7.5. Biomechanical Problems in the Dental Area

5054 Fr, 11:00-11:15 (P51)

Experimental and numerical investigation of the biomechanical behaviour of multi-rooted teeth with respect to headgear traction in a pig experiment

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Introduction: The biomechanical behaviour of molars with different stages of eruption has crucial influence on the performance of a headgear treatment in orthodontic patients. It was the goal of this study to experimentally and theoretically analyse the mobility of multi-rooted teeth in an animal model.
Material and Methods: The biomechanical set-up Hexapod Measurement System (HexMeS) was used for experimentation. The second and third premolars of fresh pig jaw segments were chosen, as these are equivalent to the human molars M1 and M2. The premolars were selected with five different stages of eruption. After measurement of the force/deflection characteristics with forces up to 15 N, 3D surface models were constructed from histological cuts or CT scans with the own developed programme ADOR-3D. The reconstruction of the jaw segment as an FE surface model contained the second and the third premolars, periodontal ligament (PDL), bone, the molar tube on M1 and headgear application. Subsequently, theoretical load/deflection curves were fitted to the experimental behaviour by varying the Young's modulus of the PDL, in order to determine the mechanical properties of the PDL. The calculations were performed with the FE package MSC.Marc/Mentat.
Results: The experimental results confirmed the clinical experience that the distal translation of the first molar after headgear force application is highest if the second molar is present as a germ or only half erupted. Maximum displacements reached values of up to 0.25 mm, maximum distal rotation was up to 1.5 degrees. With respect to the displacements, the FE results were in good accordance with experimental results. Maximum strains in the PDL reached about 0.1, stresses in the PDL were about 0.13 MPa, in the bone 0.01 MPa.
Conclusions: The results of the pig experiments are in good correlation with clinical experience. With the force systems applied, the tooth socket seems to be loaded above the physiologic limit.
This study was supported by German Israel Foundation.

4529 Fr, 11:15-11:30 (P51)

The duration of the viscoelastic PDL response due to orthodontic tipping

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The periodontal ligament (PDL) is a soft connective tissue that secures the tooth cementum to the alveolar bone. The PDL demonstrates viscoelastic characteristics typical to soft biological tissues. However, there is lack of information regarding the duration of the viscous behavior. Physiologically, teeth are heavily loaded for short durations as opposed to orthodontic treatment where long-term low forces are applied. In both cases, initial tooth movement occurs due to deformation of the PDL. Over time, like in orthodontic treatment, the applied force system constitutes biological responses that govern remodeling processes that eventually allow tooth displacement. Thus, it is expected that during orthodontic tipping, short-term tooth movement will be characterized by PDL creep response; however, the duration of this response was not investigated. We hypothesized that during orthodontic tipping in humans, creep response of the PDL stabilizes during a time-course of minutes. The objective was to develop a computational model to determine the short-term tooth movement during orthodontic tipping. Viscoelastic mechanical behavior of human PDL previously measured *in vivo* [1] was utilized to develop a mathematical model describing tooth movement due to PDL relaxation response. Fitted model parameters were used to derive a computational model which simulates short-term tooth movement caused by tipping. The time-dependent-PDL response as affected by force (0.5–3 N) and tooth-crown length (6–10 mm), i.e. magnitude and location of the applied tipping force, was studied. The results showed that initial tooth movement, governed by PDL creep response, is stabilized in a short time, ~2.25–7.5 minutes, and consequently the hypothesis was verified. This finding should be taken under consideration in numerical models such as finite element models.

References

[1] Brosh, T., Machol, I.H., Vardimon, A.D. Deformation/recovery cycle of the PDL in human teeth with single or dual CP. Archives of Oral Biology 2002; 47: 25–92.

4740 Fr, 11:30-11:45 (P51)

Complete characterization of oral occlusion loads acting in a human molar

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Many results can be found in the specialized literature concerning measurements of oral forces. The authors often propose to determine the maximum occlusion (biting) load acting in the direction normal to the occlusal surface of a tooth. This work treats biting force as a complex dynamic phenomenon that demands more parameters to be fully determined and understood. There are components of the occlusion load in the directions normal and tangential to the tooth's crown, components of the resultant oral force that varies throughout the biting period. The aim of this work is to determine the resultant oral force vector acting on a first molar, in each instant of the biting period, using a force transducer designed and built for this purpose. This transducer was a load cell equipped with strain gauges and able to provide sufficient data to calculate the resultant oral force. This cell was implanted as prosthesis in a spot in a patient's mouth with a flawed dentition; and therefore carried out the functions of the missing tooth and registered the exerted forces during occlusion. Results were obtained that depicted the evolution of the resultant force in each instant of occlusion, including its direction and modulus. Peak resultant forces of 142 N, 115 N, 101 N were obtained, corresponding to pairs of normal and tangential components of 135 N and 44 N; 111 N and 31 N; 84 N and 56 N; respectively.

7436 Fr, 11:45-12:00 (P51)

Custom suprastructures for immediately loaded, implant-supported dental prostheses

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As part of a research project on immediate loading of implants, a pilot study was performed on ten patients treated with a protocol where the final prosthesis is installed 12 hours after implant placement. The suprastructure then needs to be prepared in advance of the implant placement, making customisation more difficult. A procedure for designing and producing customised suprastructures was developed. Based on computerized treatment plans, different software designs were made for customised metal frameworks of the respective prostheses. Because of foreseen deviations between planned and executed implant positions, the designs allowed compensation for lateral misalignments (0–0.8 mm). Design of the frameworks was based on the diagnostic set-ups as manufactured by the dental lab and visible in CT images as radiopaque scan prostheses.
Alternatively, first generation routines were developed to generate the diagnostic set-up directly in the digital environment. The applicability of the routines hitherto has been limited to fully edentulous upper jaw cases, where anatomical landmarks are used to determine the positions of the virtual restorative elements.
The outer surface of each restorative element (i.e. tooth) was offset inward over 1 to 2 mm to account for the porcelain layer, which is typically applied upon finishing of the prosthesis and provides its aesthetic appearance. After the design, the frameworks were manufactured in nylon using Selective Laser Sintering and duplicated by a process similar to the lost wax casting technique, to yield the final metal suprastructure. Custom-made surgical templates (SurgiGuides™) were manufactured to assist the surgeon during the intervention in placing the four implants/jaw (Osseospeed®, Astra Tech, Mölndal, Sweden) as accurately as possible in accordance to the planning. After an average follow-up of 6 months, half of the patients were screened by Periotest®, Osstell® and digital radiography. No implant failures were reported and marginal bone levels were stable.
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6664 Fr, 12:00-12:15 (P51)

Finite element analysis of a fibre reinforced anatomical post compound for endodontic treatments

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In endodontics essentially two types of post-and-core systems are available: cast metal posts and prefabricated posts. Although these latter are widely

employed as require a modest preparatory work, their use can result critical if the treated root cavity is large and irregular and therefore it can not be efficiently filled with a single prefabricated post and a large amount of filling cement is necessary. In these cases, the intimate contact between the dental canal and post system can be obtained only by using anatomical posts customized to the profile of the residual healthy tissue. For these reasons, cast metal posts are often considered as the most suitable solution. However, their use requires a great preparatory work and may lead to root fractures because of large stress concentrations. Accordingly, the best solution appears to be the use of anatomical post systems made of materials with elastic properties very close to those of the natural tooth and able to reduce in-homogeneities and imperfections during material setting. Moreover, in order to increase the restoration's durability, the proposed anatomical post system is reinforced with multiple prefabricated posts, in order to reduce the volumes which can lead to contraction phenomena and to increase the restored-tooth bearing capacity.
The statical behaviour of the proposed restoration technique is analyzed through three-dimensional finite-element analyses, performed on a human upper premolar under several masticatory loading conditions. The non-linear behaviour of the periodontal ligament is taken into account through a discretized non-linear model, which is consistent with the experimental data available in literature. The influence of the post system materials and of the number and the dimension of the reinforcement posts is investigated, highlighting that the reinforced anatomical composite restoration allows to reduce significantly stresses inside the residual dentinal regions in comparison with other classical techniques.

5584 Fr, 12:15-12:30 (P51)

Joint forces in a mandible with unilateral hypoplasia before and after mandibular distraction osteogenesis: a simulation study using a patient-specific musculo-skeletal model

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The goal of this study was to estimate the reaction forces in the temporomandibular joints (TMJ) before and after distraction osteogenesis (DO) for different load cases using a patient-specific musculoskeletal model of the mandible based on inverse dynamics. The muscle recruitment problem was solved with a min-max optimizer. In the present work only one load case will be considered.
A three-dimensional musculo-skeletal model of a mandible with unilateral hypoplasia of the right ramus was built using the AnyBody Modeling System (AnyBody Technology A/S, Aalborg, Denmark). The model was based on CT-scans of a single patient who suffered from juvenile idiopathic arthritis. The model was equipped with 24 Hill-type musculotendon actuators controlling the mandible. The peak isometric forces of the masseter, medial pterygoid, and lateral pterygoid on the right, affected side were 7, 3 and 6 percent weaker, respectively, compared to the non-affected side.
In two simulations the TMJ reaction forces were estimated before and after DO for a clenching force of 191 N between the central incisors. Before DO the estimated TMJ reaction force was 139 N on the affected side and 173 N on the non-affected side. The patient's affected ramus had been lengthened by 15 mm using unidirectional intraoral distraction osteogenesis, which subsequently was mimicked in the model. This resulted in a more evenly distributed TMJ reaction forces of 129 N for the affected side and 139 N for the non-affected side for the same clenching force between the central incisors.
With the model it was possible to evaluate and indeed quantify the consequences of DO on the TMJ reaction forces as demonstrated here. This opens the possibility to analyse both the existing (pre-treatment) situation and the projected post-treatment situation. The effects of different DO directions can in this way also be easily assessed. However, a prerequisite for clinical use is development of methods to make patient-specific models more efficiently.

Track 8

Computer-Assisted Surgery

8.1. Surgical Planning, Modeling and Simulation

5090 Th, 08:15-08:30 (P38)

Maxillo-facial surgery simulation with a simple patient specific material model

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The Finite Element method is a very powerful tool for the simulation of biomechanical processes. Therefore it can be used to predict the outcome of maxillo-facial surgeries, such as distraction osteogenesis. During this treatment the surgeon cuts free the upper jaw (maxilla), which is then relocated into a new position with a pulling device in the course of several weeks. Our simulation tool is set up to predict the displacements of the facial tissues during and after the pulling process and is based on individual CT images of the patient's head before treatment. Its purpose is to support the surgeon in optimizing the treatment plan and avoiding additional post operative plastic surgeries.
The presentation starts with a brief description of the set of computational tools that lead from a CT of the patient's head to the employed Finite Element discretization schemes and non-linear solvers. The complexity of the resulting computational models will show the necessity for the use of high-performance computing resources for the simulations.
In a second part, we will focus on the used material laws and the specific material parameters therein. We will show, that in order to get accurate and reliable predictions of the resulting displacements of the different tissues of the patient's head, it is crucial to find patient specific material parameters.
In order to keep the effort for the parameter estimation for the medical user as small as possible, we employed a simple visco-elastic model (i.e. a Maxwell-fluid model) with only one free parameter for the soft tissues of the human head.
We will show how a validation process for our model, based on pre- post-operative CTs of various patients, was used to model this patient specific parameter. To our best knowledge such a validation has not been done before, and our first results will conclude the presentation.

7011 Th, 08:30-08:45 (P38)

Investigation of the gravity-induced brain shift using a three-dimensional FE model of the human brain

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The use of computer assisted surgery (CAS) in modern-day neurosurgery has greatly improved the ability of the surgeon to navigate more accurately during brain surgery, resulting in better surgical outcomes. Among many interrelated factors, the overall accuracy of a CAS system is influenced by the accuracy of the system itself, the quality of the imaging modality, and the reliability of registration processes. While technical advances have enhanced the accuracy of neuronavigation systems, imaging systems and registration processes, and certain intrinsic errors cannot be avoided because existing CAS systems assume that a patient's head and brain do not deform throughout the surgery. Although a specially designed intraoperative magnetic imaging (IMRI) system can be used to ascertain the amount of brain shift, such a system is very expensive and not useful when conducting pre-surgical planning. Thus, a numerical model capable of predicting brain shift is a valuable supplemental tool for CAS systems. A three-dimensional (3D) finite element (FE) model of the human brain, including a detailed representation of the scalp, skull, dura, falx, tentorium, pia, cerebral spinal fluid (CSF), venal sinuses, left and right ventricles, cerebrum (gray and white matter), cerebellum, and brain stem, has been developed in order to predict gravity induced brain shift.
Most of the brain shift is induced by gravity after craniotomy and the subsequent drainage of the CSF. Gravity causes brain tissues to move into the space created by CSF drainage. Additionally, material properties of the brain and brain tumors, and the size and type of the tumors (low and high grade tumors) can play an important role in gravity-induced brain shift during surgery. A parametric study was conducted to determine the effect of these properties on gravity-induced brain shift, using a 3D FE model of the human brain. Results from this parametric study indicate that the magnitude of brain shift varied significantly due to a combination of changes in the shear and bulk modulus of the brain. However, material properties of brain tumors and their size and type did not significantly affect brain shift.