The role of computer simulation methods in avoiding orthodontic malpractice

Cristina Bica¹, Diana Bulgaru Iliescu², Dorin Bica³, Gheorghe G. Bălan²*, Adriana Bălan⁴, Monica Monea¹

Abstract: Before the beginning of any dental treatment, the patients or their legal representatives should be completely informed about the medical procedures and potential risks and sign an informed consent. In dentistry, orthodontics is unique, as it usually extends over a long period of time and can generate disagreements with the patients based on esthetic or functional results. Therefore, the knowledge of abnormal accumulation of stress induced by an orthodontic force of excessive intensity, allows the intervention with timely therapeutic methods to avoid the iatrogenic effects. The aim of this paper is to present the use of computer-aided simulation technique, the Finite Element Method, in the evaluation of real biological phenomena specific to orthodontic treatment. We simulated the use of orthodontic forces 5 times higher than normal and studied their iatrogenic effects on the dental supporting tissues. The results showed that computer simulations can be used with considerable success in all clinical orthodontic patients, increasing their confidence in the proposed treatment plan, providing an ethical support for the dentist and a positive feedback on patient responses. The maximum stress distribution with iatrogenic effect on dental and periodontal anatomical structures has been emphasized. In conclusion, the transposition of clinical reality through the computer simulation requires continuous development of the IT systems in this field and opens new research directions and applicability regarding the iatrogenic effects of orthodontic forces.

Key Words: dental malpractice, professional liability, orthodontics, Finite Element Method.

Specialists in dental medicine had known a long period of litigation-free practice but this environment has been slowly changing and clinicians need to become aware of the issues that might lead to litigation. Due to an increasing number of legal cases against dentists, they should improve their knowledge of legal and ethical characteristics of this profession [1]. In the dental practice, the most important principle in risk management is represented by anticipation and avoidance, meaning that clinicians should take all steps in order to prevent any situation that could lead to a conflict with the patient or even a lawsuit. Among dental health care clinicians, the orthodontists are focused on correcting functions as mastication, phonation, breathing, swallowing and especially physiognomy, which determines the patient's smile and facial balance [2]. During this process they are subjected to constraint and pressure due to their patients’ strong desire to achieve aesthetic improvement in a very short time, despite iatrogenic side effects, that poses important ethic issues regarding the treatment decisions. In accordance with the Law 1995/2006 [3] there is a requirement to have a written agreement given by the physician after a thorough explanation of these procedures, signed by the patient prior to any procedure of prevention, diagnostic and treatment that might represent a potential risk to the patient. The duty of the orthodontist is therefore to fully inform the patients or their legal representatives from

1) University of Medicine and Pharmacy of Tîrgu Mureș, Faculty of Dental Medicine, Tîrgu Mureș, Romania
2) "Gr. T. Popa" University of Medicine and Pharmacy of Iași, Faculty of Medicine, Iași, Romania
* Corresponding author: 9 Sulfinei street, 700456, Iași, Romania, Email: balan.gheo@yahoo.com
3) "Petru Maior" University of Tîrgu Mureș, Engineering and Computers Department, Tîrgu Mureș, Romania
4) "Gr. T. Popa" University of Medicine and Pharmacy of Iași, Faculty of Dental Medicine, Iași, Romania
the beginning about the type of treatment, duration in time, the use of orthodontic forces reduced in intensity in order to obtain slow but stable results [4, 5].

The analysis of the reactions occurring during orthodontic tooth movements has been the object of numerous human clinical trials and experimental animals, without reaching a conclusion unanimously accepted, in order to recommend an optimal value of the force capable of producing maximum efficiency in clinical orthodontics. The optimal force, preferred for the tooth movement in modern orthodontics, is the force that does not produce an abnormal accumulation of stress in the periodontal tissues [4-6]. The orthodontist knowledge of abnormal accumulation of stress induced by an orthodontic force of excessive intensity, allows the intervention with timely therapeutic methods to avoid the iatrogenic effects [7]. There are a number of information systems specialized in simulation and analysis; among these, the Finite Element Method (FEM) is considered a convenient technique for the computer solution of health problems in different fields of medicine, including orthodontics, allowing for a highly accurate identification of the structural stress [8].

The aim of this paper is to approach the effects of orthodontic forces on the periodontal supporting structures based on FEM and to open a new direction of research into the problem of using information systems in dental medicine. Our interest in this subject is due to continued growth in the number of adults seeking orthodontic treatment, exposing themselves to iatrogenic effects with serious consequences to their dental health.

MATERIAL AND METHODS

The FEM analysis was carried out at the Department of Electrical Engineering and Computers in “Petru Maior” University of Tîrgu Mureș. For our study we used the Autodesk Simulation, a multipurpose finite element analysis software developed by ALGOR Incorporated in 2009, intended for application with Microsoft Windows. The definition and the creation of the model for a central upper incisor using the ALGOR analysing program consisted of the editing and constructing the tooth and the surrounding structures (periodontal space and alveolar bone) according to morphological and anatomical data. We obtained a tridimensional image of the tooth by creating a model with 1379 nodes and 976 finite elements. Initially, two clinical situations that are frequently seen in orthodontic practice were selected: the application of a mild force on healthy periodontal tissues that occur normally in children and the use of similar forces on teeth with affected periodontal support, a situation observed more frequent in adult patients. A third situation was represented by the use of an excessive force applied on teeth with healthy supportive structures.

RESULTS

The application of orthodontic forces at the same spot on the surface of a tooth, with variable intensity that ranges between 1 Newton (N) considered optimal to five times higher, shows the consequences of orthodontic forces and the induced iatrogenic effects on the periodontal supporting structures. The results are presented in Figs 1-3 and Table 1.

<table>
<thead>
<tr>
<th>Force intensity/ Periodontal support</th>
<th>Stress at cervical level</th>
<th>Stress at apical level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Optimal/ healthy</td>
<td>0.4 - 0.6 N/mm²</td>
<td>0.2 - 0.3 N/mm²</td>
</tr>
<tr>
<td>Excessive/healthy</td>
<td>2.5 - 3.8 N/mm²</td>
<td>1.6 - 2.2 N/mm²</td>
</tr>
<tr>
<td>Optimal/ affected</td>
<td>1 - 1.5 N/mm²</td>
<td>0.4 N/mm²</td>
</tr>
</tbody>
</table>

In the case of a mild intensity force on a healthy periodontal support we simulated the orthodontic tilting movement by applying a force of 1N on the crown of the tooth. The area of maximum stress on the surface opposite to the spot of the force applied measured pressure values of 0.4 to 0.6 N/mm²; the area of significant stress on the root tip (the apical area) had values from 0.2 to 0.3 N/mm²; the area of stress in the vicinity of the spot of the force applied, with values 0.2 to 0.26 N/mm². The graph results highlight the distribution of stress (Fig. 1).

For the case of mild force intensity on affected periodontal support characteristic for adult periodontitis the distribution and the stress values are: the area of maximum stress on the surface opposite the spot of the force applied, with values of 1 to 1.5 N/mm²; the area of significant stress on the root tip (the apical area) with values of 0.4 N/mm²; the area of stress in the vicinity of the spot of the force applied, with values from 1.1 to 1.4 N/mm² (Fig. 2).

The finite element analysis showed that the stress in the periodontal ligament due to an unusual orthodontic force is largely concentrated in the cervical area and at the apex of the tooth (Fig. 3).

The application of excessive forces on a healthy periodontal support showed that the level of stress in the cervical area was between 2.5-3.8 N/mm² and 0.2-0.3 N/mm² in the cervical area and at apical level respectively. The results obtained after the study of these three cases are presented in Table 1.

The role of the computer simulation of the orthodontic tooth movement under the action of the forces was to predict and quantify the tissue reactions based on the induced stress that can be assessed both quantitatively and qualitatively.
Among dental specialists the practice of orthodontics is considered unique, as it generally extends over a long period of time and can generate disagreements with the patients due to unrealistic expectations of esthetic or functional final results. Following clinical observations, the iatrogenic problems are more of interest to the adults than to the children and adolescents, since the undesirable phenomena of root resorption, alveolar bone height reduction or tooth mobility, are prevalent in orthodontic treatment of adults [9-11]. The importance of applying an orthodontic force of optimal intensity in conjunction with the individual’s response and the state of health of the periodontal tissues supporting the teeth is essential for the success of the orthodontic treatment [12, 13]. In addition to the effects of tooth alignment and the improvement of esthetics and functionality of the dento-maxillary system, the iatrogenic action of the orthodontic therapy should not be overlooked. From this point of view, the intensity and the dosage of the forces, depending on the state of health of the periodontal tissues supported, are of very high importance [13, 14].

Our study can be included into the vast assembly of current research concerns dictated by the realities of numerous studies based on human or animal experiments that can bring trauma or injury towards the non-aggressive simulations of real biological phenomena. This is accomplished by using modern methods of computer-aided simulation; one of these is represented by FEM, considered to be a method of computerized analysis that allows for a highly accurate identification of the structural stress. The applicability of FEM in orthodontics is due to its numerous advantages; it allows the application of forces following with different directions and with different intensities, at any place of the modelled structure; the possibility to create and build three-dimensional structures using dental tooth size and morphological data from specialized textbooks, not needing the patients consent for the development of simulations of the effects of forces applied; the ability to include the heterogeneity of the dental and periodontal structures; the possibility to include the irregularity...
of the contour of the tooth in the dental design and to draw out direct, rapid and comprehensive results with attractive graphical user interfaces; it permits a highly accurate identification of stress and follows easily specific problems where the physical parameters of the structures (teeth, periodontal ligament, alveolar bone) varies [9-11].

The specialists in orthodontics must face many medico-legal aspects related complications or potential risk factors associated to cosmetic procedures carried out in children or adult patients [8]. The main factor leading to lawsuits against dentists is an inadequate professional relationship with the patient, represented by lack of information, diagnosis or treatment procedures and an insufficient explanation on the evolution and prognosis. All medical explanations must be provided in detail and accessible language, emphasizing treatment options and their limitations, so that there is understanding, choice and acceptance. FEM is at the base of studies that have investigated the types of orthodontic forces that induce high levels of stress in the apical area, and that favours the appearance of iatrogenic effects, especially of root resorption [12, 13]. The clinical implications of this study consist in the fact that if the practitioner has any doubts regarding the use of a higher pressure at the apical area of the tooth (for a patient with a history of root resorption) he will be extremely cautious in applying the orthodontic forces.

Following an extensive analysis that relies on more than 400 articles comprising human trials and animal experiments, it appears that no conclusion was reached that was unanimously agreed upon, which would recommend a standard type of force likely to produce maximum efficiency in clinical orthodontics. As a result, it has become a necessity to adapt and orient the studies regarding biomechanical reaction through the use of mathematical modelling methods, especially the FEM [13-18]. The studies focused on the modelling of periodontal structures and on using simulations of the orthodontic forces with the help of IT systems revealed the importance and consistency of results in practical situations, providing the orthodontist with important medical milestones of orthodontic approach. Today, the use of computer simulations of human biological phenomena proved to be extremely important and inevitable in the future ongoing assessment processes in order to evaluate accurately the status and results during dental medical procedures, in particular, orthodontic treatment [17]. The major advantage is represented by the possibility of anticipating tissue reactions that occur with the evolution of treatment, based on data and the specific configuration of the initial situation. At the same time, the stage analysis of the induced stress at the structural level, allows for proper orthodontic rehabilitation by establishing, a timely corrective action (reducing the intensity of forces, rehabilitation of periodontal support, adoption of therapeutic pauses in agreement with the patient) to avoid the iatrogenic or extreme circumstances [18]. The signalling of the extreme circumstances listed is ensured by continuous monitoring of status and treatment phases, requiring a presentation and explanation to the patients.

CONCLUSION

The computer simulations of real biological phenomena are used with considerable success in all clinical orthodontic patients, increasing their confidence in the proposed treatment plan, providing an ethical support for the medic, providing feedback on patient responses until the end of the treatment. The transposition of clinical reality through the computer simulation requires continuous development of the IT systems in this field and open new research directions and applicability regarding the iatrogenic effects of orthodontic forces.

Conflict of interest. The authors declare that they have no conflict of interest concerning this article.

References