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Quantitative Bewertung der Simulationsgüte einer 3D Weichgewebeprädiktion für die Operationsplanung in der Gesichtschirurgie

A quantitative evaluation of 3D soft tissue prediction in maxillofacial surgery planning

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This abstract is preliminary - a full length paper will be submitted!

PURPOSE

For the surgical correction of complex dysmorphisms in the cranio-maxillofacial region, 3D planning techniques on basis of CT-data are undoubtly the method of choice. Besides the functional reconstruction the surgical aim is an optimal aesthetic rehabilitation. For that reason preoperative planning with reliable 3D soft tissue prediction is a highly desired feature of a 3D planning system for CMF surgery.

We present a clinical case in maxillofacial surgery, where a congenital hypoplasia of the midface is to be treated.
A 3D osteotomy planning on a polygonal skull model for three different types of osteotomies has been performed, and the different implications of bone relocation on the facial soft tissue have been assessed via Finite-Element approximation of the spatial tissue deformation.

The main part of the work is the quantitative assessment of the simulation quality of the tissue prediction by comparison with postoperative CT data. With the help of this comparison, appropriate material properties for the biomechanic simulation can be selected and evaluated.

METHODS

For an 18 year old male patient with distinct midfacial hypoplasia and class III dysgnathia a midfacial distraction osteogenesis was to be performed.

The approximate maxillary advancement was 13 mm. However, three possible alternatives for the designated Le Fort-I osteotomy were under consideration: 1) a conventional, 2) a high or 3) a modified quadrangular osteotomy acc. to Stoelinga. Since a maxillary advancement always accentuates the cheek regions and leads to a more or less conspicuous nasal alar flaring due to the compression of the nasal soft tissue, it was not clear from the aesthetic point of view which one leads to the most pleasing facial appearance.

The different osteotomies were planned and the mobilized maxilla has been advanced under collision control to achieve optimal dental occlusion. A preoperative soft tissue prediction via finite-element analysis has been performed to assess the impact of the relocated bony structures to the surrounding facial tissue. For the therapy a high Le Fort-I osteotomy has been chosen. The proposed advancement was about 12.5 mm, and due to bone remodeling and relapse an overdistraction of approx. 3 mm has been performed.

Two weeks after the removal of the retention system another CT scan has been acquired. For both scans the same imaging system with equally chosen scan parameters was used. We performed a grey value registration for the two data sets first, then the model was reconstructed in the same way as we did with the preoperative data, and finally we registered the two models with an ICP surface alignment algorithm, but only for those parts that were not affected by the surgical intervention. Afterwards we tried to mimic the osteotomy on our preoperatively generated skull model in accordance with the postoperative result and put the mobilized maxilla into the same position as found in the postoperative data.

The impact of the advancement of the maxilla on the facial tissue has been simulated according to the postoperative situation in the same way as we did for the preoperative planning. The resulting skin surface has finally been compared to the skin surface of the postoperative data set for the assessment of the simulation accuracy.

RESULTS

The simulation has been performed for a homogeneous tissue volume to determine the most suited value for the Poisson ratio of soft tissue. Afterwards the simulation has been repeated taking an inhomogeneous tissue volume into account, that consists of connective

tissue and muscle. To retrieve values for the Poisson ratio as well as Young.s modulus, a large series of simulations has been conducted for the determination of an optimal combination of the material properties with regard to the deviation between the simulated and the postoperative skin surface.

The two-sided Hausdorff distance between the actual postoperative result and our simulations finally lead to a mean value of approx. 1.00 mm with a standard deviation of 0.95 mm and an rms of 1.43 mm. For approx. 35% of the surface the deviation between simulation and postoperative outcome was below 0.5 mm (62% below 1 mm, 85% below 2 mm, and only 4.5% above 3 mm). For the facial region of interest the mean prediction error was in the range of 1.3 to 1.5 mm, depending on the choice of the histomechanical parameters.

CONCLUSION

We have shown that facial tissue prediction for 3D osteotomy planning with bone relocation leads to plausible results. We found a satisfying correspondance between our volumetric FE-simulation and the real postoperative outcome. The possibility to reliably assess an osteotomy not only with respect to bone symmetry and function but also to the facial tissue deformation makes such a computer assisted planning aid valuable for complex cases in cranio-maxillofacial surgery.