acquire a vector during volume acquisition.

10.3 Future aspects

The results of 3D imaging and fusion of multiple 3D imaging techniques are prom-
ising in the field of facial surgery as confirmed by the findings of this thesis. 3D
photographs seem to be a valuable way to evaluate the outcome in surgical patients. It’s
a non-invasive, quick and easy to learn method to capture patients’ faces. Evaluation
of surgery in this way however requires a 3D capturing hardware system, knowledge
of surface-based matching procedures, and software to perform this. To overcome all these hurdles, support from, and close cooperation between, technical engineers and surgeons is mandatory. In the Nijmegen 3D lab this close cooperation was achieved, so facilitating the use of these new imaging techniques and their possibilities on a high level. As the medical profession is evolving and the use of personal computers is part of daily work, next generations of clinicians might be able to perform these methods independently.

Nasal volume and symmetry data can be acquired relatively easy, making comparison of various rhinoplasty techniques possible. By setting up a 3D stereophotogrammetry database of volumetric data of rhinoplasty patients, but also by setting up a database of healthy controls, it will be possible to define normal nasal volumes. After having gathered large amounts of data, preoperative 3D photographs will be used to study and even simulate various surgical techniques. In this way a preoperative planning could be evaluated and even discussed with the patient making surgery more predictable and custom made.

While bone related changes can be predicted with an acceptable degree of accuracy, predicting the overlying soft tissue changes remains challenging. Most of the knowledge concerning soft tissue changes is extrapolated from 2D techniques and this data may be incomplete especially when changes occur in more than just one direction. This thesis, as small part of the 3D lab project, delivers 3D data so that predicting changes becomes more and more reliable. This will be important for predicting the changes of the soft tissues as a consequence of surgically induced bony alterations.

When facial surgery is limited to the soft tissues, 3D photographs seem to be ideal to evaluate changes pre- and postoperatively. The clinical usefulness of 3D photographs was also proven in measuring the effect of botulin toxin on masseter hypertrophy, as described by Adriaens et al.27. In this publication, 3D photographs were used to evaluate the volume of the masseter pre- and post-botulin toxin injection. In this way, a non-invasive method was used to acquire volumetric data and study the effects of the botulin toxin treatment. The use of fillers might also be an interesting field in which 3D photographs could easily be incorporated for evaluating pre- and postoperative changes. It might even be possible to preoperatively evaluate the ideal places and volumes to achieve the desired facial improvement.

The addition of time in imaging, i.e. four dimensional (4D) imaging, to the static 3D photograph is a promising technique. A 4D camera has been put on the market by 3dMD (Atlanta, USA) and Dimensional Imaging (Glasgow, UK). Three dimensional videos of a patients facial surface can be captured. This can be useful in the evaluation of patients with facial paralysis or evaluation of facial expression, especially in combination with surgical corrections. At the moment some research on 4D imaging is in progress. However the possibilities are, as of jet, limited. For evaluation it is necessary to be able to compare datasets, which is very difficult since various frames can be very different. The video sequences also deliver a large amount of data, resulting in difficult processing. When these hurdles will be overcome, more reliable patient simulations will be incorporated and used for evaluation of pathology, or even for comparison of pre- and postoperative situations.
With further improvement of the 3D systems it will become possible to acquire 3D images or 4D video sequences of higher quality at the time of acquiring bony data in one dedicated apparatus. In this way, registration errors and errors due to different facial expressions and postures will be excluded. This will lead to even more reliable datasets and better understanding of soft tissue changes as a consequence of interventions. Also growth processes could be studied in a much more realistic way. Having an all in one imaging system, the efficiency of the work flow would improve, making it more easy to implement it in a daily clinical setting. Ideally, after image acquisition the computer should generate a 3D model of soft and hard tissue automatically with a high accuracy. However, despite the abundant amount of information obtained through 3D imaging and image fusion, more scientific data have to be acquired to reach a fully realistic dataset with reliable simulation possibilities.

Predicting facial changes as a consequence of surgery with a computer aided maxillofacial software program is increasingly important in surgery planning but also in communications with the patients. Communication is important in dealing with patients especially when they will undergo elective surgery. The possibilities to inform patients improve when reliable simulations of tissue changes are available. As of now, especially in rhinoplastic and orthognathic surgery, patients become more and more demanding. They want all available information in order to have the best possible basis on which to make a well informed decision, of course together with the clinician.

Three dimensional imaging in general provides the surgeon with more and better preoperative information, which gives the surgeon the opportunity to prepare surgery more accurately and predictable. Hopefully this will lead to better functional and aesthetic outcomes for our patients in future.
10.4 References

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Discussion


Discussion


Hoofdstuk 1 begint met een algemene inleiding betreffende de historie van de neus. Aangezien de neus het aangezicht sterk bepaalt is verkleining, verandering of reconstructie vrijwel altijd zichtbaar. Door de eeuwen heen zijn verschillende rhinoplastische procedures ontwikkeld, te beginnen in Egypte (1500 v.Chr.) en India (600 v.Chr.). Vervolgens worden de mogelijkheden tot beeldvorming van de neus kort besproken en wordt 3D stereofotogrammetrie geïntroduceerd als een manier om 3D data van de neus te verkrijgen. Het 3D onderzoek, in het bijzonder het 3D laboratorium Nijmegen, wordt gepresenteerd, waarna de doelstellingen van dit proefschrift volgen. De hoofddoelstellingen worden in tweeën verdeeld: ten eerste moet de validiteit van 3D stereofotogrammetrie van het aangezicht worden bewezen en ten tweede moeten de mogelijkheden tot integratie van meerdere 3D datasets voor klinische doeleinden worden ontwikkeld.

In de beginjaren van het Nijmeegse 3D project was het 3D camerasytem van 3dMD (3dMDfaceTM System, 3dMD, Atlanta, USA) de enige hardware beschikbaar voor 3D beeldvorming. Met dit 3D stereofotogrammetrie systeem was het mogelijk om veranderingen van het aangezicht objectief te evalueren. De reproduceerbaarheid van het systeem moest echter nog worden onderzocht. Het eerste deel van dit proefschrift richt zich dan ook op de reproduceerbaarheid van het 3dMD stereofotogrammetriesytem. In de studie in hoofdstuk 2 werden 15 vrijwilligers geïncludeerd en van elke vrijwilliger werden 3D foto's gemaakt op verschillende tijdspunten. Alle 3D foto's werden op twee manieren geregistreerd, oppervlaktematig en met behulp van een gedefinieerd assenstelsel. De resultaten uit deze studie lieten zien dat de reproduceerbaarheid van 3D foto's verkregen op verschillende tijdstippen nauwkeurig genoeg is voor klinisch gebruik. De oppervlaktematige manier van registreren was nauwkeuriger dan het gebruik van een gedefinieerd assenstelsel. Door deze studie werd duidelijk dat oppervlaktematige registratie van 3D foto's een nauwkeurige manier was om 3D foto's van een individu, verkregen op verschillende momenten, te vergelijken.

In hoofdstuk 3 is onderzoek verricht naar de stabiliteit van verschillende regio's van het aangezicht, voor registratie van meerdere 3D foto's. Nadat 100 3D foto's van hetzelfde individu waren verkregen, werd de variatie in het aangezicht ook binnen verschillende regio's onderzocht. Tevens werd de invloed van een wasbeet ter stabilisatie van de mandibula tijdens het verkrijgen van de 3D foto's onderzocht. De resultaten van dit onderzoek lieten zien dat er een kleine variatie was voor het aangezicht in rust. De invloed van een was-beet was minimaal. Na evaluatie van de verschillende anatomische sub regio's werden de meest nauwkeurige waarden gevonden in de regio van het voorhoofd en de neus. De grootste variaties werden perioraal en periorbitaal gevonden. Dit zou kunnen worden verklaard door de grotere variatie die mogelijk is door de spieren in dit gebied. Nadat de validatiestudies in hoofdstuk 2 en 3 zijn besproken worden in het tweede deel...
van dit proefschrift de klinische mogelijkheden van 3D beeldvorming besproken. In het onderzoek in hoofdstuk 4 werden 12 patiënten geïncludeerd die een humpreductierhinoplastiek ondergingen. 3D foto's werden pre- en postoperatief gemaakt en oppervlaktematig geregistreerd. Een kleurenhistogram van het verschil tussen de 3D foto's werd berekend. De resultaten van deze studie lieten zien dat postoperatieve resultaten konden worden geobjectiveerd met behulp van 3D stereofotogrammetrie. Daarnaast werd er een correlatie gevonden tussen de waarden van het kleurenhistogram en de chirurgische technieken die waren gebruikt. Voor toekomstige studies was echter een betrouwbare kwantitatieve meetmethode nodig.

In de studie in hoofdstuk 5 werd de symmetrie van de neus geëvalueerd van 12 patiënten met een unilaterale cheilognatopalatoschisis (CGPS) na secundaire rhinoplastiek. Het doel van de rhinoplastiek was meer symmetrie te bereiken door de schisiszijde te augmenteren. 3D foto's werden pre- en 3 maanden postoperatief verkregen. Na oppervlaktematige registratie werden volumemetingen verkregen van de totale neus, alsook van de gesegmenteerde linker- en rechterzijde van de neus. Postoperatief nam het volume van de neus significant toe aan de schisiszijde. Aan de gezonde contralaterale zijde werd geen significante toename van het volume gevonden. In het algemeen was er postoperatief een significante verbetering van de symmetrie.

Ook in hoofdstuk 6 werden 3D foto's van patiënten met een unilaterale CGPS verkregen. Het doel van deze studie was het evalueren van de symmetrie van de lip en neus, na correctie volgens de Afroze techniek gecombineerd met een functionele neusseptum plastiek. De symmetrie werd vervolgens vergeleken met een gezonde controlegroep. Vierentwintig patiënten met een unilaterale CGPS, 1 jaar na operatie, werden vergeleken met 44 gezonde vrijwilligers zonder schisis. Lineaire en volumemetingen (sagittale neusopening, transversale neusopening, verticale liplengte, horizontale liplengte en neusvolume) werden verkregen uit 3D foto's. De controlegroep bleek tot 36% dichter bij perfecte symmetrie in vergelijking met de patiënten met schisis na operatie. Deze methode liet zien in hoeverre de neus en lip na de Afroze techniek, gecombineerd met een functionele neusseptum plastiek nog afwijkt van de normale populatie.

In hoofdstuk 7 werden de percutane en endonasale laterale osteotomietechniek, gebruikt tijdens rhinoplastieken, vergeleken voor wat betreft een mogelijk verschil in postoperatieve zwelling. 3D foto's werden pre- en postoperatief verkregen en oppervlaktematig geregistreerd. Volumemetingen richtten zich op de paranasale regio's. Twintig patiënten werden geïncludeerd. De resultaten lieten geen significant verschil zien in postoperatieve zwelling.

In hoofdstuk 8 werd 3D stereofotogrammetrie gecombineerd met 3D reconstructies van de benige delen verkregen uit CBCT data. Tand-gedragen (hyrax) expansie en botgedragen (TPD) expansie na “surgically assisted rapid maxillary expansion” (SARME) werden vergeleken. Veranderingen van de neus (neusbreedte, neusvolume en nasale luchtwegvolume) werden in beide groepen geëvalueerd. Tweeëndertig patiënten met een transversale maxillaire hypoplasie werden in deze studie geïncludeerd. Bij 19 patiënten werd een tand-gedragen distractor gebruikt en bij de overige 13 een bot-gedragen distractor. Na expansie nam de neusbreedte, het volume van de neus, en het nasale luchtwegvolume in beide groepen toe, er was echter geen statistisch significant verschil
De onderzoeken van hoofdstuk 8 en hoofdstuk 9 bewezen dat veranderingen van de neus en lip konden worden geobjectiveerd en gecorreleerd aan de verrichte operaties.
Chapter 1 starts with a general introduction about the nose in an historical perspective. Since the nose is front and center of appearance, reduction, reshaping or reconstruction of this facial unit is always obvious. Through the centuries rhinoplastic procedures were developed, starting in Egypt (1500 BC) and India (600 BC). Next, imaging of the nose is shortly discussed and 3D stereophotogrammetry is introduced as a way to acquire data of the nose in a 3D way. The 3D research framework, especially the Nijmegen 3D lab, are presented, followed by the aims and objectives of this thesis. The main objectives are twofold: firstly, the validity of facial 3D stereophotogrammetry has to be proven, and secondly, the possibilities of integrating multiple 3D datasets for clinical data acquisition have to be developed.

In the beginning years of the Nijmegen 3D project, the only hardware available for 3D imaging consisted of a 3D camera system from the 3dMD company (3dMDfaceTM System, 3dMD, Atlanta, USA). Using this 3D stereophotogrammetry technique it was possible to evaluate facial treatment changes objectively in three dimensions. However, the reproducibility of the system needed to be investigated still. Therefore the first part of this thesis focused on the evaluation of the reproducibility of the 3D stereophotogrammetry. In the study presented in Chapter 2, fifteen volunteers were included and facial 3D photographs of the same individuals were captured at different points in time. All 3D photographs were registered in two ways, surface-based and reference-based. The results of this study showed that the reproducibility of acquiring 3D photographs at different moments was accurate enough for clinical use. The surface-based registration method was more accurate as compared to reference-based registration. From these results, it became clear that surface-based registration is an accurate method to compare 3D photographs of an individual acquired at different points in time.

In Chapter 3, it was investigated which region of the face was the most stable for registering multiple 3D photographs. After having acquired 100 3D photographs of one and the same individual, the variation within the face as well as the variation within different anatomical regions, was evaluated. Also, the influence of a wax bite to stabilise the position of the mandible during acquisition was investigated. The results of this study showed a small variation for the face in rest with a minimal influence of the wax bite. Evaluating the different anatomical subunits, the most accurate values were found in the region of the forehead and the nose. The largest variations were found in the peri-oral and the peri-orbital area. Both might be explained by the larger overall possible variation of the muscles in this region.

After performing the validation studies described in Chapter 2 and 3, more clinical applications of 3D imaging are described in the second part of the thesis. In Chapter 4, 12 patients who had undergone a hump reduction rhinoplasty, were included. 3D photographs pre- and postoperatively were surface-based registered and a distance kit was
calculated. On one hand, the study proved that clinical postoperative findings could be objectified using 3D stereophotogrammetry. On the other hand, a correlation between the values of the distance kit and the applied surgical techniques was found. However, for future studies, a more quantitative reliable method had to be developed.

In the study presented in Chapter 5, nasal symmetry was evaluated in 12 patients with unilateral cleft lip and palate (CLP) who underwent secondary rhinoplastic surgery for correction. 3D photographs were acquired preoperatively and 3 month postoperatively. After surface-based registration, volumetric measurements were acquired from the total nose, but also from the segmented left and right side. Postoperatively, the volume increased significantly on the cleft side. This was to be expected since the cleft side is usually underprojected. On the non-cleft side, no significant volume changes were found. In general, a significant improvement of nasal symmetry was determined.

Also in Chapter 6, 3D photos from unilateral CLP patients were acquired. The aim of this study was to assess the outcome of lip and nasal symmetry in a group of patients with complete unilateral CLP after cleft lip correction in combination with a primary septoplasty using the Afroze technique and to compare this outcome with a healthy control group. 44 one year postoperative complete unilateral CLP patients and 44 healthy control patients without cleft defects were included. Linear and volumetric measurements (nostril sagittal length, nostril transversal length, vertical philtrum length, horizontal philtrum length, nose volume) were acquired from 3D photographs. The control group was found to be up to 36 % closer to perfect symmetry compared to the operated CLP group. This study proved that the Afroze technique in combination with a functional repair of the nose is not able to achieve perfect symmetry.

In Chapter 7 the percutaneous and the endonasal lateral osteotomy technique used during rhinoplasty were compared to study a possible difference in the degree of swelling caused by each of the techniques. 3D photos were acquired pre- and 4 days postoperatively and registered using surface-based matching. Volumetric measurements focused on the paranasal regions. Twenty patients were included. Concerning postoperative swelling no significant differences were found.

In Chapter 8 3D stereophotogrammetry was combined with 3D reconstructions of the bony tissues acquired from CBCT data. Tooth-borne (hyrax) expansion and bone-borne (TPD) expansion after surgically assisted rapid maxillary expansion (SARME) were compared. Nasal changes (alar width, volume of the nose and the nasal airway volume) were evaluated in both groups. This study included 32 patients, 19 underwent tooth-borne expansion and 13 patients underwent bone-borne expansion. Following expansion, the nasal volume, the alar width and airway volume increased in both groups, however, there was no statistically significant difference between the two groups.

In Chapter 9 3D stereophotogrammetry was again combined with 3D reconstructions of the bony tissues acquired from CBCT data. Nasal (inter alar width and volume) and upper lip (volume) changes, due to maxillary orthognathic surgery, were evaluated pre- and postoperatively. Thirty-six patients who underwent a Le Fort I osteotomy were included in this study. The results indicated that the inter alar width and the volumetric measurements of the lip changed significantly. Regression analysis indicated cranial
translation of the maxilla to be responsible for an increase of the alar width. Anterior translation and clockwise pitching of the maxilla showed significant increases of upper lip volume.

Chapter 8 and chapter 9 proved that changes of the nose and lip region could be objectified and correlated with the surgery performed.
Dankwoord
Curriculum vitae
List of publications
Dankwoord

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Curriculum vitae

Bram van Loon was born in ‘s-Hertogenbosch (The Netherlands) on March 13, 1983. In 2001, he completed pre-university secondary education (VWO) at the Jeroen Bosch College in ‘s-Hertogenbosch and started to study Medicine at the Radboud University Nijmegen. In 2007 he obtained his Medical Degree. He then spent two years as a researcher at the department of oral and maxillofacial surgery Radboud University Nijmegen, Medical Centre working with other engineers and medical doctors at the 3D project. From 2009 he studied dentistry within a specific program for medical doctors (Tandartsen Opleiding Voor Artsen) at the Radboud University Nijmegen, and obtained his Dental Medical Degree in 2012. In 2011 he started his residency at the department of Oral and Maxillofacial surgery Radboud University Nijmegen, Medical Centre (current head: professor dr. S.J. Bergé) which he will complete in 2015.
List of publications


11. Anteromedial thigh flaps: An anatomical study to localize and classify anteromedial