Evaluation of stress distribution in different miniplate designs: a study for finite element analysis

Avaliação da distribuição de tensão em diferentes projetos de miniplacas: um estudo para análise de elementos finitos

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ABSTRACT
The aim of the study is to propose new designs of orthodontic miniplates, which were evaluated by finite element method, regarding to the distribution of stress after application of forces on them. Six three-dimensional models of miniplates were designed, in the forms of T, Y, and I with inverted hook ends and two buttons. Forces of 1N, 2N, and 3N

were applied in vertical, horizontal and diagonal directions. Charging was performed. It was observed that the T-shaped miniplates were the ones that showed greater tension accumulation located in the region of the neck of the device. The "Y" shaped miniplates showed a region of tension accumulation in the neck region of the accessory only when 3N horizontal force was applied and the "I" miniplates showed good voltage distribution in all magnitudes and directions of force applied. A different distribution of forces was still observed when the activation end was changed. In general, the miniplates showed a good distribution of tensions, being a good option of skeletal anchorage in orthodontic treatments.

Keywords: Orthodontic, Orthodontic appliances, Orthodontic anchorage procedures, Miniplate; Bone plate.

RESUMO
O objetivo do estudo é propor novos desenhos de miniplacas ortodônticas, que foram avaliadas pelo método de elementos finitos, em relação à distribuição de tensões após a aplicação de forças sobre elas. Seis modelos tridimensionais de miniplacas foram projetados, nas formas de T, Y e I, com pontas de gancho invertidas e dois botões. Forças de 1N, 2N e 3N foram aplicadas nas direções vertical, horizontal e diagonal. O carregamento foi realizado. Observou-se que as miniplacas em forma de T eram as que apresentavam maior acúmulo de tensão localizadas na região do pescoço do dispositivo. As miniplacas em "Y" mostraram uma região de acúmulo de tensão na região do pescoço do acessório somente quando a força horizontal 3N foi aplicada e as miniplacas em "I" mostraram uma boa distribuição de tensão em todas as magnitudes e direções de força aplicada. Uma distribuição diferente de forças ainda foi observada quando o fim de ativação foi alterado. Em geral, as miniplacas mostraram uma boa distribuição de tensões, sendo uma boa opção de ancoragem esquelética em tratamentos ortodônticos.

Palavras-chave: Ortodontia, Aparelhos ortodônticos, Procedimentos de ancoragem ortodôntica, Miniplaca; Placa óssea.

1 INTRODUCTION

Anchoring is a key factor for successful orthodontic treatment[1]. The anchorage of the dento-supported type is one of the major limitations in modern orthodontics, since the teeth move in response to the applied forces[2]. In addition, conventional anchoring methods often depend on patient collaboration and may result in undesired reciprocal dental movements[3]. Temporary skeletal anchorage, such as dental implants, miniplates and mini-implants, were developed and are an aid in dental anchoring[2,4].

One of the first reports related to the use of miniplates as skeletal anchorage were performed by Umemori et al[5] who used them in a mandible molar intrusion and Jenner and Fitzpatrick[6] who described the use of miniplates for mandibular molars distalization. The most significant advantage of using miniplates, such as skeletal anchorage, is the possibility of three-dimensional molar movement, including distalization, intrusion, protraction, extrusion and lingual motions[5,7,8,9,10,11]. In a systematic review performed by Shatzle et al[12], when comparing the types of skeletal anchorage system, miniplates offer greater stability than mini-implants, with a mean success rate of 93.7% when the mini-implants have 84.6%[12]. However, miniplates have the disadvantage of requiring surgical access to be installed[13,14]. In addition, patients report difficulty in hygienizing the transmucosal stem, which may lead to inflammation in the region and consequent loss of the accessory[4,7,14].

As a result, studies have been conducted for the development of more stable miniplates models, comfortable and resistant to applied forces during the orthodontic treatment[3,15,16]. In the present study, new designs of orthodontic miniplates with rounded edges were presented, altering the fixation means, the design of the rods and the activation ends with the intention of facilitating the installation and the use of auxiliary orthodontic devices (elastic chain, NiTi springs and intermaxillary elastics), promote healing, and consequently reduce the incidence of inflammation and infection. Thus, the objective of the study was to evaluate the mechanical behavior, specifically the stress areas, of these new models of miniplates, using the Finite Element Method (FEM)[7,17].

2 MATERIALS AND METHODS

This study presented new models of orthodontic miniplates. The changes involved width and roundness of the rods beyond the activation ends, which were designed in two ways: the first having the end with two hooks inverted and the second with two buttons. Three different miniplate designs (NeoOrtho® - Curitiba, Brazil) were evaluated: I-shaped, T-shaped and Y-shaped, which were named A1 (I-shape with inverted hooks), A2 (I-shape with two buttons), B1 (T shape with inverted hooks), B2 (T shape with two buttons), C1 (Y-shaped with inverted hooks) and C2 (Y-shaped with two buttons) with different lengths and configurations (Fig 1). The miniplates are titanium grade 2, the material flow limit is 275 MPa and the poison coefficient is 0.361. Its stems are 1.2mm wide and 0.7mm thick.

Figure 1. Three-dimensional models of the studied miniplates separated by types. A1: 20 mm, A2: 23 mm, B1: 20 mm, B2: 19 mm, C1: 19 mm, C2: 23 mm.

The geometric models of miniplates were generated by computer-aided design (CAD). Then, knowing the quality of the material and the dimensions of the plates, three-dimensional models with 10-node tetrahedral elements and triangular base were obtained through the FEMAP software version 10.2, being compatible with the FEM.

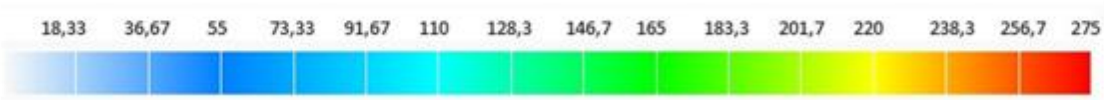
In order to perform the analysis, the miniplate fixation was simulated demonstrating the regions in which the fastening screws and pre-fixation studs would be installed. Voltage regions were observed in the miniplates, applying forces of magnitudes 1N, 2N, 3N, in the vertical, horizontal and 45° directions, simulating the orthodontic forces for intrusion, retraction and maxillary protraction motions[2,7,18]. The criterion for analysis of the results was by Von Mises.

After obtaining the results, it was carried the descriptive analysis of the stress distributions of the six miniplates designs.

3 RESULTS

Ninety analyses were obtained. The results were demonstrated in a color scale of different shades representing different stress levels (Fig 2).

Figure 2. Color scale representing the stresses (MPa) of titanium grade 2 material - 275 MPa of flow voltage. Variation: 18.33-275 MPa.



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Analysis of force application in the vertical direction

The miniplates presented satisfactory voltage distribution in the three applied force magnitudes, remaining far from the material flow limit (Fig 2). A1, B1, C1, showed a low level of tension and the most affected regions were limited to the activation ends (inverted hooks) (Fig 3) and, in groups A2, B2, C2, the tensions were distributed by the rod (Fig 4).

Figure 3. Regions of tension when applying vertical force, according to the end with hooks inverted.

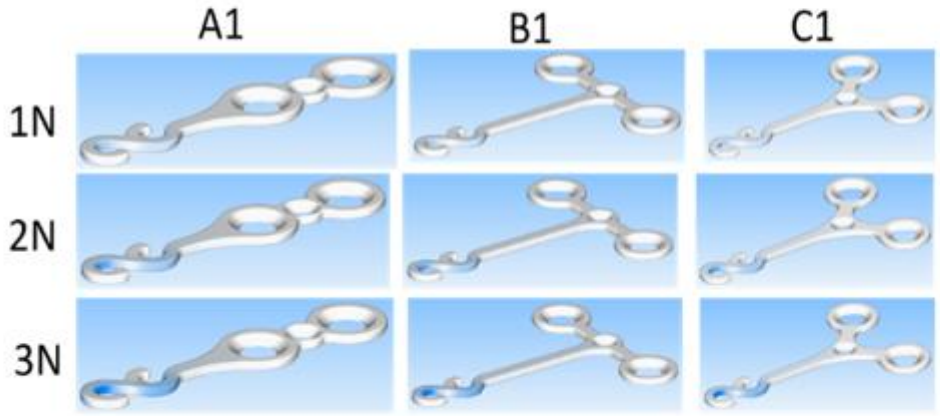
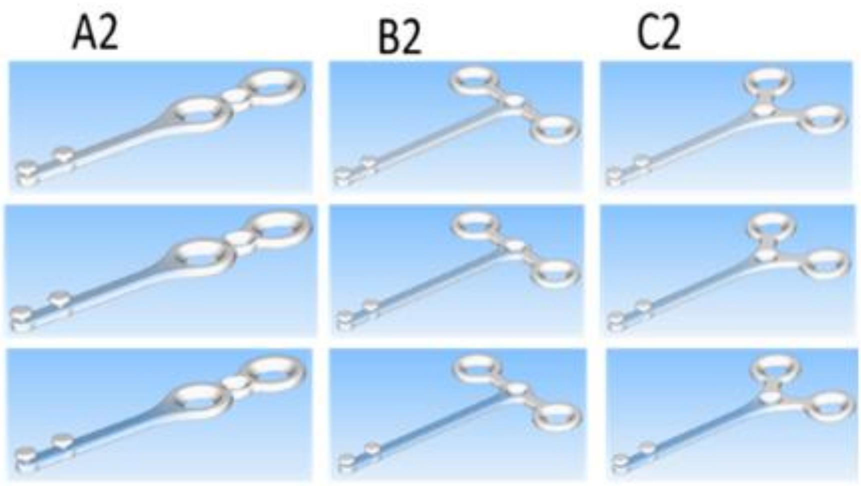


Figure 4. Regions of tension when applying vertical force, according to the end with buttons.



The stress distribution of the miniplates with inverted hooks and two buttons, respectively, are highlighted when 3N force is applied, being the heaviest load of the study.

Analysis of force application in the horizontal direction

The B1, B2 and C2 mini-plates reached the limit of material flow in the region of the neck near the place of insertion of the fixing screws, when they were loaded with 3N, which is represented in red color (Fig 5 and 6). The "T" miniplates showed higher voltage localized in this analysis.

Figure 5. Regions of tension when horizontal force is applied, according to the end with inverted hooks.

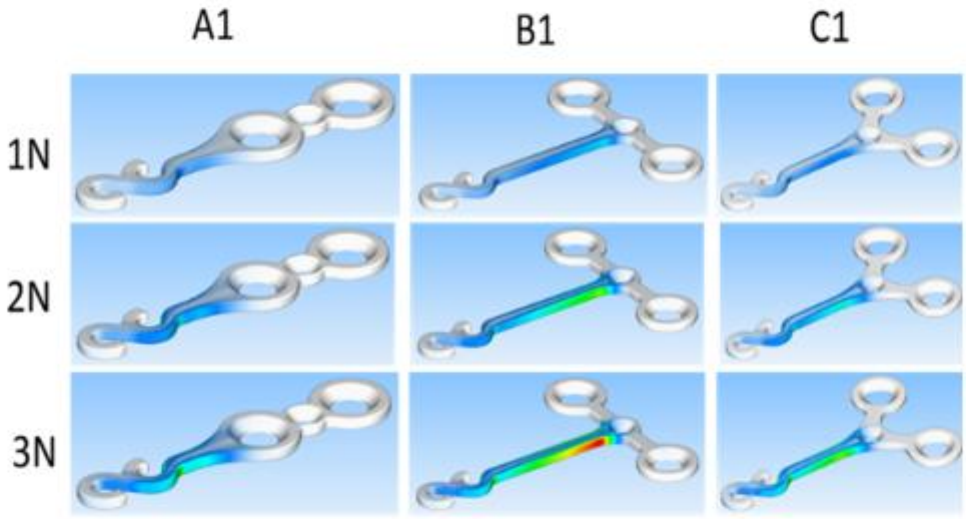
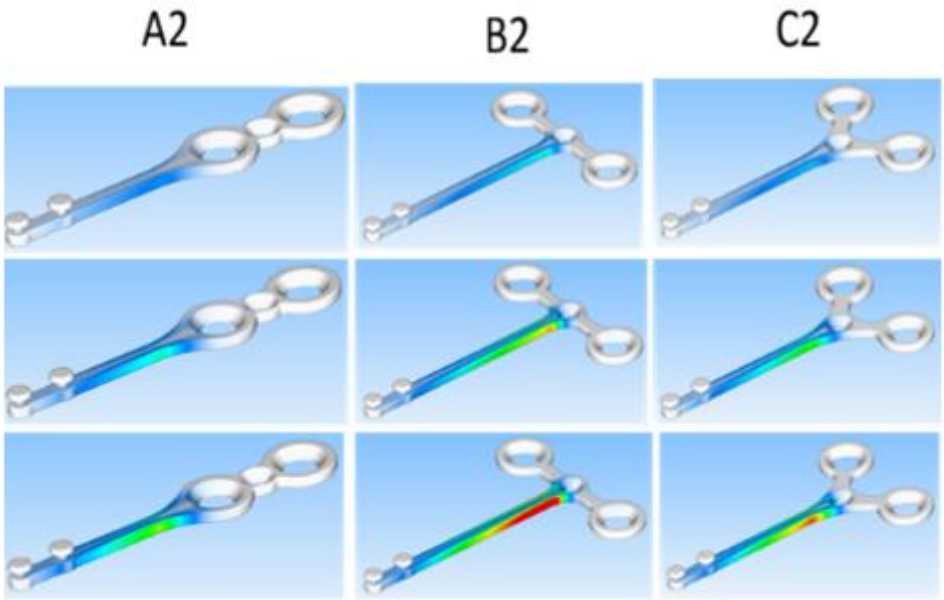


Figure 6. Regions of tension when applying horizontal force, according to the button end.

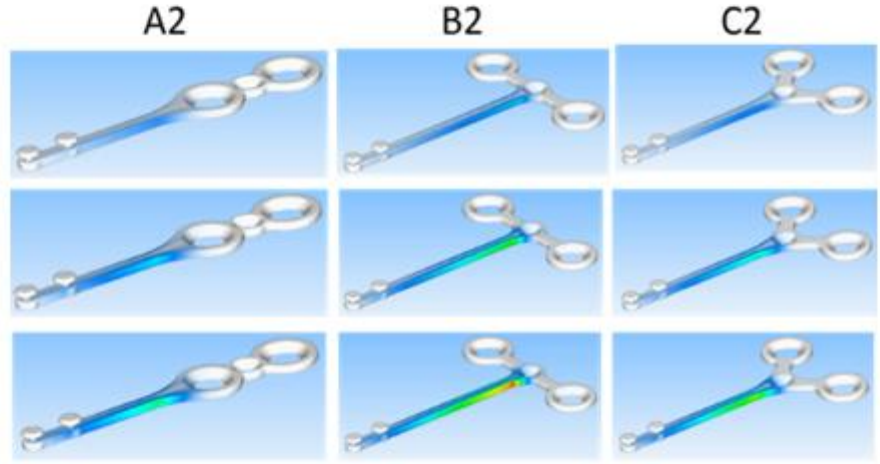


Analysis of application of forces in the diagonal direction

The A1, B1 and C1 miniplates with force application in the diagonal direction demonstrated satisfactory voltage distribution.

Among the miniplates with buttons, type B2 was the one with greatest localized tension with magnitude of force of 3N, which was along the rod, reaching the limit of flow of the material superficially close to the junction of the rod with the body (Fig 7).

Figure 7. Regions of tension when applying force in the diagonal direction.



4 DISCUSSION

According to the literature, miniplates do not interfere in tooth movement[10]. They can withstand heavy forces due to their stabilization by multiple screws and are versatile when the anatomical situation prevents the installation of a mini-implant[18]. Still, the use of the miniplates has simplified orthodontic treatment mechanics, reducing treatment time[19]. Miniplates are also predictable for a wide range of orthodontic movements having a high success rate[20]. There are clinical situations in which miniplates are preferable, as in cases of open bite requiring posterior intrusion[5,9,11] and, when necessary, mass distalization[7,8,11], as they allow efficient tooth movement without the need for removal and reinstallation of the accessory[9]. Miniplates can also be used in Class III therapy with maxillary protraction, as introduced by De Clerck et al[21] in 2009.· Studies demonstated a success rate of miniplates varying from 90% to 97%[2,15,22,23,24].

However, there are situations that may lead to loss of the miniplate during orthodontic treatment, one of which is inflammation[3,7,22]. De Clerck[22] in 2011, observed that the design of the miniplate complicated the hygiene of the same, as reported in the literature[3]. This evidences the relevance of the present study when altering the design of the miniplates, making them more refined and rounded in the region of transmucosal stem and appropriate for a better accommodation / healing in mucous tissue.

The design of the miniplate also interferes in the stress distribution throughout the system, which can cause accumulated tensions that directly affect the fastening screws[25], and can lead to accessory losses. This also demonstrates the importance of the present study, when evaluating, through MEF, the regions of tension that the miniplates are subjected to when applying orthodontic and / or orthopedic forces. This method of analysis was chosen because of its advantages of being precise; enabling the simulation of in-vitro buccal structures, simulating the system of clinically applied orthodontic forces, and enabling non-invasive studies of new materials before clinical uses[26]. According to the literature, being a numerical method, one can have greater accuracy in the results[27]. In the present study, the 10-node mesh was used, as well as in the studies performed in 2012 by Liu et al[27] and in 2014 by Largura et al[24].

The changes in the miniplates extremities in this study were designed with the purpose of facilitating the use of orthodontic devices, with the buttons being designed for the use of closed nickel-titanium springs[7,23] and elastic chain and those of inverted hooks, mainly made up for the use of intermaxillary elastics, but used closed nickel-titanium springs and elastic chain. Veziroglu et al[26] in 2008 observed that stresses mainly occur in the bone around the fixation screw and at the activation ends, corroborating with a study carried out by Huang et al[28], which observed that the greatest displacement of the miniplates occurred at the loading site and concluded that the stress distribution on the miniplates also depends on the type of activation end. In the present study, it was observed that the voltage distribution is different in both types of boards. The inverted hooks dissipate part of the tension that would be on the rod, as can be seen in all miniplate designs, but especially when applying vertical forces.

In the present study, the diagonal direction simulates maxillary protraction[29], the horizontal simulates anterior retraction and molars distalization and vertical, anterior and posterior intrusion[28]. In regard to maxillary protraction with the use of miniplates, De Clerck et al[21] advocated the application of 100g of force in the first month of treatment and 200g in the second, which is close to the study carried out in 2011 that described the use of 150g[22] and diverges from the study carried out by Heymann et al[29] which used 250g of force for the same procedure. Choi et al[7] used miniplates to perform anterior retraction using 300 to 400g of force. A more recent study demonstrates success in maxillary molars distalization using 150g of force. Based on the literature, the miniplates of the present study were tested by applying forces of 1N, 2N and 3N which is equivalent to approximately 100g, 200g and 300g, simulating the different orthodontic mechanics[7,10,21,22,29].

In the evaluation of the I-shaped miniplates, a good distribution of the tensions in all the magnitudes and directions of applied forces was observed, remaining far from the limit of material flow and presented different behaviors when comparing the miniplates with inverted hooks and with two buttons, therefore in the first one was observed tensions located specifically in the hooks and the second with tensions distributed along the miniplate, not affecting the buttons. This result differs from the study carried out by Nalbantgil et al[25] who studied three models of "I" miniplates, evaluating regions of higher stress by MEF, and resulted in localized tension in the neck region of the miniplate when 200g of Horizontal force, reaching the yield limit of the evaluated material. However, these results resemble those of the present study when it comes to the T-shaped plates, which showed greater tension in the neck region when horizontal force was applied above 2N, despite, according to the literature, the "T" and "Y" shaped plaques generate less bone stress[28]. Regarding to the "Y" miniplates, when applying horizontal forces, a difference in stress distribution is observed in cases of different ends. In C1 mini-plates, there was a better stress distribution along the accessory having less regions of localized tension, whereas the miniplates of type C2 showed tension located in the neck, corroborating the results of Nalbantgil et al[25].

In a mechanical study with three mini-plates trademarks, Trandem et al[30] when applying vertical forces of 0-100N, found that the three types supported forces above 1300g. This method of analysis does not locate the regions of higher stress before occurring the plastic deformation, which is an advantage of the MEF. Huang et al[28] carried out a study to evaluate bone stress caused by orthodontic forces. They used four types of miniplates: "I", "T", "Y" and "L", applying force magnitudes of 2,4 and 6N in the 0° and 90° directions. They observed that the horizontal forces induce greater stress in the bone than the vertical forces, which resembles the results of the present study.

To understand the behavior of the miniplates when subjected to horizontal loading, we can compare them to the teeth, which when they receive a horizontal load with the line of force action not coinciding with their center of resistance, is generated a moment, which is based in the multiplication of the distance between the point of application of force and the center of resistance of the tooth and the magnitude of applied force[31]. Thus, when we have a longer mini-plate and apply a horizontal force line of action, it generates more momentum than when we have a shorter mini-plate, due to the decrease in the distance between the force line of action and the center of the device. In the present study, designs of miniplates with shorter stem were designed, aiming at greater ease of installation and practicality in its use. Although the decrease in length minimizes the generated moment, the mini-plate "T" still needs modifications regarding the neck and thickness of the stem.

5 CONCLUSIONS

The miniplates showed, in a general way, a good distribution of tensions, characterizing in a good option of skeletal anchorage for the orthodontic treatments.

REFERENCES

1. Leung MTC, Rabie ABM, Wong RWK. Stability of connected mini-implants and miniplates for skeletal Anchorage in orthodontics. Eur J Orthod 2008 Oct;30(5):483-9.

2. Creekmore TD, Eklund MK. The possibility of skeletal anchorage. J Clin Orthod 1983;17:266-9.

3. Cornelis MA, Scheffler NR, Nyssen-Behets C, De Clerck HJ, Tulloch JF. Patients 'and orthodontists' perceptions of miniplates used for temporary skeletal anchorage: a prospective study. Am J Orthod Dentofacial Orthop 2008;133(1):18-24.

4. Takaki T, Tamura N, Yamamoto M, Takano N, Shibahara T, Yasumura T et al. Clinical Study of Temporary Anchorage Devices for Orthodontic Treatment- Stability of Micro/Mini-screws and Mini-plates: Experience with 455 cases. Bull Tokyo Dent Coll 2010;51:151-63.

5. Umemori M, Sugawara J, Mitani H, Nagasaka H, Kawamura H. Skeletal anchorage system for open bite correction. Am J Orthod Dentofacial Orthop 1999;115:166-74.

6. Jenner JD, Fitzpatrick BN. Skeletal anchorage utilizing bone plates. Aust Orthod J 1985;9:231-33.

7. Choi BH, Zhu JS, Kim HY. A clinnical evaluation of titanium miniplates as anchors for orthodontic treatment. Am J Orthod Dentofacial Orthop 2005;128:382-4.

8. De Clerck HJ, Geerinckx V, Siciliano S. The Zygoma Anchorage System. J Clin Orthod 2002 Aug;36:455-9.

9. Park JH, Tai K, Takagi M. Open-bite treatment using maxillary and mandibular miniplates. J Clin Orthod 2015;49:398-408.

10. Sugawara J, Nishimura M. Minibone Plates: The skeletal anchorage system. minibone plates: the skeletal anchorage system. Semin Orthod 2005;11(1):47-56.

11. Sugawara J. Temporary skeletal anchorage devices: the case for miniplates. Am J Orthod Dentofacial Orthop 2014;145(5):559-65

12. Schatzle M, Mannchen R, Zwahlen M, Lang NP. Survival and failure rates of orthodontic temporary anchorage devices: a systematic review. Clin Oral Implants Res 2009;20:1351-9.

13. Cornelis MA e De Clerck HJ. Maxillary molar distalization with miniplates assessed on digital models: A prospective clinical trial. Am J Orthod Dentofacial Orthop 2007;132:373-7.

14. Miyahira YI, Maltagliati LA, Siqueira DF, Romano R. Miniplates as skeletal Anchorage for treatment mandibular second molar impactions. Am J Orthod Dentofacial Orthop 2008;134:145-8.

15. Cornelis MA, Scheffler N, Mahy P, Siciliano S, Clerk H, Tulloch C. Modified miniplates for skeletal anchorage in orthodontics: placement and removal surgeries. J Oral Maxillofacial Surg 2008;66:1439-45.

16. Volkan A¸ Cagri U, Cagri T. Effects of a newly designed orthodontic miniplate platform for elevating the miniplate over the gingiva: A 3-dimensional finite element analysis. Am J Orthod Dentofacial Orthop 2015;148:110-22.

17. Dalstra M, Cattaneo P, Melsen B. Load transfer of miniscrews for orthodontic anchorage. Orthod. 2004;1:53-62.

18. Chung KR, Kim SH, Kang YG, Nelson G. Orthodontic miniplate with tube as an efficient tool for borderline cases. Am J Orthod Dentofacial Orthop 2011;139:551-62.

19. Tseng YC, Chen CM, Wang HC, Wang CH, Lee HE, Lee KT. Pain perception during miniplate-assisted orthodontic therapy. Kaohsiung J Med Sci 2010;26(11):603-8.

20. Lam, R, Goonewardene M, Allan B, Sugawara, J. Success rates of a skeletal anchorage system in orthodontics: A retrospective analysis. Angle Orthod 2018;88(1).

21. De Clerck HJ, Cornelis MA, Cevidanes LH, Heymann GC, Tulloch CJF. Orthopedic Traction of the Maxilla with Miniplates: A New Perspective for Tratment of Midface Deficiency. J Oral Maxillofac Surg 2009;67:2123-29.

22. De Clerck EEB, Swennen GRJ. Success rate of miniplate anchorage for bone anchored maxillary protraction. Angle Orthod 2011;81:1010-13.

23. Kim S, Herring S, Wang IC, Alcalde R, Mak V, Fu I, et al. A comparison of miniplates and teeth for orthodontic anchorage. Am J Orthod Dentofacial Orthop. 2008;133(2):189-97.

24. Largura LZ, Argenta MA, Sakima MT, Camargo ES, Guariza-filho O, Tanaka OM. “Bone stress and strain after use of a miniplate for molar protraction and uprighting: A 3-dimensional finite element analysis”. Am J Orthod Dentofacial Orthop 2014;146:198-206.

25. Nalbantgil D, Tozlu M, Ozdemir F, Oguz M, Tulin O. FEM analysis of a new miniplate: stress distribution on the plate, screws and the bone. Eur J Dent 2012;6:9-15.

26. Veziroglu F, Uckan S, Ozden UA. A Stability of Zygomatic Plate-Screw Orthodontic Anchorage System. Angle Orthod 2008;78:902-7.

27. Liu TC, Chang HC, Wong TY e Liu JK. Finite element analysis of miniscrew implants used for orthodontic anchorage. Am J Orthod Dentofacial Orthop 2012; 141:468-76.

28. Huang YW, Chang CH, Wong TH e Liuc JH. Bone stress when miniplates are used for orthodontic anchorage: Finite element analysis. Am J Orthod Dentofacial Orthop 2012;142:466-72

29. Heymann GC, Cevidanes L, Cornelis M, De Clerck HJ, Tulloch C. Three-dimensional analysis of maxillary protraction with intermaxillary elastics to miniplates. Am J Orthod Dentofacial Orthop 2010;137(2):274–84.

30. Trandem KC, Korach CS, Schindel RH. Comparision of deformation of 3 orthodontic miniplate lever arms. Am J Orthod Dentofacial Orthop 2011;140:531-6.

31. Viecilli A, Viecilli R. Determinação da linha de ação da força de e ativação de cantiléveres para movimentos ortodônticos. Rev Clin Ortodon Dental Press 2015;14(4):17-24.