Arch Health Invest (2022)11(4):646-652
http://doi.org/10.21270/archi.v11i4.5601
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Original Research

Biochemical Analysis of Different Implant-Abutment Connections in the Prosthetic Rehabilitation of the Anterior Maxilla: a Finite Element Study

Análise Bioquímica de Diferentes Conexões Implante-Pilar na Reabilitação Protética da Região Anterior da Maxila: um Estudo de Elementos Finitos

Análisis Bioquímico de Diferentes Conexiones Implante-Pilar en la Rehabilitación Protésica del Maxilar Anterior: un Estudio de Elementos Finitos

Cássia Bellotto **CORRÊA**
PhD, Department of Diagnosis and Surgery, School of Dentistry at Araraquara, Univ Estadual Paulista, UNESP, Arararaquara- SP, Brazil
https://orcid.org/
Rogério **MARGONAR**
PhD, Department of Health Sciences, Implantology Post Graduation Course, School of Dentistry, University Center of Araraquara-UNIARA, Araraquara - SP, Brazil
https://orcid.org/
Pedro Yoshito **NORITOMI**
PhD, Renato Archer Center of Information Technology, Campinas - SP, Brazil
https://orcid.org/
Suzane Cristina **PIGOSSI**
PhD, Department of Clinics and Surgery, School of Dentistry, Alfenas Federal University (Unifal-MG), Alfenas - MG, Brazil
https://orcid.org/
Luís Geraldo **VAZ**
PhD, Department of Dental Materials and Prosthodontics, School of Dentistry at Araraquara, Univ Estadual Paulista, UNESP, Araraquara - SP, Brazil
https://orcid.org/0000-0003-0916-1962

Abstract

Purpose: This study aimed to evaluate, through 3D finite elements method, the biomechanical behaviour of three different types of prosthetic connections (external hexagon (EH), internal hexagon (IH) and morse taper (MT)) in implant-supported fixed partial dentures (ISFPD) placed in the anterior region of the maxilla. Methods: A 3-dimensional (3D) anatomical model of the anterior maxilla was constructed using a computed tomography database. The implants were positioned in the lateral incisor positions and pontics in the central incisor positions simulating an ISFPD with four cemented elements. The prosthetic rehabilitation was made with three connections implant systems including MT, EH and IH. The applied load of 150N was distributed at the center of the palatal surface of each tooth, with an angle of 45° related to the tooth long axis. The distribution of strain/stress was analyzed in all groups. Results: The implant connection design influences the distribution and intensity of stress/strain on the prosthesis/implant system. The EH connection promotes less displacement of the prosthetic structure in the case studied; however, the abutment screw of this connection receives the most of the von Mises stress of the system. The MT connection showed small values of von Mises stress in the screw in comparison to EH and IH connections type. Conclusions: The MT abutment seems to be more advantageous than the EH and IH connections concerning stress distribution in our study model.

Descriptors: Dental Implants; Dental Prosthesis; Finite Element Analysis.

Resumo

Objetivo: Este estudo teve como objetivo avaliar, através do método de elementos finitos 3D, o comportamento biomecânico de três diferentes tipos de conexões protéticas (hexágono externo (EH), hexágono interno (IH) e cone morse (MT)) em próteses parciais fixas implantossuportadas. (ISFPD) colocado na região anterior da maxilla. Métodos: Um modelo anatômico tridimensional (3D) da região anterior da maxila foi construído usando um banco de dados de tomografia computadorizada. Os implantes foram posicionados nas posições dos incisivos laterais e os pônticos nas posições dos incisivos centrais simulando um ISFPD com quatro elementos cimentados. A reabilitação protética foi feita com três sistemas de implantes de conexões incluindo MT, EH e IH. A carga aplicada de 150N foi distribuída no centro da superfície palatina de cada dente, com um ângulo de 45° em relação ao longo eixo do dente. A distribuição de deformação/estresse foi analisada em todos os grupos. Resultados: O desenho da conexão do implante influencia a distribuição e intensidade da tensão/deformação no sistema prótese/implante. A conexão EH promove menor deslocamento da estrutura protética no caso estudado; no entanto, o parafuso do pilar desta conexão recebe a maior parte da tensão de von Mises do sistema. A conexão MT apresentou pequenos valores de tensão de von Mises no parafuso em comparação com as conexões EH e IH. Conclusões: O pilar MT parece ser mais vantajoso do que as conexões EH e IH quanto à distribuição de tensões em nosso modelo de estudo.

Descritores: Implantes Dentários; Prótese Dentária; Análise de Elementos Finitos.

Resumen

Propósito: Este estudio tuvo como objetivo evaluar, a través del método de elementos finitos 3D, el comportamiento biomecánico de tres tipos diferentes de conexiones protésicas (hexágono externo (EH), hexágono interno (IH) y cono morse (MT)) en prótesis parciales fijas implantosoportadas. (ISFPD) colocado en la región anterior del maxilar. Métodos: Se construyó un modelo anatómico tridimensional (3D) del maxilar anterior utilizando una base de datos de tomografía computarizada. Los implantes se colocaron en las posiciones de los incisivos laterales y los pónticos en las posiciones de los incisivos centrales simulando un ISFPD con cuatro elementos cementados. La rehabilitación protésica se realizó con tres sistemas de implantes de conexiones que incluyen MT, EH e IH. La carga aplicada de 150N se distribuyó en el centro de la superficie palatina de cada diente, con un ángulo de 45° con respecto al eje longitudinal del diente. La distribución de tensión/estrés se analizó en todos los grupos. Resultados: El diseño de la conexión del implante influye en la distribución y la intensidad de la tensión/deformación en el sistema prótesis/implante. La conexión EH promueve un menor desplazamiento de la estructura protésica en el caso estudiado; sin embargo, el tornillo de pilar de esta conexión recibe la mayor parte de la tensión de von Mises del sistema. La conexión MT mostró valores pequeños de tensión de von Mises en el tornillo en comparación con las conexiones tipo EH e IH. Conclusiones: El pilar MT parece ser más ventajoso que las conexiones EH e IH en cuanto a la distribución de tensiones en nuestro modelo de estudio.

Descriptores: Implantes Dentales; Prótesis Dental; Analisis de Elementos Finitos.

INTRODUCTION

Oral rehabilitation with dental implants in the anterior region of the maxilla is considered one of the most challenging approaches, in which the peri-implant bone level maintenance is considered critical in this esthetic zone[1]. The long-term stability of the peri-implant bone level depends on the reliability of the connections among different parts of the implant, mainly in implant-abutment connection[2]. The application of an overload to the implant/abutment structure that results in tensile or compressive stress in the crestal bone coronal portion can cause bone resorption in reaction to a microtrauma in the bone trabeculae[3]. In this way, the implant-abutment connection design has been suggested to be one of the major aspects affecting peri implant bone remodelling[2].

Different types of implant-abutment connection design can create diverse biomechanical behaviour[4]. The external hexagonal geometry (EH) was firstly proposed in the Brånemark system (Nobel Biocare) to facilitate implant insertion and to provide an anti-rotation feature which ensures reversibility and compatibility with different systems[5]. However, HE connections have been associated with concentrated stresses in the first threads of the implant and the implant-abutment interface[4]. The stresses resulted in abutment micromovements that occasion prosthetic interface instability, screw loosening, gap formation, or fatigue fracture[5].

To overcome these HE biomechanical limitations, several internal-connection implants designs (IC), including internal hexagon (IH) and morse taper (MT), were developed to ensure a stable implant-abutment connection, reducing micromovements[6]. It's suggested that a long connection into the body of implant would ensure a better[6] lateral stresses distribution[6,7]. Moreover, the IC has shown better implant-abutment seal, which could potentially result in a smaller microbial reservoir and better esthetics by maintaining the restorative margin closer to the implant body[6,8]. However, although IH connection showed easy abutment connection, suitability for one stage implant installation, higher resistance to lateral loading and high stability; some disadvantages were described including thinner lateral fixture wall at the connecting part and difficulty for adjustment of divergences between implants[9]. For MT connection, a better sealing capacity and high mechanical stability were observed due to the intimate contact between the implant and abutment[10].

There are several biomechanical techniques to evaluate the stress distribution of occlusal forces in peri-implant bone simulating different clinical situations. The finite elements method (FEM) has been applied to the dental implant field to predict stress distribution patterns in the implant bone interface not only in comparisons of shapes of implants (cylindrical or conical), diameters and lengths, but also to model various clinical scenarios and prosthesis designs[11,12]. FEM is a numerical method that enables the calculation of stress, displacement and deformation based on the evaluation of the mechanical behaviour equation of materials. The method has the advantage of solving complex structural problems, such as the maxillary structure, by dividing the complex geometries of the structure in much smaller domains (elements), to be able to calculate the result of applied force on this structure[13].

Although the impact of different implant connection systems has already been studied in implant-supported dentures, the influence of implants connections designs in the rehabilitation of the anterior maxilla region using a cemented rehabilitation of four dental elements has not yet been evaluated. Based on that, this study aimed to evaluate, through 3D finite elements method, the biomechanical behaviour of three different types of prosthetic connections (EH, IH and MT) in implant-supported fixed partial dentures placed in the anterior region of the maxilla. The null hypothesis was that no significant difference among different types of prosthetic connections evaluated.

MATERIAL AND METHOD

A 3-dimensional (3D) anatomical model of the anterior maxilla with an intercanine distance of 27.3 mm was constructed using the software Rhinoceros v4.0 SR8 (McNeel North America, Seattle, WA, USA) (Figure 1)[14]. The model was generated by combining several anatomical structures of maxillar bones obtained from the computed tomography database owned by the Renato Archer Center of Information Technology (Campinas, São Paulo- Brasil)[14].

The geometric models of the implants and abutments were provided by the manufacturer (Neodent Ltda, Brazil) and edited by the same software used to generate the maxillar bone geometry, to promote some essential simplifications. Three connection systems were compared including EH, IH and MT. The implants diameters and heights (4.3 x 13mm) as well as abutment type (mini pilar cônico, Neodent Ltda, Brazil), were the same for all connection types. The mechanical properties of the structures were provided by the manufacturer (abutments, abutment screw and implants materials) or available in the literature

http://doi.org/10.21270/archi.v11i4.5601

(prosthetic structure (nickel-chromium alloy)[15], cortical and trabecular bone)[16,17] with the values shown in Table 1.

Table 1. Material properties used in finite element analysis studies of dental implants

Materials	Young's modulus (E) – Mpa	Poisson's ratio (nu)	Reference
Cortical Bone	13.70	0.30	Meijer et al.[16] (1993) Menicucci et al.[17] (2002)
Trabecular Bone	1.30	0.30	Meijer et al.[16] (1993) Menicucci et al.[17] (2002)
Implant (commercially pure titanium grade 4)	103.000.00	0.36	Manufacturer
Abutment and Abutment screw (titanium alloy)	105.000.00	0.36	Manufacturer
Prosthetic Structure (nickel-chromium alloy)	210.000.00	0.28	Anusavice[15] (2003)

The implants were positioned in the lateral incisor positions and pontics in the central incisor positions, based on a previous study[14], simulating implant-supported fixed partial dentures with four cemented elements (Figure 1). To simplify the bone model, a plateau was drawn in the region of the posterior teeth and the threads of implants were represented by symmetric rings. A controlled FEM mesh was used to represent the model of the implants and the bone (Figure 1).

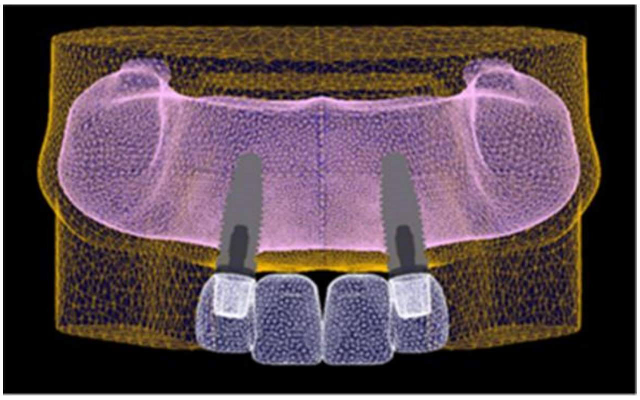

Figure 1. Front view of the finite element model of the anterior maxilla with the implants positioned in the lateral incisor positions and pontics in the central incisor.

The number of elements and nodes used in this study are given in Table 2.

Table 2. The number of elements and nodes used in finite element models.

	Models of Morse-taper connection	Models of external hexagon connection	Models of internal hexagon connection
Elements	140,136	1,038,096	1,235,794
Nodes	908,588	669,839	796,626

The bone-implant interface was considered bonded, and all the screw threads were filled with a bone to simulate an osseointegrated implant. The interfaces between cortical-trabecular, trabecular implant, cortical-implant, prosthetic structure-abutment, and abutment screw implant were considered bonded; the interfaces between abutment-implant and abutment-abutment screw were considered common contact[14] (Table 3).

Table 3. Description of the contact type in each interface

Interface	Contact type
Cortical/Trabecular	Bonded
Trabecular/Implant	Bonded
Cortical/Implant	Bonded
Abutment /Implant	Common
Abutment/Abutment screw	Common
Abutment screw/Implant	Bonded
Prosthetic Structure/Abutment	Bonded

The maxilla mechanical models were configured as linear-elastic, isotropic, and homogenous properties[18,19]. The forces were applied on the region equivalent to the cingulum of each tooth present in the prosthesis, perpendicular to the surface of each tooth and in an angle of 135° related to the long axis of the tooth[20,21]. A total load of 150N was applied to the prosthetic structure[22].

RESULTS

Concerning prosthetic displacement profile, the IH and MT connections have similar profiles of prosthetic displacement (Figure 2A and 2C) in this type of prosthetic configuration. The EH connection has shown the same pattern of stress distribution with differences in terms of absolute values of 0.02mm lower than the other connection types (Figure 2B).

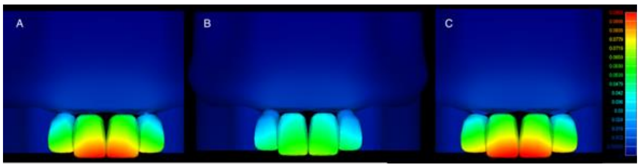

Figure 2. Front view of the prosthetic structural displacement for the Morse taper (A), external hexagon (B) and internal hexagon (C) implants connection.

The von Mises stress was used in this study as a parameter to view the mechanisms of stress dissipation and to compare among connection types. In the MT connection, the peak of von Mises stress was in the anterior region of the abutment with a concentration in the abutment top. On the back, these stresses were more dissipated and have less area of concentration (Figure 3A). In EH connection, the von Mises stress was also located in the anterior region, however, this stress was specifically in the base of the prosthetic abutment in the abutment-implant contact. A small amount of stress was distributed in hexagon edges and walls (Figure 3B). For IH connection, the propagation of von Mises stress starts in the base of the abutment. In the coronal portion, the stress was concentrated in the back and bottom of the hexagon edges (Figure 3C).

http://doi.org/10.21270/archi.v11i4.5601

In the region of the implants, the von Mises stress distribution tended to be in the first threads of the implant insertion, corresponding to the cortical bone (Figure 4). Moreover, the stress distribution was predominantly located in the anterior region for MT and IH connections (Figure 4A and 4C). For both connections, the von Mises stress distribution was observed in the implant platform area and the internal region of the implants; however, the HI connection have a smaller area of von Mises stress distribution compared to Morse-taper implants (Figure 4A and 4C). For EH connections, the highest von Mises stresses were concentrated in the posterior region of the base, walls and edges of the hexagon external part with the stress peak located at the edges of the implant hexagon (Figure 4B).

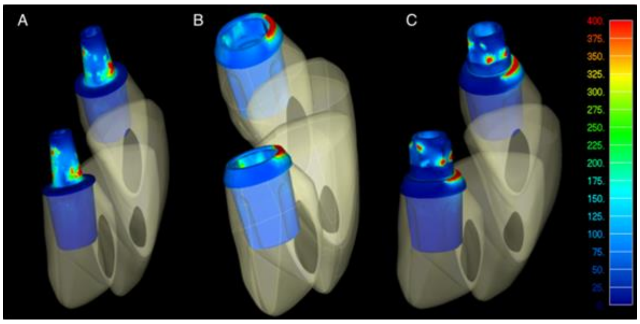

Figure 3: Von Mises stress in abutment of Morse taper (A), external hexagon (B) and internal hexagon (C) implants connection.

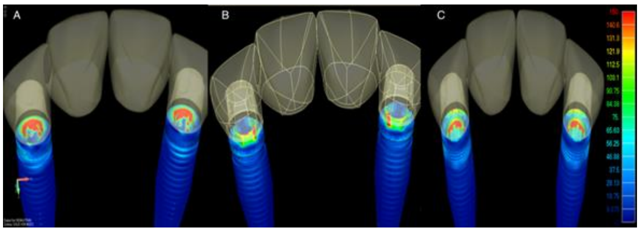

Figure 4: Von Mises stress in implant body of Morse taper (A), external hexagon (B) and internal hexagon (C) implants connection.

For the von Mises stress distribution description in the implants abutment screws (Figure 5), the screw was divided into parts including screw head, screw shaft top, screw shaft bottom, screw thread screw top and thread bottom. For MT connection, the stress was localized in the screw thread bottom region and mainly at the screw shaft bottom, with the peak of stress less than 150MPa (Fig 5A). In the abutment screw of the EH connection, the peak of von Mises stress was observed in the base of the screw head and shaft, with an intensity of about 270MPa. Stress concentration was also observed with lower intensity in the region of top screw thread top (Fig 5B). In IH connection, the von Mises stress peak was localized in the regions of the head, shaft top and thread top of the screw with the peak stress of 260Mpa (Figure 5C).

In the posterior view (Figure 6), all the abutment screws show high values for von Mises stress, distributed in large areas. In the MT connection, the von Mises stress was presented in the region of contact in the screw head, shaft bottom and thread bottom. The peak stress value of this screw was about 150MPa (Figure 6A). The screws of IH and EH connections showed higher stress values in comparison to MT connection screw with the maximum von Mises stress of 300Mpa in both screws. The stress was mainly located at the base of the screw head, shaft bottom and thread top for EH connection (Figure 6B). For IH connection, the regions of highest stress concentration were base of the screw head, shaft top and thread top (Figure 6C). Although, the maximum stress area of IH was lesser than the EH, the same von Mises stress peak value of 300Mpa was observed for both connection types.

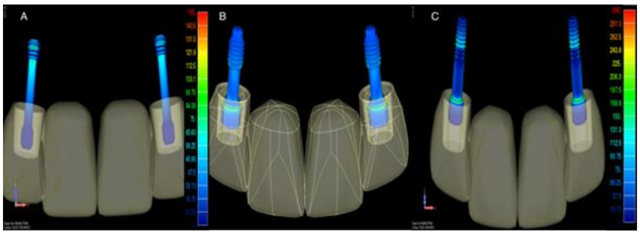

Figure 5: Frontal view of von Mises stress in abutment screws of Morse taper (A), external hexagon (B) and internal hexagon (C) implants connection.

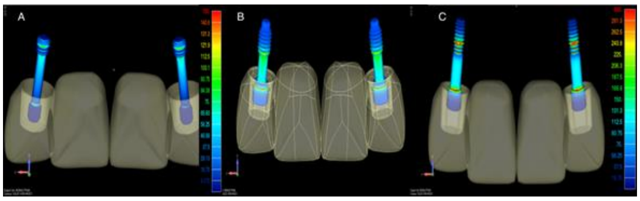

Figure 6: Posterior view of von Mises stress in abutment screws of Morse taper (A), external hexagon (B) and internal hexagon (C) implants connection.

DISCUSSION

Mechanical stress distribution and prosthetic structure displacement are important factors for appropriate functioning and stability of implant rehabilitation and these aspects are directly associated with the accurate and precise implant-abutment connection[23]. Based on that, the present study evaluated the biomechanical behaviour of three different types of prosthetic connections (EH, IH and MT) using a 3D finite element method to simulate an implant-supported fixed partial denture with four cemented elements placed in the anterior region of the maxilla. The implants placed in the lateral incisor positions and pontics in the central incisor positions was based on our previous study which demonstrated that this prosthetic configuration limited the displacement of the prosthetic structure[14].

The null hypothesis of this study was rejected based on the difference between the mechanical behaviour of the different types of prosthetic connections studied. The type of prosthetic connection showed an influence on the distribution and intensity of stress/strain in the prosthesis/implant system simulated in this study. Primarily, the EH connection showed the smallest prosthetic structure displacement in this study which is favourable for the maintenance and longevity of the prosthetic structure. However, in terms of the stress distribution, the MT connection showed lower stress distribution at the implant-abutment interface in comparison to the EH connection, which is consistent with the stress distribution observed in previous studies[24-27]. Moreover, the distribution stress was more broadly dissipated over the MT conical surface, while the von mises stress was localized at the edges of the hexagonal abutment in EH and IH connections. This EH connection stress distribution pattern was also observed by Faegh and Müftü[25]. According to these authors, this stress distribution can be attributed to the geometric discontinuities of the abutment shape. Therefore, the MT abutment seems to be more advantageous than the EH and IH abutments concerning stress distribution in our study model.

Concentrated stress along the neck of the implant was found in all connection type evaluated in this study. This implant region corresponds with the cortical bone surface and this finding corroborate with the results observed in other studies[28,29] suggesting that the cortical bone contributes effectively in absorbing loads transferred through the abutment[29]. For HI and MT, the von mises stress distribution was observed mainly in platform area and the internal region of the implants, while in EH connections the stress peak was located at the edges of the implant hexagon. Similarly, Hanoka et al.[29] described that the conical abutment/implant system transmitted the axial tensions to the internal walls of the implant, providing a location closer to the apex. Following some authors, this type of connection can improve the stress distribution on the alveolar bone crest, diminishing the marginal bone reabsorption deriving from the stress accumulation in the implant neck [28-30]. Furthermore, Minatel et al.[4] also showed a significant increase in stresses among the MT abutments, as demonstrated in this study. Its can be justified by the MT internal connection which results in the centralization of stresses along the axis of the implant and adequate stability[4].

Regarding von Mises stress in the abutment screws, the high stress was observed in the EH screws following by IH screws. According to Burguete et al.[31] the screw is responsible for the implant-abutment connection stability in the EH connection under functional forces. As our study, higher stress values were also observed to be concentrated on some points over the screw surface (screw shaft top, screw shaft bottom and screw thread top) in other studies[2,19,32] indicating a higher possibility of screw loosening or even fracture at the corresponding regions[2]. Several retrospective clinical studies have shown a high incidence of screw loosening and/or fracture, usually associated with EH connection[33-35]. The EH incidence of screw loosening can be associated with the short external hexagon that does not stabilize the system during the application of lateral forces resulting in higher stress values in the screw.

In contrast, the MT connection seems to reduce the stress on the portion of the abutment screw suggesting a mechanical advantage of conical connections over EH connection[2,36]. The mechanics of the MT connections resulted in lower incidences of mechanical complications, specifically abutment screw loosening and fracture, in comparison with those reported for EH implants[10]. According to Sutter et al.[36], the conical angled design could reduce screw loosening by creating a friction lock. This mechanical advantage suggested that MT connection can be more indicated for cemented prosthesis, once the screw loosening/fracture can cause the loss of all prosthetic treatment in this rehabilitation type. However, the screws loosening phenomenon can also be reduced by choosing abutments with accuracy for the implant-abutment fitting, suitable materials and execution of preload of abutment screw[37,38]..

The FEM is an excellent method to obtain detailed quantitative data, and it enables accurate visualization of the stress distribution and displacement in models of complex geometries such as the maxilla. In the present study, the model properties were considered homogeneous, isotropic, and linearly elastic. Similarly to other studies[29,39,40], a condition of 100% bone/implant contact and the application of static loads was utilized to simulate a specific clinical situation since several variables are unable to be reproduced[29]. However, although this inherent limitations in any FEM study that limit the extrapolation of the results to clinical situations, the results presented in this study are important to conduct more relevant clinical studies on this question.

In conclusion, the EH connection promotes less displacement of the prosthetic structure in the case studied; however, the abutment screw of this connection receives the most of the von Mises stress of the system and can be subject to mechanical failure. The MT connection showed small values of von Mises stress in the screw, which can be favourable to a cemented prosthetic rehabilitation, avoiding the abutment screw loosening.

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CONFLICTS OF INTERESTS

The authors declare no conflicts of interests.

CORRESPONDING AUTHOR

Luís Geraldo Vaz
School of Dentistry at Araraquara/ FOAr-UNESP,
UNESP - Univ Estadual Paulista
Rua Humaitá, 1680
14801-093, Araraquara – SP, Brazil
Fone: +55 16 33016420
e-mail: geraldo.vaz@unesp.br

Received 05/10/2021
Accepted 04/01/2022