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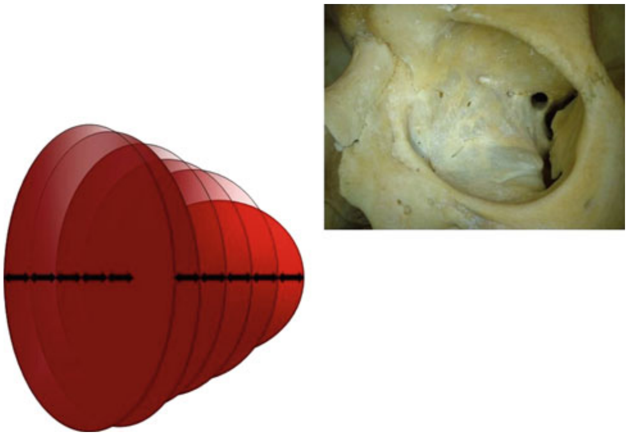

Fig. 2 Slices were made at 4.8 mm intervals in the ventrodorsal direction in the frontal plane

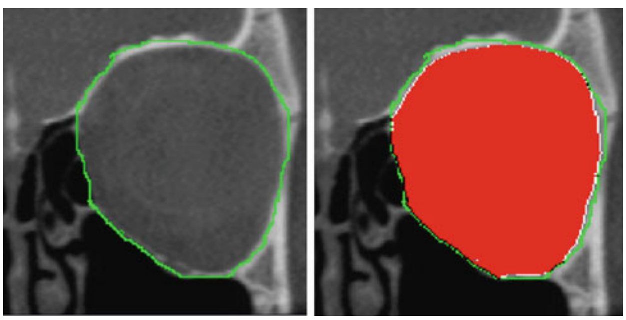

Fig. 3 The bony orbital border is marked by a *green line*, than the program automatically colours the area *red* and measures it in mm^2

preferred for routine soft tissue visualization on spiral CT because of the increased noise with thinner slices [1]. CBCT has a number of advantages comparing to conventional CT. The i-CATTM cone beam provides unprecedented imaging of the maxillofacial area with less radiation than with that of traditional fan beam CT systems [2]. In spite of all this there has been no appropriate method available for exact measurement of the bony orbital volume so far, which would be of particular importance in orbital injury reconstruction. However, the use of CBCT scans and Cranioviewer orbital program software appear to offer a reliable method for the measurement of changes in orbital volume. In our research it became evident, that the comparison of the area of the analogue frontal levels gives more accurate details of the changes in the morphology of the bony orbit than evaluating the orbits as a unified volume.

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Role of the temporomandibular joint for macroscopic biomechanics of the human mandible: a finite element study

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Purpose

Based on the mechanical adaptation of bone, finite element simulation of mammalian skeletal organs valuably contributes to a better understanding of pathologies in this field. Nevertheless, there are still plenty of open questions subject to ongoing research, e.g. the realization of joints.

Inter alia due to its 6° of freedom, the temporomandibular joint (TMJ) is one of the most complex joints within the human body. Notably, about 20 % of the population suffer from often painful and long lasting temporomandibular disorders (TMD). Within this context, the question arises how the condition of the TMJ influences the human jaw and, one step further, how this influence is altered for the case of (1) various TMD and (2) mandibular pathologies as partial loss of dentition or atrophy. Therefore, within a detailed research project about mandibular biomechanics, the influence of the TMJ on the load carrying behavior of the human mandible has been considered.

The objectives of this contribution are, firstly, a modeling strategy for the realization of the TMJ within mandibular finite element analysis (FEA) and secondly, a sensitivity analysis concerning this strategy with special regard to pathological cases.

Methods

The highly differentiated anatomy of the TMJ consists of the joint capsule with the articular disc, several ligaments, and the retrocondylar tissue between the mandibular condyle and the temporomandibular fossa (Fig. 1, left). For mandibular FEA, the mechanical guidance by the TMJ is a boundary condition which means that its influence on the mandible is exerted via the contact surface. Thereby, the complicated inner formation of the TMJ—notably highly anisotropic and nonlinear—is only of indirect relevance.

Biomechanical simulation of skeletal organs is often based on computer tomography (CT) with reduced soft tissue contrast. Therefore, the modeling strategy is structured in two parts, (1) a refined derivation based on individual reconstruction, and (2) a generalization applicable to routine simulation.

For part I, we referred to CT data with acceptable soft tissue contrast and resolution. After application of special image processing, visualization of the TMJ capsule by direct volume rendering was possible for anatomical orientation. Thereon based, the joint capsule, the lateral ligament, and the lateral pterygoid muscle could be segmented and reconstructed in 3D (Fig. 1, middle). Inter alia with regard to the special attachment of the lateral pterygoid muscle to the articular capsule and disc, this model is by far too complex to be directly transferred to FEA of the entire mandible. Therefore, the capsule was simplified mimicking its original coverage of the

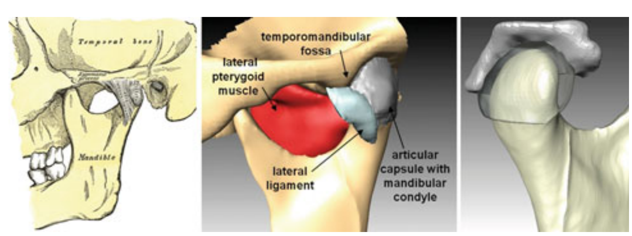

Fig. 1 Anatomy of the TMJ (*left*), refined 3D-model (*middle*), simplified capsule with part of the skull (*right*)

condyle, but without ligaments, disc, and the special attachment to the lateral pterygoid muscle. As the role of the TMJ within mandibular FEA is a boundary condition, stress and strain within the capsule are not subject of this study. Therefore, the simplified capsule was modeled as isotropic and linear with some substitute Young's modulus and Poisson ratio. The capsule's attachment to the skull was modeled by (partial) rigid attachment. The mandibular condyle and the capsule were in direct bond whereby the condyle was somehow freely mobile within the capsule mimicking the six degrees of freedom (Fig. 1, right).

For standard simulation, this individual strategy was generalized especially for reduction of modeling efforts (part II). After segmentation of the mandible, this segmentation was enlarged by about 5–7 pixels (with the mandibular segmentation locked) and cut so that only the condylar head was covered. After freeing the frontal part of the condyle for the attachment of the lateral pterygoid muscle, the additional segmentation was smoothed and reconstructed in 3D. The result is equivalent to the one of the individual strategy.

The simplified capsule could be successfully added to mandibular FEA. The modeling strategy was subjected to a sensitivity analysis with regard to (a) the capsule's shape, (b) its attachment to the skull, (c) capsular Young's Modulus, and (d) Poisson ratio. Based on micromechanical considerations, we chose the volumetric strain as indicator variable. We tested physiological biting on selected teeth with focus on pathological cases with beginning atrophy, so kind of "symmetric" case, partially edentulous and atrophic at both sides, and an "asymmetric" one with severe atrophy at one side and some residual dentition at the other one.

Results

The strategy could be successfully implemented with acceptable efforts. The sensitivity analysis revealed that a too "small" capsule, so not covering the full condylar head, produces high unphysiological strain at the condyles. A "too small" or "too large" attachment of the capsule to the skull, highly exceeding or undergoing the anatomical reality, also results in unrealistic strain profiles. The choice of capsular elastic variables showed very high quantitative influence (Fig. 2). The high compressive strain at the alveolar corpus, which we found as typical for atrophic mandibles, decreased monotonically, but non-linearly with increasing capsular Young's modulus. The same is true for increasing Poisson ratio. Interestingly, the effect on physiological loading at the mandibular incisura and ramus was non-monotonic. We found some "optimal" capsular Young's modulus of about 5 MPa where the strain profile best resembled physiological loading known from previous studies. The FEA of the case characterized by asymmetric pathology revealed that even partial dentition seemed to protect the mandible from unphysiological loading.

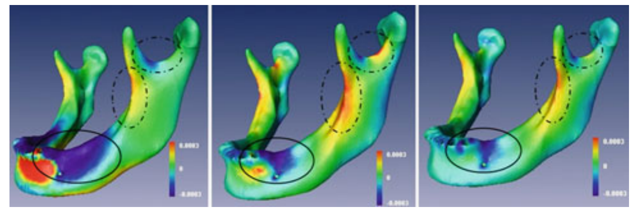

Fig. 2 Volumetric strain due to a lateral bite, capsular Young's modulus 0.1 MPa (left), 5 MPa (*middle*), and 50 MPa (*right*), *bold circles* indicate monotonically decreasing unphysiological compressive strain, *dashed circle*s indicate non-monotonic physiological loading

Conclusion

A modeling strategy for realization of the TMJ within mandibular FEA was presented and tested by a sensitivity analysis. The observed high influence of the TMJ is in agreement with clinical observations that alterations of the TMJ affect the entire jaw. The endorsement of this inter-dependence by the presence of mandibular pathologies as atrophy of the alveolar corpus, see the high unphysiological compressive strain there, indicates a vise versa stimulating procedure, whereas, on the other hand, even partial dentition contributes to protection of the mandible from unphysiological loading.

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