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# Volumetric analysis of implanted biphasic calcium phosphate/collagen composite by three-dimensional cone beam computed tomography head model superimposition

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ABSTRACT

Facial onlay augmentation is often performed as an ancillary procedure simultaneously with orthognathic surgery to improve facial appearance, with hydroxyapatite (HAp) and HAp-based composites often used as the materials of choice. The ability to apply HAp in a granular rather than solid shape form may be responsible for its comparatively reduced rate of complications. However, a known complication of HAp and HAp composites is reduction of implant volume over time associated with resorption of the material. Evaluation of the volumetric changes of implanted biphasic calcium phosphate (HAp/β-TCP)/collagen composite in the malar areas from baseline to 4 months, 9–12 months, and 18–24 months after surgery using cone beam computed tomography (CBCT) surface superimposition and volumetric subtraction was done. The average decrease of volume of implanted HAp/β-TCP 4 months after surgery was 18.6%. Further volumetric decreases were negligible and a mean total volume loss of 21.65% was found at 18–24 months postoperatively.



## 1. Introduction

Cone beam computed tomography (CBCT) is a validated methodology for obtaining accurate linear and angular measurements of bony morphologies (Moreira et al., 2009). It has recently been used for treatment planning and outcome evaluation for orthodontics (Cevidanes et al., 2007a). Segmentation and registration of CBCT data followed by superimposition of 3D models allows quantitative comparison between different phases of treatment (Cevidanes et al., 2006; Motta et al., 2011; Park et al., 2013), different periods of growth (Krarup et al., 2005; Cevidanes et al., 2005b, 2009, 2011) or virtual versus actual outcomes (Tucker et al., 2010), as well as assessment of the stability of surgical outcomes over time (Carvalho et al., 2010).

The superimposition of CBCT data from different phases of treatment can reveal the change in position and morphological adaptation of surgically affected sites (Nout et al., 2012). Motta et al. investigated the short-term and 1 year postoperative changes in the position of the condyles, rami and chin after mandibular advancement (Motta et al., 2010, 2011). Almeida et al. analyzed the soft tissue response to mandibular advancement (Almeida et al., 2011). Maal et al. assessed both hard and soft tissue volumetric changes at 1 year after mandibular advancement (Maal et al. 2012). Park et al. and Kim et al. recently used CBCT data to investigate the effect of bimaxillary orthognathic surgery on condylar head remodeling, the effect of fixation technique on intersegmental displacement after mandibular setback surgery and midfacial soft tissue and nasal changes after advancement of the maxilla (Kim et al., 2011, 2012; Park et al., 2012a, 2012b). Economopoulos et al. proposed a method to assess volumetric differences in particular areas of interest in the alveolar region (Economopoulos et al., 2012), whereas Ahmad et al. measured longitudinal mandibular bone remodeling under implant-retained overdentures 1 and 2 years post-treatment (Ahmad et al., 2013). We are not aware of any studies investigating morphological changes after malar augmentation using CBCT superimposition.

Facial onlay augmentation is often performed as an esthetic ancillary procedure simultaneously with orthognathic surgery due

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to the availability of surgical access to the malar, maxillary and mandibular areas without the need for additional incisions. Prominence at the malar areas is associated with a younger appearance and may delay the visible effects of facial aging (Hinderer, 1975). Since autogenous bone grafts demonstrate significant resorption over time (Maas et al., 1990) and osteotomies are associated with higher surgical morbidity (Zim, 2004), standard shape alloplastic implants have been most widely used to increase malar projection (Freihofer and Borstlap, 1989; Terino, 2005; Terino and Edwards, 2008). Approximately 10–12% of implants historically failed due to infection, incorrect implant size or position (Yaremchuk, 2008), whereas rigid fixation between the implant and the zygomatic bone appeared to be the most important factor for implant survivorship (Boutault et al., 1997).

Onlay augmentation with hydroxyapatite (HAp) granules or paste has been advocated to produce more predictable results and less complications than with solid implants (Byrd et al., 1993). Malleability, fast vascularization through the granules, and ability to acquire the shape of recipient bed eliminates the problem of postoperative movement that may be seen with solid implants. One of the few disadvantages of granules or custom made semi-solid moldable implants from granules is the unknown compaction and resorption rate. Using radiographic evidence, Mendelson et al. reported that porous HAp granules maintained contour projections at 2 years when used for augmentation of the facial skeleton in the esthetic patient (Mendelson et al., 2010).

We studied the short- and long-term volumetric change of a biphasic calcium phosphate (HAp/β-TCP)/collagen composite implanted into malar areas by means of surface-based CBCT superimposition.

## 2. Material and methods

The medical records as well as the pre and postoperative CBCT scans of 17 consecutive patients who underwent orthognathic surgery and onlay facial augmentation with on-site prepared implants were reviewed. The inclusion criterion was the presence of the full series of qualitative CBCT scans taken at five timepoints: 1 week preoperatively (T0), within 1 week after surgery (T1), 4 months after surgery (T2), between 9 and 12 months after surgery (T3), and between 18 and 24 months after surgery (T4). This study was retrospective and it did not influence the protocol of treatment. One preoperative and four postoperative CBCT scans in two years period were justified by low risk of modern CBCT scanners (the effective dose generated by the CBCT during extended FOV scan ranges from 82 to 182.1 μSv for the classic i-CAT, as compared to five-fold doses between 569 and 1073 μSv for standard CT) (Ludlow et al., 2006). The purpose of repetitive imaging is to monitor the precision of surgery (T1), bone healing process (T2), airways and orthodontics-induced condylar position (T3) as well as late condylar remodeling (T4).

All 17 patients met the inclusion criterion; however, four patients were excluded because the augmentation sites were other than malar areas. All scans had been performed on the iCAT machine (Imaging Science International, Hatfield, PA) with a $16 \times 22$ cm field of view and a voxel size of 0.3 mm.

### 2.1. Source of implantable materials

In this study, biphasic calcium phosphate (BCP) ceramic granules with a HAp/β-TCP ratio of 90/10 were used. Calcium deficient hydroxyapatite (CDHAp) was synthesized by an aqueous precipitation technique, where calcium hydroxide and phosphoric acid were used as raw materials following the reaction Ca(OH)2 + H3PO4 → Ca10-x(HPO4)x(PO4)6-x(OH)2-x + H2O. The filtered precipitates were formed into granules, dried and sintered at 1150 °C for 2 h. During the sintering process, CDHAp transformed into BCP ceramics with the HAp/β-TCP ratio of 90/10. Sintered granules between 0.5 and 1 mm were obtained using vibrational sieves and the sieved granules were washed in ethanol and dried in a drying oven at 105 °C for 24 h. Prior to application, the dried granules were sterilized using steam sterilization.

Referring to Fig. 1, after precipitation, the CDHAp particles (Fig. 1a) acquired a rod shape of 30–50 nm in diameter and 150–200 nm in length. The sintered BCP ceramic granules had an irregular form (Fig. 1b) with a grain size of approximately 500 nm and minor micro-porosity with a pore size of approximately 200 nm (Fig. 1c).

The X-ray diffraction pattern of the sintered BCP ceramics confirmed that two phases, HAp and β-TCP, were present in the sample with a mass ratio of 90 to 10 respectively. In the Fourier transform infrared (FT-IR) spectra, only the HAp and β-TCP characteristic absorption maximums can be seen indicating the absence of foreign phases.

The second component used for on-site preparation of implants was Avitene™ Microfibrillar Collagen Hemostat (Davol, A Bard Company, Warwick, RI, USA).

### 2.2. On-site preparation of implants

The implant materials were combined based on a modification of techniques described by Byrd et al. (Byrd et al., 1993) and Arnett GW (US patent 6506217 by G. William Arnett). HAp/β-TCP granules were moisturized with an adequate amount of saline solution and 1/3 g of Avitene™ Flour (MCH) was added. The mixture was demoisturized using manual pressure and then divided into six blocks. The blocks were tailored into cone shapes with sterile surgical instruments and heat-cured under a 150 W heating lamp for 60 min at a distance of 30 cm. Heat curing caused evaporation of water and enabled solid shape cones for surgical handling. Once ready, the implants were placed into subperiosteal pockets (Fig. 2). To secure them in place and avoid postsurgical wash out or displacement, the entry gates were closed by suturing the deep layer of soft tissues or trapping it to the bone with a screw and a ring fragment of an osteosynthesis plate.

In total, 25 surgical sites in thirteen patients were augmented: twelve patients had bilateral malar augmentation, whereas one patient had a unilateral procedure. According to the medical records, all surgical sites healed uneventfully. To enhance symmetry, patients were instructed to massage around the implantation sites starting 2 weeks after surgery. All surgical procedures were performed by the same consultant surgeon over a period of 13 month. The oblique view photographs of a selected patient before and after the procedure are presented in Fig. 3.

CBCT scans from the five timepoints were processed in identical manner. Each dataset was imported separately into SimPlant® 13.0 OMS (Materialise Dental, Leuven, Belgium). The segmentation of hard tissues was performed by setting the lower threshold between 300 and 350 units of gray level scale. The anatomical regions that were preserved during cropping were the full cranial base with orbits and the frontal and temporal bones. A 3D surface model of maximum quality was generated from the mask and the file was saved.

3D surface models were generated for all timepoints for all patient datasets. Surface models from all timepoints were imported into a single file in SimPlant OMS and each of postoperative 3D surface models was manually superimposed on the preoperative 3D surface model by placing 15 to 20 pairs of landmarks on corresponding well-defined anatomical structures. The landmarks were individually chosen for each pair of models using a visual search of high definition details present in both 3D surface models, most likely but not limited to the lateral aspect of frontozygomatic