FEM IN ORTHODONTICS: A REVIEW OF THE PALATAL EXPANDERS CLINICAL INVESTIGATION

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SUMMARY

Introduction. The finite element method (FEM) is an engineering resource that allows to obtain the stresses and deformation of complex structures. It is very useful in orthodontics to investigate complex mechanical or results that are achieved with specific appliances. The purpose of the study is to investigate which studies have been produced on expanders with this method.

Material and methods. A search was performed using PubMed, as keywords we have included "finite elements orthodontics", "finite elements orthodontics" and "finite elements method orthodontics" "FEM orthodontics". The number of articles turned out to be 724. Choosing only the ones published in English with a clear description of the study, a human model and limited to clinical aspects we have come to select 209 articles. 41 of them focused on expanders.

Result. FEM allows to ideally compare every type of palatal expanders and evaluate which one is more effective in terms of the results obtained and the stress suffered by the structures involved.

Conclusion. FEM, with a valid model, can investigate aspects of palatal ecpansion that are difficult to test with clinical evaluations.

Key words: finite element method, orthodontics, palatal expanders.

Background

In orthodontics different questions are difficult to be answered because of the biomechanical complexity of the stomatognathic system and the ethical issue of simulating invasive procedures on human patients.

In these cases, the computational techniques such as the Finite Element Method (FEM) can come to the rescue.

FEM is an engineering resource used to calculate stress and deformation in complex structures and has been widely applied in biomedical research. By applying the FEM, orthodontics is able to model and analyze any dento-maxillo-facial material or structure. The principle of FEM is based on the division of a complex structure into smaller sections called elements in which physical properties, are applied to indicate the object's response to an external stimulus as an orthodontic force. The great advantage is that the degree of simplification can be controlled (1).

There are three fundamental steps to proceed with finite element analysis: Pre-processing, processing and post-processing. The pre-processing consists of the creation of the geometric model and its finished conversion element, representation of the data of the properties of the materials, definition of the boundary conditions and configuration of the loading. With post-processing the results are interpreted (2). To build a

virtual model, we generally start from a Cone beam computed tomography (CBCT) of the bone/structural component that we want to reproduce. From CBCT in DICOM files (Digital Imaging and Communications in Medicine) a 3D model of the structure is elaborated with softwares like MIMICS (Materialise NV) that allow to isolate the chosen structure and create the raw digital model in STL that will then be refined with a second software like Rapidform (INUS Technology, Inc.)for example. Structural elements such as miniscrews, expanders or cantilevers can be scanned and reproduced in STL format or created using programs such as SolidWorks. The analysis with FEM, once defined the properties of the models, will then allow us to calculate the stresses, movements, and strains induced on the model according to the forces that we impose on it. It all ends with the post-processing phase in which the results are analyzed and conclusions are drawn.
The purpose of the study is to investigate which studies have been produced stomatognathic system and the ethical issue of simulating invasive procedures on human patients.

Material and methods

The Authors developed a search strategy on electronic databases including Medline, Web of Science and Scopus. The aim was to identify all papers dealing with FEM in Orthodontics as keywords we have included “finite elements orthodontics”, “finite elements orthodontics” and “finite elements method orthodontics” “FEM orthodontics”. The number of articles turned out to be 724. When the abstracts were read, a first selection of the articles was made according to the following criteria:

1. Study published in English;
2. A clear description of the study and its purpose;
3. Studies performed only on human structures;
4. Studies on clinical and biomechanical aspects of orthodontics.

Studies have been excluded regarding only biological or purely engineering aspects of model validation such as the creation of a model of a tooth.
The number of papers eliminated by the research due to a language different than English turned out to be 58. The studies eliminated instead since not concerning clinical or biomechanical aspects of orthodontics or since related to other non-orthodontic dental branches were 447 and are therefore valid results 209 studies. These have been divided into the 4 categories of our interest: expanders, other devices (which are not expanders), miniscrews and orthodontic movements.

Results

Of the 209 selected articles, 41 belong to this subgroup. Of these 41 29 are concerned with investigating the effects, stresses, movements and deformations produced by an expander (anchored to the teeth, to the miniscrews or both), 11 compare various types of expanders and 1 deals with determining whether a bicortical anchorage gives more stability to the expander than a monocortical anchor.
Almost all the Authors agree that the expansion obtained with an expander anchored to the teeth or one on two miniscrews is pyramidal having a base at the incisal level and tip pointing towards the oral cavity when seen in axial vision and with apex towards the nasal bone if viewed from the front (3-10). Park et al. (11) and Mathew et al. (12) observe a more posterior than anterior expansion with expanders on 4 miniscrews. In particular, two other Authors state that the different types of expansion and the inconsistencies between the various studies could derive from a

constructional difference between the models, the correct creation of a palatal suture, the expander design and the use of a model circumscribed to the maxilla and not of the whole face (6, 13). Ghoneima et al. illustrates with the aid of the FEM another well-known effect of the palatal expansion: an increase in volume at the level of the nasal and nasopharyngeal cavity with a decrease in the pressures present in this area (14).

A study compares the effects of a removable expander and those of an expander bonded to the teeth and demonstrates how stress at the apical and periodontal levels, those at the cortical and spongiotic level and the molar tipping are greater with the removable (15).

As for the comparison between expander on miniscrew and classic expander all agree that a palatal expander on miniscrew limits the side effects of a classic rapid palatal expander (RPE). Mathew et al. using models of patients with palatal cleft, notice how the expansion with RPE is more dental and more stress is created in the dental area, unlike with the MARPE (Miniscrew assisted rapid palatal expansion) which avoids tipping phenomena (16).

MacGinnis et al. also notes that the use of the miniscrews allows to impose the expansion force as close as possible to the center of resistance of the maxilla and obtain a better expansion of the bone bases avoiding the tipping of the teeth on which the bands would be placed (17). Matsuyama further states that if the MARPE had any support arms to the teeth it would in any case give a more balanced arch expansion. This last aspect should make the clinician incline to use MARPE in the dolicfacial patients (13). A study by Trojan et al. notices how with an activation of the MARPE you get the equivalent of 3 activations of the RPE (18).

MARPE was also proved to be useful in adult patients. MacGinnis et al. states that the used palatal expander must be able to withstand stress and have the capacity to withstand expansion loads, in this way expansion can also be performed in the patient where the suture is now closed. The model taken into question by the researcher is however isotropic and this is a point against his measurements (17). Still remaining on the topic of adult expansion, Boryor et al. carries out an in vitro study and with the FEM evaluating the possibility of opening the fused palatine suture on the skull of 3 women (69, 73, 77 years) with an expander on 4 miniscrews (19). The results are positive and the Author states that it is possible to open the median suture of the palate with a MARPE, in fact, the forces that were gradually used have led to a suture rupture without surgery. Obviously, the stress on the suture and on the miniscrews are greater. However, it is very important to place the screws in thick bone to avoid bone breakage in the implant area during expansion. These statements must therefore induce the clinician to use an expander on 4 miniscrews when the patient has passed the growth peak and the sutures are merging together. A study, comparing different palatal expanders with different SARPE (surgical assisted rapid palatal expansion) techniques shows that MARPE promote a more parallel expansion (20).

Some studies focus on identifying which sutures suffer the greatest amount of stress during expansion. Clearly the greatest stresses are on transversal sutures (21-24). Jain et al, in a study carried out on a 12-year-old human skull model, finds the major movements in the pterygomascellar sutures and palatine suture. With the use of MARPE, stress also shifts to maxillary zygomatic and pterygomaxillary sutures (25). Another Author points out that the expansion is mainly countered by sutures with the zygomatic bone and much less by the maxillary lacrimal, the frontal and the nasomaxillar ones (8). Işeri et al. states that probably a slower expansion would lead to a greater adaptation of the nasomaxillar structures with a reduction of recurrence, but there are no studies confirming this assessment (26).

In the adult things change and if we apply a palatal expander on bands the stresses would be too high and the results unfavorable. By some Authors it is illustrated the need, to use surgery to achieve the desired results. To reduce stress in the adult a surgical division of the pterygomascellar suture is necessary (27-33). The same supports Jafari et al. which highlights how the release of the pterygoid bases is necessary to allow a freer posterior expansion since this bone is single with both pterygoid processes attached (unlike the maxilla which is an even bone) (34).

In the case of SARPE in the adult patient a study comparing a Hyrax expander, a Haas-type MARPE on 4 miniscrews, another Haas-type MARPE on 4 miniscrews with SARPE, the same previous combination with the addition of the pterygomascellar suture separation and finally also a case with the addition of Le Fort and concludes that the best choice is to use a MARPE on 4 miniscrews with attached SARPE (4). Boryor et al. also adds that female bones have rupture points lower than male ones when subjected to high loads (200N for females and 400N for males), this still leads to greater attention of the clinician in the therapeutic choice (35).

Some Authors have analyzed the effects of a palatal expansion on a patient with labiopalatoschisis. Zhang et al. state that the expansion in a patient of this type leads to a transverse improvement and is known as the deformations are different between the two sides. The affected side remains more contracted and therefore an asymmetric expansion is recommended. Expanding to gain archery becomes very important (36). The aforementioned Author Mathew, comparing RPE and MARPE on 4 miniscrews known as in its model the transverse expansion occurred more on the side of the cleft. MARPE has given greater palatal expansion and has expanded more posteriorly than anteriorly and its greatest stress point is on the screws positioned on the side of the cleft (12). Holberg et al. tries to expand a patient with labiopalatoschisis with an Elix quad-type device and manages to obtain skeletal effects even with this type of expander. Positioning it identical on a model without cleft the results are much less encouraging, to show that the patient with cleft offers less resistance to expansion (37). For completeness also Kumar and Khanam compare two removable devices in healthy patient, Quad Elix and NPE2 and considers them also capable of orthopedic expansions on a 12-year-old skull model (38). Geramy with his colleagues however considers the removable ones guilty of more dental and skeletal effects than the fixed ones (15).

Gautam et al. show that the ideal therapy for a surgically assisted expansion for a patient with labiopalatoschisis is a unilateral leFort 1 with pterygoid disjunction and SARPE. A more extensive surgery could reduce stress but increase difficulties. If we want to be more conservative, we should only choose the SARPE (39).

The same Authors in another study points out that in patients of this type the personalization of therapy is even more fundamental (40). Lee at al. for example, to create more anterior space in a patient without cross-bite, it illustrates how positioning the expander more anteriorly obtains a greater expansion in the cleft side and almost nothing in the healthy side (41).

Matsuyama et al., on the other hand, analyzes how the constructive characteristics of the expander affect the expansion and explains that the more the palate becomes deeper, the longer the arms become longer and the expander becomes more effective. A larger diameter of the arms, of the arms connected by a diagonal or shorter bar, favors arch expansion. The skeletal anchorage favors the expansion, from a bodily movement to the teeth (if it has the arms) and expands the two bony heads in a parallel way (13). A study finally concludes that a bicortical anchorage is to be favored at a monocortical anchorage. In fact, the first type has less peri-implant stress, greater stability and obtains a more parallel expansion of the bone bases (42). Araugio et al. analize the influence of screw height during expansion and detect how the expansion screw is at the level of the occlusal plane, the greater the molar tipping will be. The higher this will be, the less will be this side effect. With the screw above the center of resistance the molars tend to extrude and distalize (43).

Conclusion

The results obtained show that the palatal expansion is, as already confirmed in the clinical literature, an excellent means for the correction of transverse problems in growing patients. Moreover, with the use of miniscrew, satisfactory expansion can be achieved even in adult patients. However, some Authors suggest the use of the surgery for safer and more stable results. The negative effects of an expander anchored to the teeth on patients of all ages are also limited with a miniscrew expander. Finally, the constructive and design aspects of the device are also fundamental: aspects such as the diameter and length of the arms or the position of the central screw can greatly change the outcome of the therapy.

From this review of the literature it is clear that FEM is a useful method to analyze effects of palatal expansion. This allows to ideally compare every kind of orthodontic device in terms of results obtained and stress involved. The limitation of this method lies in the model used to simulate the orthodontic mechanics on which the Authors wish to investigate; in fact, geometric summaries models or isotropic models can in many cases deviate the experiment from reality. It is therefore recommended for the future to use anisotropic models that represent better the oral and maxillo-facial structures.

Availability of data and supporting materials

Data sharing not applicable to this article as no datasets were generated or analysed during the current study.

Competing interests

The Authors declare that they have no competing interests.

Funding

No funding.

Authors' contribution

DB found the articles and write the introduction section, ADS and GB wrote the methods and discussion session, AG wrote the conclusion and coordinated the entire manuscript.

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