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Volumetric analysis of fat injection by computerized tomography in orthognathic surgery: preliminary report on a novel volumetric analysis process for the quantification of aesthetic results

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Abstract:

An integrated approach to orthognathic surgery should include accurate volumetric evaluation of the skull and soft tissues. In patients with dentofacial deformities, the most frequent aesthetic deficits are attributable to an underdevelopment of hard and soft tissues. Traditional osteotomic procedures often fail to guarantee a stability of soft tissues over time. For this reason, in selecting a surgical strategy, the surgeon should consider not only traditional osteotomies, but also soft-tissue improving procedures, such as lipofilling. Preoperative surgical planning systems, such as the Virtual Surgical Planning (VSP) Protocol®, are based mainly on skeletal movement prediction. Quantitative estimation of soft-tissue modifications is not part of common clinical practice. In contrast, the evaluation of soft-tissue modifications after orthognathic procedures is performed mainly by clinical qualitative means rather than with objective quantitative systems. This study describes a novel CT-based volumetric analysis process for the quantification of injected autologous adipose tissue in patients who have undergone simultaneous orthognathic and lipofilling procedures. Sixteen female patients who underwent combined orthognathic surgery and lipofilling were enrolled in this study.

Preoperative planning included clinical evaluation and virtual osteotomy planning according to the VSP Protocol®. The volume of fat to be injected was estimated clinically by comparing virtual renderings with preoperative clinical photographs. The surgical technique involved Le Fort I and sagittal split mandibular osteotomies, combined with autologous fat injection in the malar and perioral regions. Postoperative evaluation was performed with a novel imaging process based on CT image segmentation to quantify the exact volume of injected fat. Skeletal stability was also evaluated at 3 months. The mean difference between the fat tissue injected and that quantified postoperatively was 6.01 cm3. All patients had clinically satisfactory facial convexity, with complete restoration of the cheekbone contour, at 3 months.

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Introduction

Modern orthognathic surgery is performed not only to correct functional occlusal impairment but also to improve facial aesthetics in patients with altered maxillary morphology (1,2).

In patients with dentofacial deformities, the most frequent aesthetic deficits are attributable to an underdevelopment of hard and soft tissues. Middle third of the face is the most interested area. Traditional orthognatic skeletal movements often fail to guarantee soft tissues stability over time. Furthermore, Le Fort I and sagittal split mandibular osteotomies act on the lower third of the face, without changing the volume of the middle third. For this reason, in selecting a surgical strategy, the surgeon should consider not only traditional osteotomies, but also soft-tissue improving procedures, such as lipofilling.

Even in the preoperative planning phase, a complete and integrated approach to facial aesthetics should include accurate evaluation of the skeletal morphology and soft-tissue layers (3,4) leading to a careful definition of surgical strategy (5,6).

To improve surgical precision, preoperative surgical planning systems have been developed, and their fields of application are expanding. Virtual surgical planning (VSP) enables surgeons to project interventions using three-dimensional (3D) renderings of radiological images of the patient, thereby achieving reliable prediction of the postoperative result in the preoperative phase (7,8). Computerized tomography (CT)-based virtual models of the maxillofacial skeletal structures are now the gold standard in orthognathic surgical planning. They are the result of the evolution of traditional planning systems based on the use of mechanical articulators for occlusal splint production (9–11). The main objectives of orthognathic VSP are typically related to the osteotomies and bony structure movements (12).

Recent reports have described the virtual prediction of soft-tissue changes after orthognathic interventions (13). Most of these experiences have been based on 3D photography and were circumscribed to the research setting in few specialized centers (14, 15, 16). To date, no report on the volumetric evaluation of implanted adipose tissue following orthognathic surgery has been published. Currently, the evaluation of final results after autologous fat injection is based exclusively on the comparison of preoperative and postoperative clinical photographs (17,18, 19).

This preliminary study aims to describe a novel CT-based volumetric analysis process for the quantification of injected autologous adipose tissue in patients who have undergone simultaneous orthognathic and lipofilling procedures.

Matherials and methods

Sixteen female patients with a mean age of 24.5 years (standard deviation, 2.54 years; range, 18–36 years) were enrolled in this study. All patients were referred for malocclusion with functional and aesthetic impairments (i.e., sagittal mandibular excess, sagittal maxillary defect, combined disorders) requiring surgical correction with combined maxillary and mandibular osteotomies. Preoperative virtual planning revealed volumetric soft-tissue deficits requiring facial fat-pad augmentation in all enrolled patients. No patient enrolled in this study had undergone a previous surgical procedure involving the facial soft tissues.

All patients underwent simultaneous orthognathic surgery and autologous fat transfer. The orthognathic procedures consisted of combined maxillary (Le Fort I) and mandibular (bilateral Obwegeser sagittal-split) osteotomies with rigid fixation of the bone segments and genioplasty. The facial areas injected with autologous fat were the cheek, malar, and submalar regions and the paranasal and nasolabial folds.

For all patients, preoperative cone-beam CT examinations were performed for complete virtual planning of the impact of surgery on the bony structures and soft tissues. The study protocol required control evaluations at 1 and 3 months postoperatively. Three months after surgery, all patients underwent cone-beam CT examinations.

This study received no outside funding and was not associated with any insurance reimbursement. Ethical Committee authorized this study. All procedures performed in studies involving human participants were in accordance with the ethical standards the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

In this article, clinical photographs are essential for scientific purposes. The participants whose photographs are displayed in this article have given written informed consent for publication.

Preoperative clinical analysis

All patients underwent preoperative clinical and radiological assessments. The preoperative analysis was based on standard craniofacial photographs (frontal, lateral, and three-quarter views; Fig. 1 and Fig. 2), cone-beam volumetric tomography, cephalometry, and clinical evaluation. Frontal-view clinical and photographic evaluations aimed to determine the extent of facial convexity loss due to malar deficiency and deficits of the paranasal and nasolabial folds. Three-quarter and lateral evaluations aimed to determine the extent of cheekbone contour loss.

Mladick's (20) method was used to determine the proper sites of autologous fat injection. According to this method, one line is traced from the ala to the tragus, and another line is traced from the lateral canthus to the commissure. The crossing point is used as the reference point for symmetrical adipose grafting (Fig. 3). The malar prominence is generally located near this point.

Preoperative planning and clinical volumetric estimation

Preoperative CT images were examined using the VSP Protocol® (VSP Orthognathics, Littleton, CO, USA) to define the exact positions of the osteotomies and to quantify the linear translation and angular rotation of each detached bony segment. The VSP process enabled 3D simulation of the bony segment positions after surgery and highly accurate quantification of each translation and rotation (Fig. 4). This process also permitted the fabrication of customized occlusal splints for the intraoperative guidance of the bony segment positions to achieve correct occlusion.

The preoperative volume of bone and soft tissues was obtained with a segmentation process from preoperative CT images (21, 22).

The quantification of fat volume to be injected has been determined in a clinical way, not being a quantification of a volumetric deficit directly deducible from the 3D planning: the 3D reconstruction of the maxillofacial skeleton and of the soft tissues showed to the clinician the overall preoperative facial volume, the maxillary skeleton volume and the soft tissue volume.

In this way, it was possible to clinically determine if the volume defect was related more to a skeletal maxillary retrusion or to an excessive soft tissue thinness.

The final decision about the volume of adipose tissue to be injected was eminently clinical, related to surgeon's experience and to the patient's aesthetics (17, 18, 19).

<u>Surgical procedure</u>

All procedures were performed by the authors between June 2016 and May 2017 at the Department of Cranio-Maxillofacial Surgery, Academic Hospital of REDACTED, REDACTED. Fat graft harvesting and injection were performed after suturing of the incisions made for the previous orthognathic procedure. In all cases, the abdomen served as the fat donor site. A 23-gauge needle was used to create access in the umbilical skin, and the abdominal fat was infiltrated with 250 ml tumescent solution. No incision was performed. Fat was harvested from the abdominal wall with 20-ml Luer-Lock syringes (with suction maintained manually) connected to a Goisis aspiration cannula (Tulip Medical, a division of Black Tie Medical Inc., San Diego, CA, USA). Fat was aspirated gently using finger pressure on the plunger of the syringe to minimize trauma to the fat particles. The aspirated material was then processed under sterile conditions, and the fat was purified from blood and oil. Centrifugation and washing were avoided (23).

The fat graft was collected and transferred to 1-ml syringes, and fat injection was performed with cannulas of different lengths (5–7 cm) and cross-sections (0.9 and 1.2 mm). The treated areas were the cheek, malar, and submalar regions and the paranasal and nasolabial folds. Cheek, malar, and submalar fat injections were performed using an access incision over the upper lateral cheek. Paranasal and nasolabial fat injections were performed using an access incision in the area of the modiolum and a lateral zygomatic approach (Fig. 5). The fat was injected in a radial pattern during the withdrawal stroke of the cannula under low pressure. Approximately 1 ml fat was injected during each withdrawal stroke. The average total volume injected into all facial sites was 15.5 ml (range, 10.5–19.5 ml). The injected volumes corresponded to the volume gaps clinically estimated in the preoperative phase (Table 1).

Postoperative volumetric analysis

The postoperative volumetric analysis was based on the use of *3DSlicer*, an advanced quantitative imaging program developed by a partnership between the A.I. Laboratory of MIT and the Surgical Planning Laboratory of the Brigham and Women's Hospital. This analysis followed the protocol developed by the authors for preoperative craniofacial planning in a previous preclinical study (21).

All CT images were subjected to volumetric 3D reconstruction of the bony structures and soft tissues to obtain quantitative data. This process was based on a segmentation algorithm by which the volumes associated with bony, adipose, and cutaneous tissues were defined by their radiological densities (Fig. 6). In the injection areas, fat was distinguished from surrounding tissues by its radiological appearance as a well-demarcated non-homogeneously hypodense (density range, –100 to –50 HU) area at the implant site. The non-fatty soft tissues were characterized by densities ranging from –50 to 160 HU (24) (Table 2). Only areas that met these criteria were selected as parts of the injected fat volume in the segmentation process. In this way, the postoperative images of adipose tissue injected in the perioral and malar areas were three-dimensionally rendered to quantify volume and thickness (Fig. 7).

Once 3D objects had been created from the bony, fatty, and cutaneous structure data, their volumes were assessed quantitatively (Fig. 8). The postoperative volumetric models of the injected fat were compared with the preoperatively estimated volumes. Postoperative clinical evaluation included photography (frontal, lateral, and three-quarter views) and cephalometry. Volumetric differences between the preoperative plans and the postoperative results were determined and analyzed statistically.

Data on volumetric differences between preoperative estimations and postoperative results were summarized descriptively by the calculation of means and standard deviations.

The volumetric increase can be given by new adipose tissue (newly formed) or by an adipose tissue previously infiltrated during our surgical procedure. The fibrous component generated by the surgical procedure must also be considered.

Results

The mean volume gap calculated on preoperative clinical analysis was 15.5 cm^3. The volumes of injected fat tissue corresponded to the calculated volume gaps. The mean adipose tissue volume estimated on postoperative CT images was 9.49 cm^3 (standard deviation, 2.95 cm^3). The mean difference between the amount of fat tissue injected and the surgical outcome was 6.01 cm^3. No supplementary diagnostic procedure was required for postoperative volumetric evaluation of the injected fat.

All patients had clinically satisfactory facial convexity, with complete restoration of the cheekbone contour, at 3 months (Figs. 9–10), also evaluated with cephalometric analysis. Quantification of injected fat was possible in all patients, and volumes that satisfied the morphological detection criteria were observed on all postoperative CT images.

Discussion

Orthognathic surgery aims to correct stomatognathic function and aesthetic disharmony by repositioning segments of the maxillary bones.

However, as reported by O'Ryan and Lasseter, (3) patients' evaluations of the success of orthognathic surgical procedures depend principally on the achievement of an aesthetic facial outcome. Surgical movement of the skeletal framework may worsen the intrinsic lack of soft-tissue volume. To improve the final results, most authors have recommended the use of alloplastic implants or autologous tissue injection (20,25–27). Patients with skeletal malrelationships caused by maxillary anteroposterior defect and midface hypoplasia may present with an alteration of cheekbone contour. High osteotomies, segmental osteotomies of the zygomatic complex, and malar expansion with alloplastic materials can be performed to improve facial aesthetics

Several studies have shown that the combined use of orthognathic surgery and autologous fat transfer is a valid approach to improve the aesthetic result (19,28).

Autologous fat transfer is currently used to correct facial soft-tissue volumetric deficiencies and is associated with long-lasting results (29,30). The use of autologous fat implants is strongly supported in the literature, as it is associated with a lower risk of complications, such as prothesis displacement, infection, and fibrotic reactions (31,32). The main disadvantage of autologous fat tissue implantation is the relative unpredictability of the outcome, with a reabsorption rate ranging from 20% to 70% (33).

This research provides data on a novel analytic process that enables volumetric evaluation of the injected adipose tissue. To date, few articles have described the use of a quantitative image-based approach to evaluate the outcomes of lipofilling procedures (17). Moreover, these reports describe a method based on the quantification of only fat pad thickness, with no evaluation of adipose tissue volume. All these articles describe the use of magnetic resonance imaging to support fat pad evaluation, which entails exposure of the patient to an expensive diagnostic procedure that is normally not required for follow up after aesthetic surgical intervention (34).

In this work, no control group has been employed, because it was not possible to determine a gold-standard technique for volumetric injected fat assessment that could serve as reference. In fact, up to now, no other strategies for injected fat volume quantification have been described in literature, therefore it was not possible to compare this CT-based volumetric quantification protocol with another volume evaluation technique.

This study introduces a novel concept for aesthetic assessment in the orthognathic field; it involves the use of volumetric CT-based quantification for the evaluation of the postoperative results of fat injection. The aesthetic outcomes after bimaxillary orthognathic surgery with simultaneous facial lipofilling can be determined by quantifying the volume of fat injection on the routine postoperative CT images acquired as part of the standard follow-up protocol for patients undergoing orthognathic procedures. The main advantage of this imaging evaluation protocol is that it is based only on diagnostic examinations that are normally included in follow up after orthognathic surgery, thereby avoiding excessive postoperative diagnostic efforts. Moreover, CT images allow surgeons to simultaneously evaluate the bony structures and soft tissues, obtaining information on the outcomes of the orthognathic procedures and fat implantation.

The postoperative analysis of bony segment stability forms the backbone of outcome analysis in the orthognathic field. In addition to a detailed assessment of postoperative skeletal stability, an integrated approach to facial aesthetics should include an accurate evaluation of soft-tissue volumetric changes. For this reason, the quantitative approach to fat implant volume assessment described in this study represents an innovation; it enables 3D evaluation of the postoperative facial morphology, leading to the possibility an accurate assessment of the surgical outcome. Moreover, the ability to volumetrically compare the preoperative estimation with the real postoperative outcome provides the opportunity to collect data on the accuracy with which the preoperative clinical evaluations predicted actual surgical results.

The possibility to separately identify the volume of the bony component and of the fat component could also help to assess their contribute to the final postoperative facial aesthetics.

The postoperatively evaluated fat volume can be related either to the previously injected adipose tissue or to a newly formed fat pad, possibly due to the stem cells and growth factors contained in the injected fatty graft. Fibrous tissue resulting from the surgical tissue trauma may also contribute to the postoperative overall volume of the injected areas. Regardless of the histologic features and of the pathophysiological mechanism, the goal of the aesthetic procedures on soft tissues is to obtain a volume increase.

The analytic technique described in this work allows to identify the contribution of the fat pad in the injected site to the postoperative soft tissue volume increase.

This kind of analysis could be useful especially in complex aesthetic interventions involving both the bony structures and the soft tissue, helping surgeons to introduce a quantifiable variable, such as injected fat volume, for outcome assessment. In fact, such volumetric analysis could be the baseline for further evaluation of lipofilling outcome, defining as a clinical endpoint the postoperative injected fat volume.

A limitation of this study can be seen in the 3-month postoperative evaluation. In order to better define the postoperative volume increase at steady state, further long-term evaluations should be performed.

However, the aim of this work is not the definition of the long-term stability of injected fat, but it is the description of a novel analytic method for postoperative quantitative volume evaluation.

Figure legends

Fig. 1 Preoperative clinical evaluation (patient 1, see Tab. 1).
Frontal, three-quarter and lateral views show malar prominence deficiency, sagittal mandibular excess, and a maxillary defect.

Fig. 2 Preoperative clinical evaluation (patient 9, see Tab. 1).
Frontal, three-quarter and lateral views show malar prominence deficiency, sagittal mandibular excess, and a maxillary defect.

Fig. 3 Mladick's reference lines, used to identify malar prominence. Two intersecting lines (one from the ala to the tragus and the other from the lateral canthus to the labial commissure) are used to determine Mladick's point (patient 1).

Fig. 4 Preoperative surgical planning. The VSP Protocol® allows surgeons to obtain 3D renderings of the osteotomies and to quantify translational and rotational movements (patient 1).

Fig. 5 Intraoperative view of the lipofilling procedure performed during orthognathic surgery. From the surgical access in the modiolum area (A) and from the malar area (B), fat was injected in multiple linear patterns to homogeneously fill the malar region (patient 1).

Fig. 6 Axial (A) and sagittal (B) views of segmentation. The areas on CT images satisfying the criteria for radiological fat detection (non-homogeneous density ranging from –100 to –50 HU at the anatomic site of previous fat injection) are segmented and depicted in yellow. The bony structures are depicted in beige (patient 1).

Fig. 7 3D rendering of the segmented areas from postoperative CT images. The skull, soft tissues, and injected fat previously segmented on 2D CT images are depicted volumetrically (patient 1).

Fig. 8 Images from the *3DSlicer* quantitative imaging tool. 3D rendering of the adipose tissue (right) and the volume of the 3D object (left). Volumetric data are expressed in cubic millimeters (patient 1).

Fig. 9 Six-month postoperative clinical evaluation. Frontal (A), lateral (B), and three-quarter (C) views showing the restoration of facial convexity and cheekbone contour (patient 1).

Fig. 10 Six-month postoperative clinical evaluation. Frontal (A), lateral (B), and three-quarter (C) views showing the restoration of facial convexity and cheekbone contour (patient 9).

Tables

	Injected Volume		Injected Volume
Patient 1	10,5	**Patient 9**	15,5
Patient 2	14,5	**Patient 10**	11,5
Patient 3	19,0	**Patient 11**	18,0
Patient 4	15,5	**Patient 12**	16,0
Patient 5	12,5	**Patient 13**	19,5
Patient 6	17,5	**Patient 14**	11,0
Patient 7	19,5	**Patient 15**	15,0
Patient 8	15,0	**Patient 16**	17,5
Average Injected Volume: 15,5 ml			

Table 1 Injected fat volumes (calculated on clinically estimated volume deficits).

	Density
Adipose tissue	-160: -50
Non-fatty soft tissues	-50: + 160

Table 2 Radiological density ranges used for fat tissue detection.

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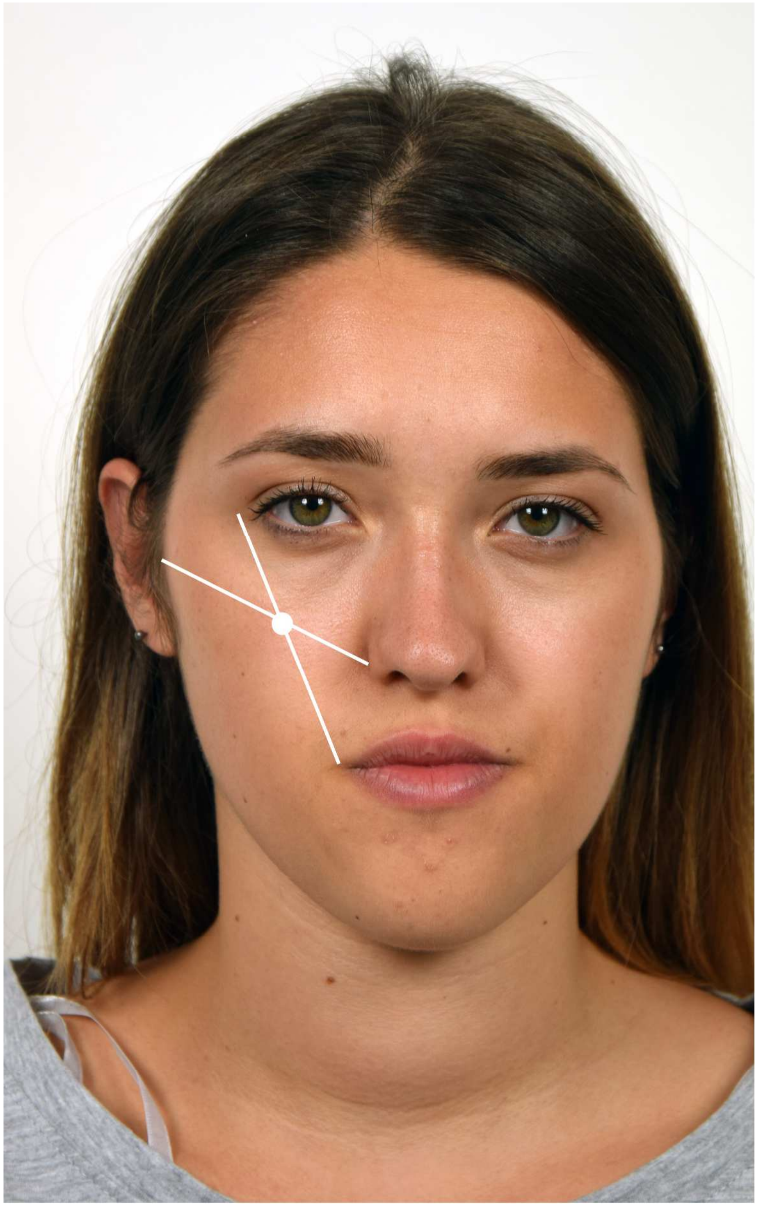

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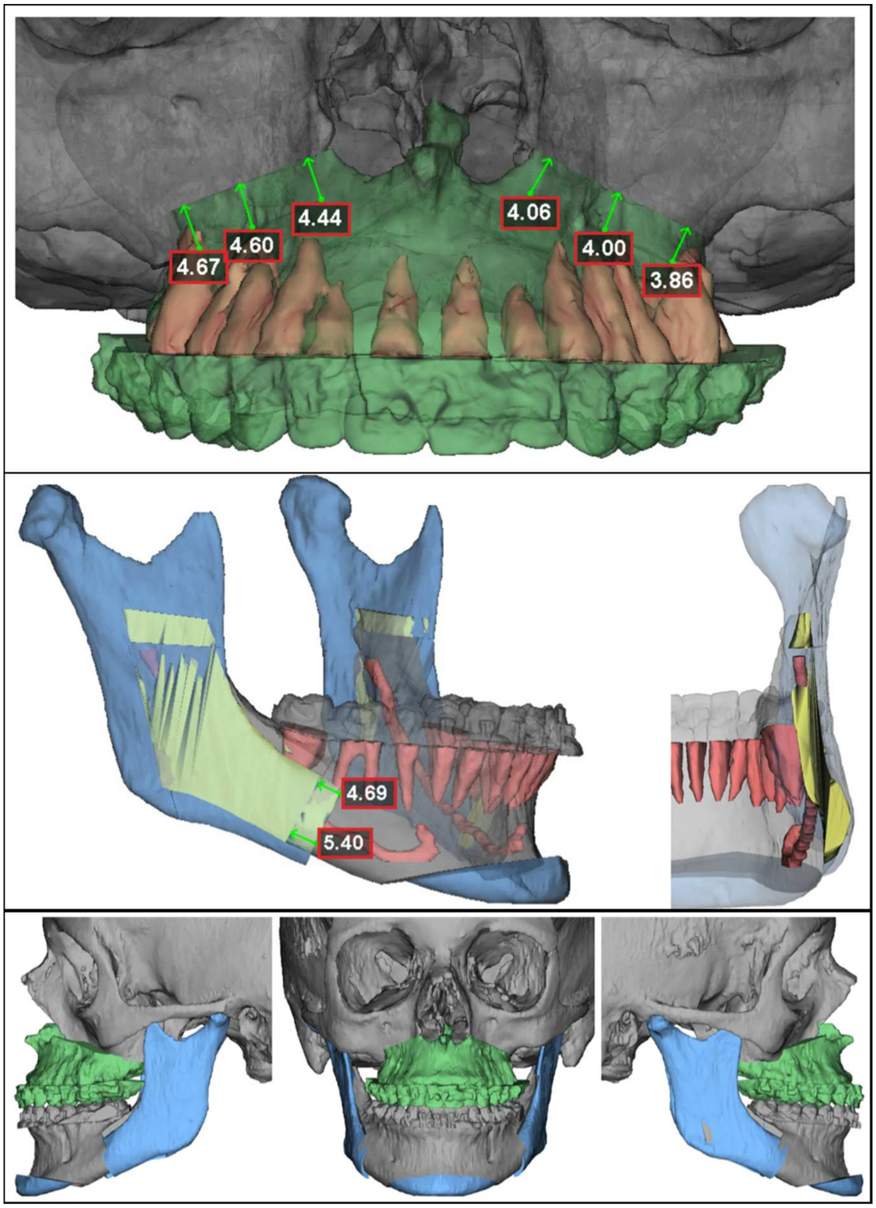

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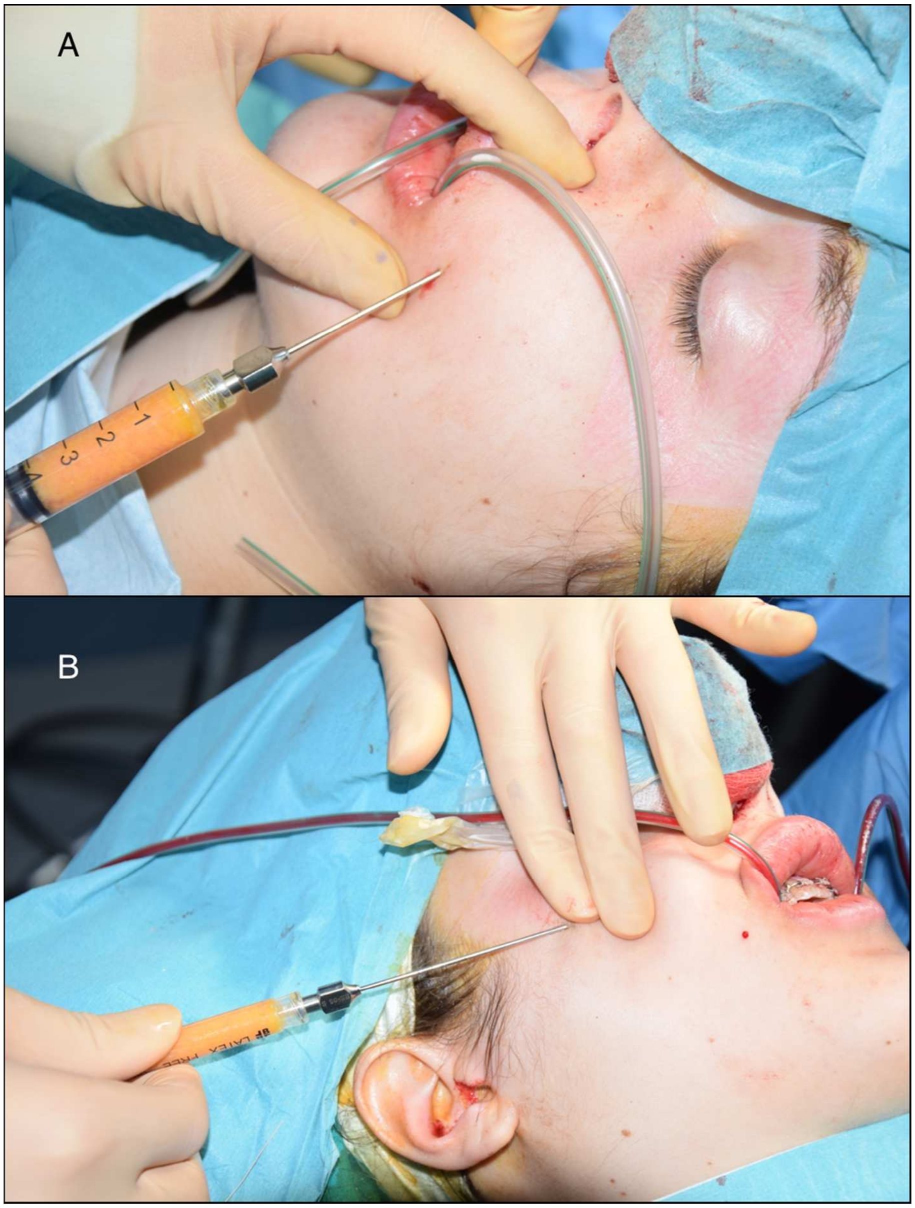

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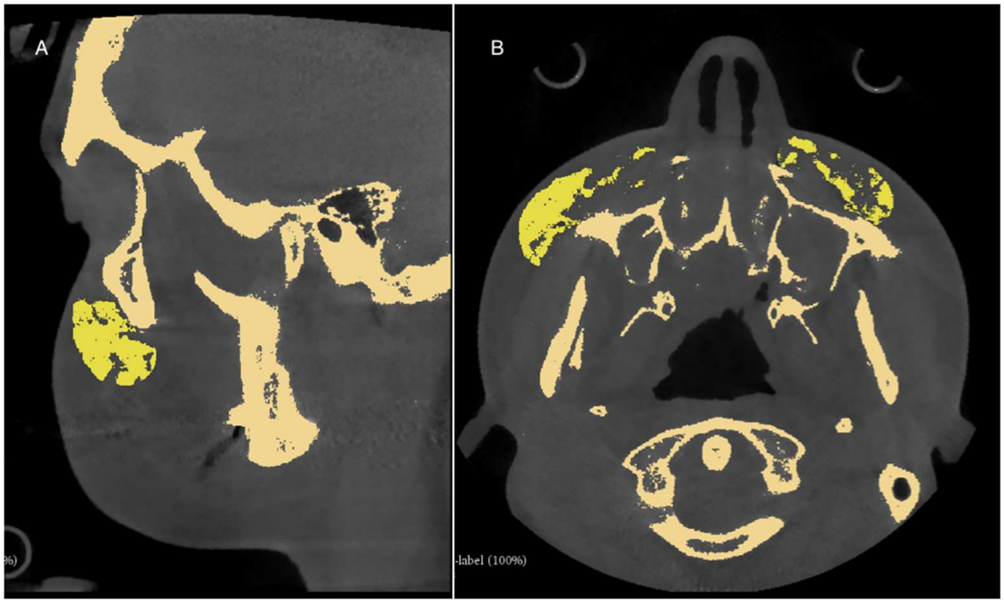

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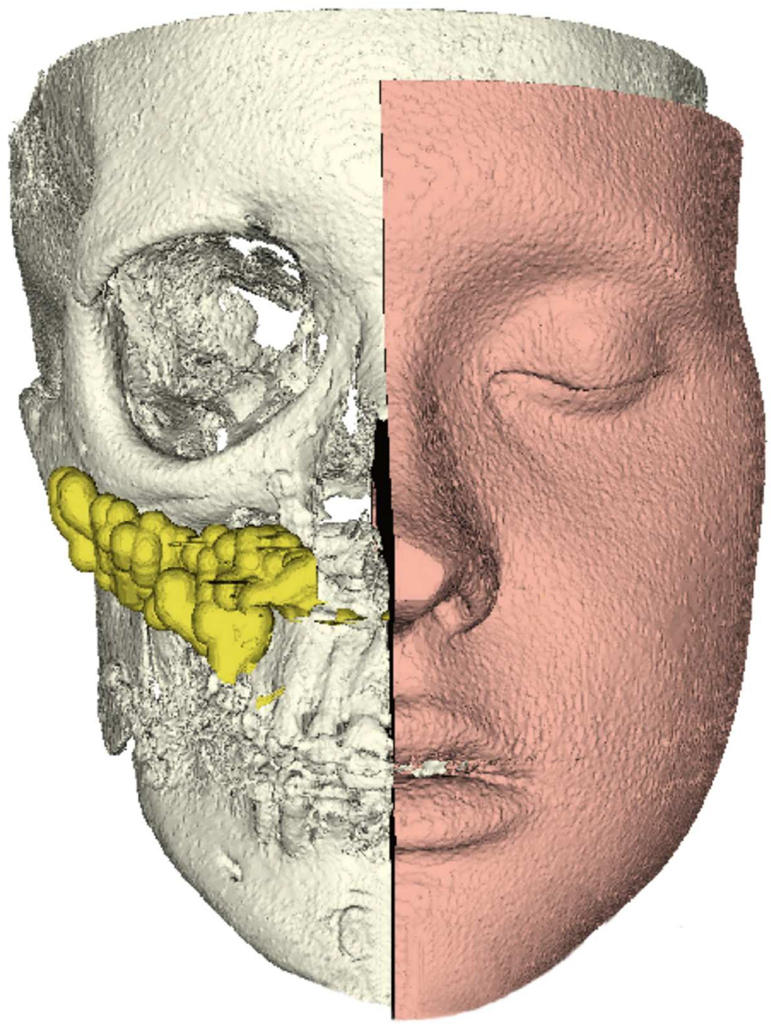

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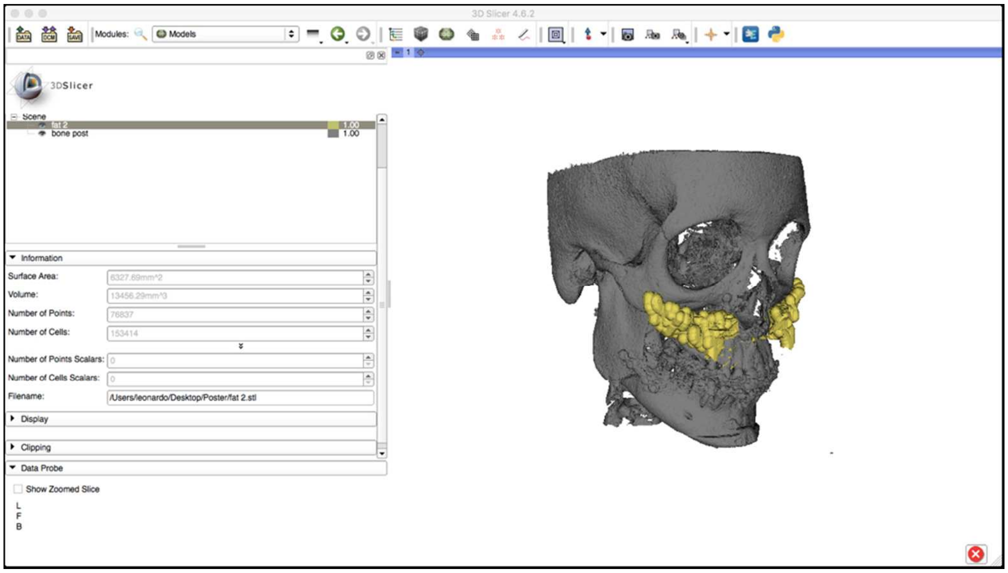

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