3D-Analysis of soft Tissue Changes following Maxillary Distraction Osteogenesis

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Abbreviations

CT: computed tomography

DOG: distraction osteogenesis

Glossary

DOG: distraction osteogenesis is a rather novel method to lengthen bone and soft tissue. In conventional operations bone is divided, the surrounding soft tissue is stretched and a gap is created which might be filled with autologous harvested bone. In DOG the bone to be lengthened is fully or partially osteotomized and after a latency period of about four days, the two bony parts are slowly moved apart. Thus the soft bony regenerate is stretched and allowed to mineralize in the consolidation period after full lengthening has been achieved. Then the distractor is removed. This way, lengthening is possible without bone grafting and with minimal risk of necrosis or infection. Futhermore, the surrounding soft tissue is simultaneously expanded which is important in case of scarring or limited amount of tissue.

Hounsfield units: each pixel in CT imaging has ist own Hounsfield unit depending on the specific tissue density and is displayed in 12 bit grey scale. E. g. bone is displayed white (> 1200) and air in black.

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Abstract

Maxillary distraction osteogenesis is a new procedure in the treatment of severe maxillary hypoplasia and retrusion. By now most investigations have focused on questions regarding the procedure, bony changes, and dental occlusion . Therefore an investigation was started to look after the concomitant soft tissue changes associated with large bony maxillary advancements.
Methods: 20 patients were analyzed, most of them suffering from cleft lip and palate. Pre- and posttreatment CT scans were compared using a novel tool chain based on rigid and non-rigid registration. This tool chain allows to extract data for individual anatomical landmarks and displays changes in a colour pattern. Furthermore soft tissue and bony changes could be compared. In addition to time-series analysis, a 3D cephalometric tool is integrated into the tool chain which permits pre- and post-operative comparison to control groups. To assess precision of the tool chain, cadaver studies were carried out.
Results: Our novel tool chain permits an excellent overview over bony and soft tissue changes. Looking at the soft tissue after an average bony advancement of 8 mm in the malar prominence region, similar changes could be seen. Facial appearance was altered towards a harmonic relation. Cadaver studies showed that the tool chain works well within the limitations of the CT-data.

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In the treatment of severe maxillary and midfacial retrusion and hypoplasia, distraction osteogenesis (DOG) has evolved as the method of choice. DOG offers the unique option to lengthen bone and soft tissue almost unlimited and has opened new dimensions in orthognathic surgery. By now most investigations on maxillary DOG have focused on questions regarding technical aspects which device to use or how to perform DOG. Further stress has been laid on postoperative stability with respect to dental occlusion and some 2D cephalometric landmarks. By now, however, no investigations have been carried out with respect to 3D hard and soft tissue changes, which was the incentive for this work. With the aid of a novel tool chain for the 3D analysis, the relation between soft and hard tissue changes was to be investigated in a group of patients treated at the Leipzig University Department of Oral and Maxillofacial Plastic Surgery.

Methods

Patient Group

From 2002 to 2004, 20 patients were treated by way of maxillary DOG. 18 suffered from cleft lip and palate, age ranged from 10 to 63 yrs (Ø 24 yrs). In all cases an external, halo-frame based distractor and a miniplate system for bony anchorage were used (RED II and Leipzig Retention Plate; Martin Medizintechnik, Tuttlingen, Germany). After a subtotal modified quadrangular osteotomy, the distraction procedure started on the 4^{th} – 5^{th} day after surgery. Advancement was 1mm/day until an overcorrection of 15 – 20 % was achieved. The consolidation period lasted 4 – 8 weeks depending on age and dentition. Then the distractor was removed [1].

Time Series Analysis

All measurements performed were based on pre- and postoperative CT scans. Data acqusition at time point 1 was 3 – 5 weeks before surgery. Postoperative scanning was performed 2 – 4 weeks after removal of the distraction device. Scanning was performed on a Siemens Volume Zoom plus scanner. Slice thickness was 1 mm without overlapping. The data was transferred in DICOM format and all computation was performed on a conventional PC.

Analysis Software

The tool chain for 3D-analysis consists of two programs which were developed by G. Wollny. All programs run on LINUX platform and use the VISTA-format for data input. Therefore all data had to be converted first from DICOM into VISTA. The first program is a tool to assess 3D landmark coordinates of a given volume data set. The data is loaded and can be shown by way of volume rendering. Soft and hard tissue display is possible via adjusting a Hounsfield units slider. Futhermore, zooming, pan and rotate options can be performed with mouse buttons. After importing the data, a landmark table has to be created. Then, by simply clicking on the surface (bone or soft tissue, as adjusted) landmarks are located. X, y, and z coordinates are allocated to the landmarks which serve as the basis for the cephalometric analysis. For better performance, the position, zoom, and Hounsfield units of all landmarks are saved in the landmark table, thus when proceeding through the analysis on the next patient, the area of the subsequent landmarks is presented. Thus almost no zooming or rotating of the skull is necessary on the following data sets. Furthermore, snapshots of the landmarks can be taken to show the exact position of an ideal landmark (Figs. 1, 2).

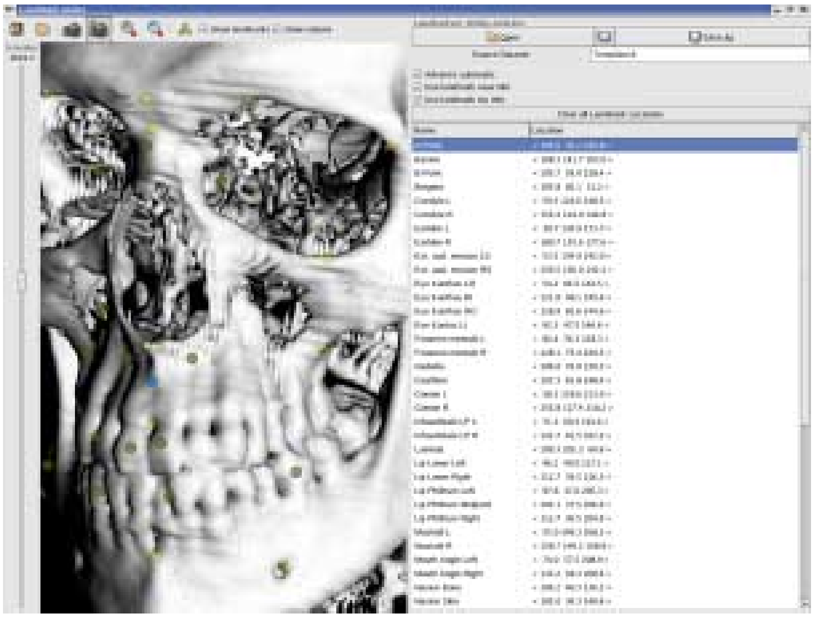

Fig. 1. Screenshot of the 3D cephalometric tool. Here the slider on the left has been adjusted to bone. Dots mark the landmarks seen in the table. The active landmark is highlighted. Changing the position is simply done ba a mousclick. The x, y, and z coordinates are displayed in the table and saved in a spreadsheet for further calculations.

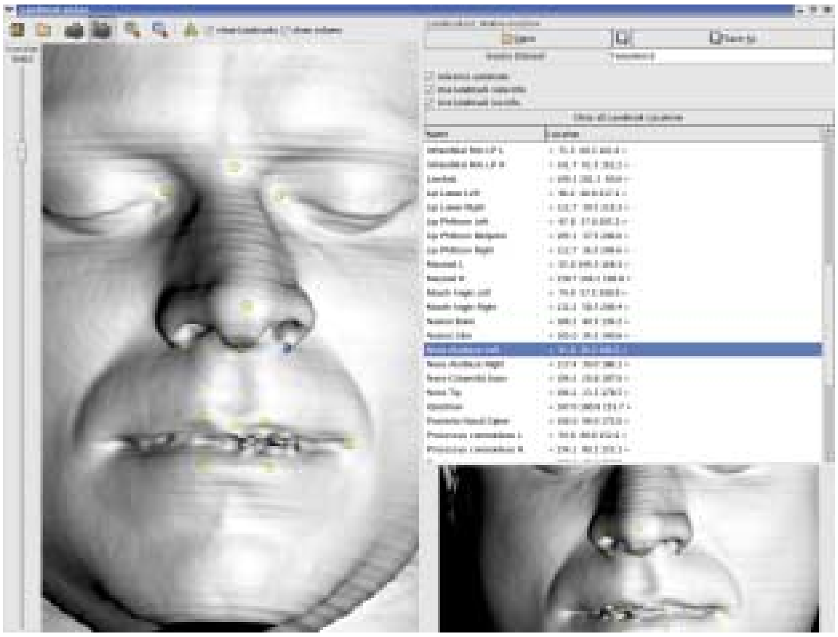

Fig. 2. Screenshot of the 3D cephalometric tool with soft tissue display. If required, the position of an „ideal" landmark can be demonstrated in the window below the landmark table.

The second program consists of a toolchain to segment, register and show the displacement of corresponding areas in pre- and postoperative CT-scans. First, both data sets are segmented using an intensity filter. According to the chosen Hounsfield units, bone or soft tissue changes will be analyzed. Next step is a linear registration of the the postoperative scan to the preoperative one to adjust position and head orientation. To quantify the structural changes of the skull, a non-linear registration based on a visco-elastic approach is performed last [2]. For visualizing the shape changes, two ways are implemented. After creating surfaces from the volume data, the deformation vectors are shown as arrows ending at the surface. Alternatively, deformation is displayed by a colouring scale. Here colour intensity reflects deformation magnitude (Figs. 3, 4). A more detailed description of the toolchain may be looked up in the literature [3].

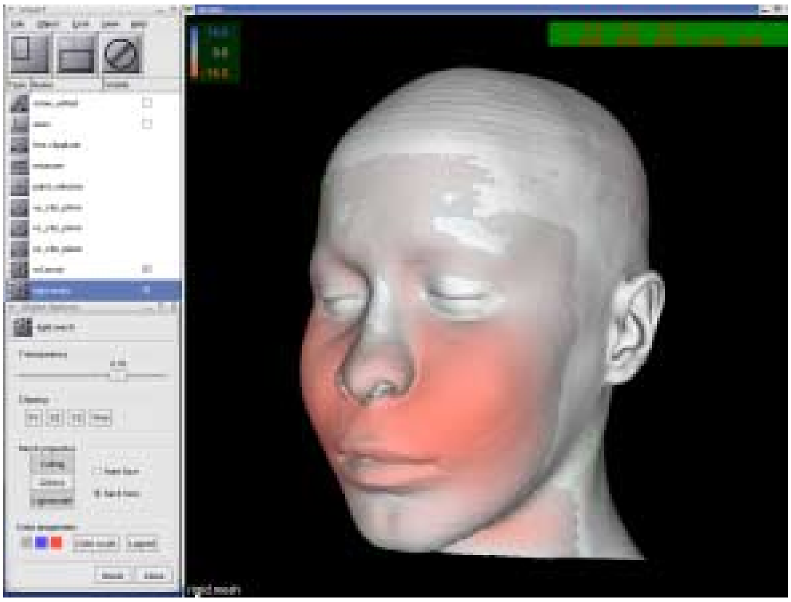

Fig. 3: Soft tissue changes in the midface of a 21-ys-old female patient. The relevant areas are colour-coded, colour intensity resembles the amount of displacement.

Fig. 4: Bony displacements in an 23-ys-old male patient. Colour-coded display of bony changes, furthermore the displacement vectors are shown. The movement in an anterior-kaudal direction is easily recognisable.

Study Protocol

To investigate the relationship between hard and soft tissue changes, pre- and postoperative CT-scans were evaluated in the following manner. First, pre- and posttreatment CT scans were registered (see above) and the displacement vectors of hard and soft tissue landmarks calculated. Therefore a limited number of easy to locate landmarks was chosen (Table 1). Landmarks, which proved to be difficult to locate were omitted [4]. By way of Wilcoxon test, the interdependence of soft and hard tissue changes was evaluated (program: PC-Medas, Fa. Grund, Margetshöchheim).

Furthermore, soft tissue thickness was measured on these bony landmarks directly using the landmark location tool. Here corresponding soft and hard tissue landmarks could be easily detected by just moving the Hounsfield unit slider. Then the distance could be computed. This data served as a control measurement for the displacement vectors as again pre- and post data were statistically compared with the Wilcoxon test.

Table 1: Anatomical landmarks used in this study

Landmark	**Definition**
Anterior nasal spine	most anterior point of the anterior nasal spine
Columella base	turning point of the columella and upper lip
Nasion (bone)	deepest point of the nasofrontal suture
Nasion (soft tissue)	point in the soft tissue concavity above the nasofrontal suture
Piriforme aperture left	most lateral-kaudal bony point of the left piriforme aperture
Piriforme aperture right	most lateral-kaudal bony point of the right piriforme aperture
Alar base (nose) left	soft tissue point of the most lateral-kaudal point of the nasal alar base left
Alar base (nose) right	soft tissue point of the most lateral-kaudal point of the nasal alar base right
Zygomatic prominence left	bony point of the zygoma, most anterior-lateral point left
Zygomatic prominence right	bony point of the zygoma, most anterior-lateral point right
Zygomatic prominence left (soft tissue)	soft tissue cheek prominence left
Zygomatic prominence right (soft tissue)	soft tissue cheek prominence right

As the novel toolchain had to be validated, cadaver studies were performed. First, micro titanium screws (1.5 mm) were implanted in five skulls in the position of medical cephalometric landmarks (Fig. 5). Then the distance could be measured with precision calipers and the skulls were scanned. Now these distances could be compared with those measured in the 3D-landmark tool. 162 distances were calculated that way.

Afterwards, maxillary osteotomies of the skulls were performed and the advanced maxillae were fixated with titanium miniplates. Now a second CT scan was acquisitioned and again, directly measured distances were compared with the displacements computed by the registration software. Now the maxillae were fixated in more advanced position and the procedure was repeated.

Fig.5: Validation study: CT scan of a cadaver specimen with titanium microscrews.

Results

The results of the validation studies showed, that the landmark location tool worked well with deviations ranging from 0.1 – 1.8 mm (mean deviation 0.7 mm) between directly measured and computed distances. Keeping in mind that slice thickness was 1 mm, these results proved excellent. Looking at the registration tool, deviations lay between 0.1 – 3.5 mm with a mean deviation of 1.3 mm (32 measurements of 162 showed deviations of 2.0 mm or more). As CT slice thickness was 1 mm differences up to 2 mm are withhin the accuracy of the scans. Thus the registration tool showed in over 80 % of the landmarks acceptable results. The crucial question is now, whether valid and invalid displacement vectors can be discerned. As starting and ending points of all vectors are located on the appropriate pre- and postoperative surface, a visual quality check is easy. Regarding displacement vectors of anatomical landmarks, erroneous vectors can be easily recognized.

Patient data analysis showed an average bony displacement in the piriforme aperture region (equals Le-Fort-I plane) of 8.1 mm with a soft tissue displacement of 8.0 mm. Regarding cheek prominence displacement distances lay at 8.6 mm (bone) and 8.3 mm (soft tissue). No statistical significant difference could be noted. Looking at directly measured soft tissue thickness, no significant difference between pre- and posttreatment data was seen, too (average soft tissue depth over bony landmarks ranged between 13 – 16 mm).

Figs. 6 and 7 show a typical displacement result. In all patients a clinically significant improvement in facial harmony was seen and posttreatment 2-dimensional cephalometric data showed „normal“ values [5]. A typical pre- and posttherapeutical situation is given in Fig. 8.

Fig. 6: Pre-post comparison of soft tissue changes in another study patient. The postoperative situation is shown on the right, whereas the left side resembles the preoperative appearance. Areas of change are colour coded, displacement vectors are visible.

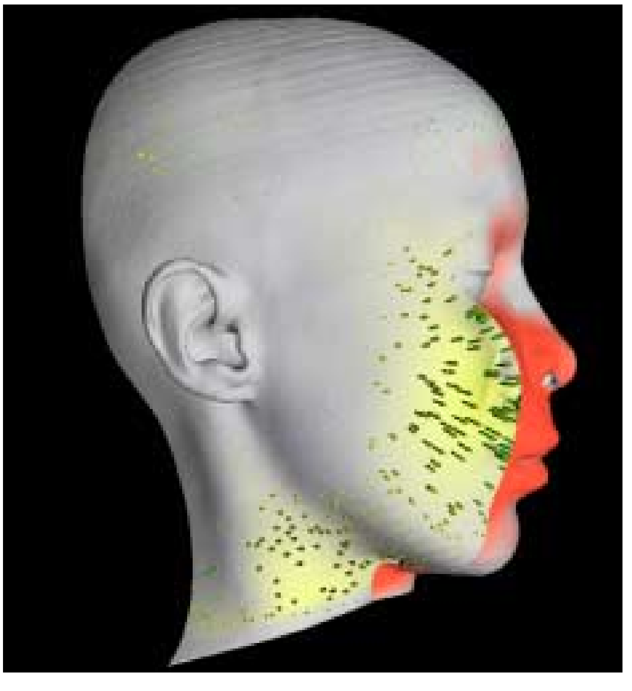

Fig. 7: Soft tissue analysis of the patient seen in Fig. 3. Colour-coded display with vectors.

Fig. 8: Pre- and posttreatment clinical situation of a 21-ys-old female (cf. Fig. 3). Marked midfacial hypoplasia and unilateral cleft lip and palate preoperatively. On the right the posttreatment situation is given.

Discussion and Conclusion

We present a novel tool chain to evaluate 3D changes of hard and soft tissue. By now most studies working with 3D data have focused on soft tissue, aquisitioned with surface scanning or CT analysis [6 – 11]. Simultaneous 3D evaluations of soft and hard tissue are not known to have been performed so far to our knowledge.

The novel tool chain proved to lead to clinically acceptable results. The landmark location tool worked accurate, whereas 20 % of the registration tool landmark data was clinically inacceptable. Reasons for that are not known but may lie in specific geometry problems of the intricate bony structure of the human skull. Therefore, until the reasons for these mistakes have been found, a second method to evaluated the data has to be performed like in this study. On the other hand, this is the first software to our knowledge which allows time series analysis of CT data in 3D. By showing changes graphically and giving the displacement vectors, the impact of surgical therapies can be evaluated quickly. Furthermore the software works on normal PCs at the clinicians desktop and needs no special knowledge in programming, a point which is extremly important in our opinion.

In our patient group, the analysis of the results is extremely important. Besides correcting dental occlusion, a „perfect“ look is the main goal in correcting dentofacial deformities. The problem is, however, that surgery is planned on the underlying bony structures and concomitant soft tissue changes are solely expected if the bony deformity is corrected. Here the results help to define the level of osteotomy (where has the bone to be cut to lead to soft tissue changes) and the amount of hard tissue displacement needed for soft tissue changes. In this study similar displacements of soft and hard tissue in the esthetically important cheek area were found. This implies that osteotomy lines can be planned according to the preoperative soft tissue situation.

Of course, further investigations are needed to evaluate long-term results which will be affected be remodeling and aging. Here surface scanning is thought to be the method of choice and will be performed in regular instances. Therefore our analysis software will be adapted to that data format.

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