UDC: 616.314−085.273:616.314−77−039.71

PRF SUPPORTED SOCKET PRESERVATION - A PREDICTABLE IMPLANT OUTCOME

ПРЕЗЕРВАЦИЈА НА ПОСТЕКСТРАКЦИОНА АЛВЕОЛА СО ТРОМБОЦИТНО ЗБОГАТЕН ФИБРИН ЗА ПРЕДВИДЛИВ ИМПЛАНТЕН УСПЕХ

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Abstract

After the extraction of teeth due to cavities, trauma or periodontal disease, the subsequent healing of postexstraction alveolar socket results in bone irregularities of the residual alveolar ridge (reduction of height and width). The factors of bone resorption can be divided into: anatomical, metabolic, functional and prosthetic factors. Postextraction alveolar resorption is significantly higher in the buccal aspects of both jaws. **The process** of bone remodeling will be more pronounced in clinical cases with present dehiscence and fenestration of the buccal lamina. The extent of bone resorption of the residual ridge is proportional to the time elapsed after the dental extraction. Deformities of the residual alveolar ridge are classified according to morphology in three consecutive classes. A case of 50-year-old male patient is presented with new regenerative protocols with PRF and a sticky bone for socket preservation. Using a combination of a sticky bone and PRF membranes for socket preservation is a simple and cost-effective source of growth factors that increase the predictability and success outcome of implant supported prosthodontics solutions. **Key words:** socket preservation, bone resorption, PRF protocol, immediate loading, dental implants.

Апстракт

По загубата на забите поради кариес, траума или пародонтално заболување, последователното заздравување на алвеолата по екстракција, резултира со неправилности на резидуалниот алвеоларен гребен (намалување на коскениот квантум во вертикална и хоризонтална насока). Факторите на ресорпција на коските може да се поделат на: анатомски, метаболитички, функционални и протетски фактори. Алвеоларната ресорпција на постекстракционата алвеола е значително поизразена во предел на букалните аспекти на двете вилици. Процесот на ремоделирање на коската ќе биде поизразен во клиничките случаи на присутна дехисценција и/или фенестрација на букалната ламина. Обемот на ресорпција на резидуалниот алвеоларен гребен е пропорционален со времето поминато по денталната екстракција. Деформитетите на резидуалниот алвеоларен гребен се класифицираат според морфологијата во три класи. Во трудот е презентиран клинички случај на 50-годишен пациент каде е претставена современа техника на презервација на постекстракционата алвеола со помош на најнови регенеративни протоколи (PRF мембрана и т.н.„леплива коска" за зачувување на коскениот волумен и квалитет). Користењето на комбинирана техника на „леплива коска" и PRF мембрана е едноставен и економичен извор на фактори на раст кои јаподобруваат прогнозата и успехот на имплантно-носената протетска реставрација. **Клучни зборови:** презервација на постекстракциона алвеола, коскена ресорпција, PRF протокол, имедијатно оптеретување, дентални импланти.

Introduction

After the tooth extraction resulting from caries, trauma or periodontal disease, the subsequent healing of the alveolar socket results in bone irregularities of the residual alveolar ridge (reduction of height and width). Unfortunately, many routine extractions are performed without paying attention to the alveolar ridge. Therefore, while performing the extractions in modern dentistry, an enormous attention is paid to minimizing trauma during the oral surgery procedure.

After the extraction, the socket is filled with blood containing proteins and damaged cells that initiate the formation of a fibrin network with adhered platelets (blood coagulum in the next 24 hours). Coagulum is taken as a physical matrix that initiates the movement of mesenchymal stem cells with their coagulation factors. Later in the wound, neutrophils and macrophages digest tissue debris and bacteria. Afterwards, fibrinolysis of the blood coagulum occurs. The proliferation of mesenchymal cells leads to a gradual replacement of the coagulum with granulation tissue (2-4 days). Within a week, the vascular network is formed, while in the two weeks the marginal surface of the extraction wound is covered with young connective tissue rich in inflammatory cells and blood vessels. In 4-6 weeks, the majority of the socket is filled with young bone tissue without a trabecular form, while the soft tissue is gradually keratinized. In 4-6 months, the mineral tissue in the socket is strengthened with new layers of lamellar bone[1,2].

The loss of the alveolar bone can be associated with various factors, such as endodontic pathology, periodontology, trauma or aggressive manipulation of the therapist during routine extraction. The anatomical pre-existing conditions, the metabolic status of the patients and the functional load could also play an important role considering the bone remodeling patterns. Mechanical stimulation of the alveolar bone during mastication is crucial in maintaining the bone volume[3].

The resorption pathway is different in the maxilla and the mandible. As a result, after a few years, the maxilla progressively becomes smaller while the mandibular arch becomes wider. There is a tendency to create a class III intermaxillar ratio. Postextraction alveolar ridge resorption is significantly higher in the buccal aspects of both jaws. Bone remodeling is of greater significance if dehiscence and fenestrations are present, resulting in a larger buccal concavity of the residual alveolar bone. The extent of bone resorption of the residual ridge is closely related to the time elapsed after dental extraction. The loss of tissue contours is higher in the early postextraction period (the first 6 months). The wound healing in the maxilla occurs more rapidly, and therefore, resorption in the maxilla is faster.

Preservation of the alveolar ridge with the guided bone and tissue regeneration technique should be carried out at the time of tooth extraction, in order to control bone resorption, to preserve the original dimensions and contours of the alveolar ridge and create conditions where the implant placement would be easy predictable.

Contemporary trends in regenerative procedures include using autologous blood derivates (second generation of platelet rich fibrin –PRF) combined with various graft materials as a gold standard in postextraction alveoli (sticky bone). Sticky bone presents bone graft material entrapped in fibrin mesh.

Case description

A 50-year-old male patient, nonsmoking, without any history of systemic disease was referred to our Department for oral surgery, after several episodes of dentoalveolar abscesses related to the tooth 14. The clinical examination presented a remaining, not endodontically treated root. Vitality tests on the tooth were negative and on vertical percussion, slight pain was present. Retroalveolar radiographic examination showed a diffuse, radiolucent chronic periapical lesion (Figure 1).

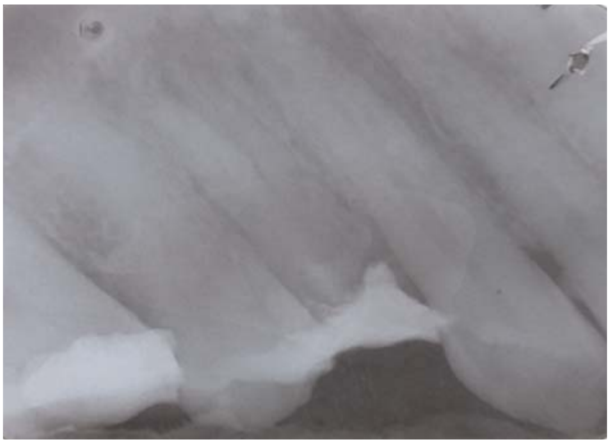

Figure 1. *Retroalveolar rtg evaluation of tooth 14*

Figure 2. *Advanced platelet rich fibrin (A-PRF) preparation*

Extraction and socket preservation using „sticky bone“ was planned. A prophylactic antibiotic regimen was used. Prior to the procedure of socket preservation, a procedure of „sticky bone“ preparation was done that included venepunction and fast drawing of blood into A-PRF red tubes. Immediate centrifugation protocol for A-PRF was done according to Dr. Choukroun's instructions, 1300 rotations per minute during 8 minutes. At the end of the spin, tubes were removed from the centrifuge and placed in the metal holder. Caps were removed and after a period of 5 minutes for enhanced clot formation, clots were removed. A-PRF can be used as a barrier membrane; extraction socket plugs may be cut into pieces and combined with bone grafts, they can also be punched and sutured (Figure 2.).

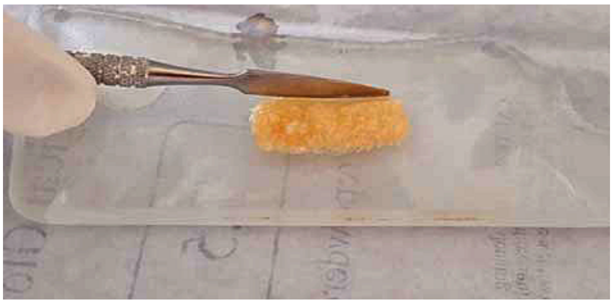

Figure 3. *Sticky bone process*

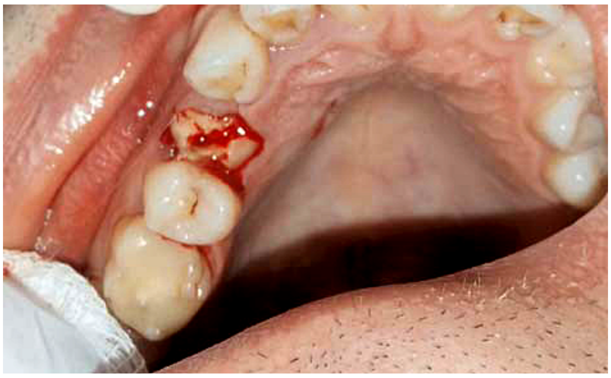

Figure 4. *Atraumatic extraction*

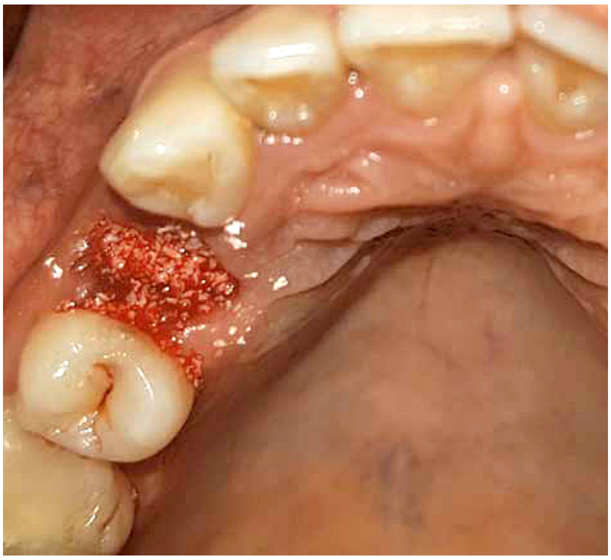

Figure 5. *Sticky bone graft material was placed in the postextraction alveoli*

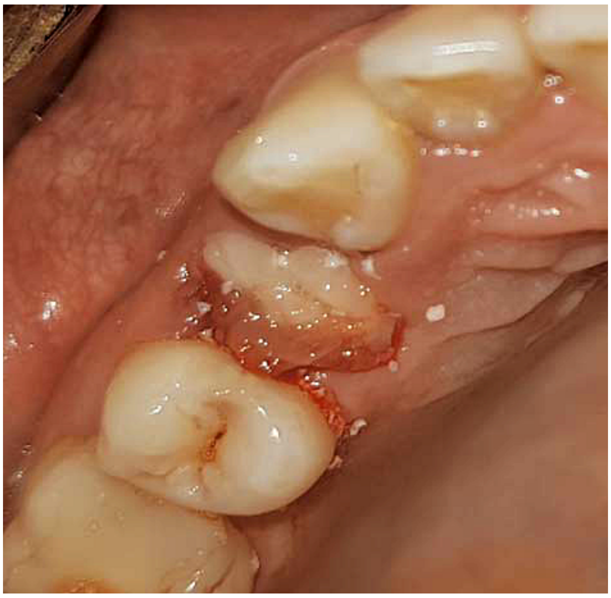

Figure 6. *A-PRF membrane placement*

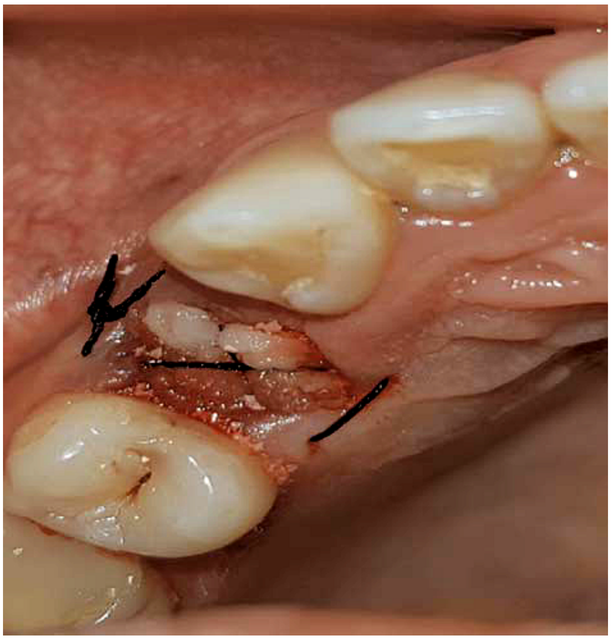

Figure 7. *Stabilization suture placement*

The i-PRF protocol includes using i-PRF orange tubes for centrifugation with 700 rpm and centrifugation time of 3 minutes. At the end of the spin, an orange supernatant is formed on the surface. I-PRF remains liquid for about 10-12 minutes, and then it clots. The aspiration of the supernatant is done with the needle.

In the PRF box special compartment, the „sticky bone" was created. The fibrin membrane was cut into small pieces and mixed with a bone grafting material

Figure 8. Clinical view of healed site after 5 months

Figure 11. Final implant supported prosthodontic restoration

Figure 9. Implant placement

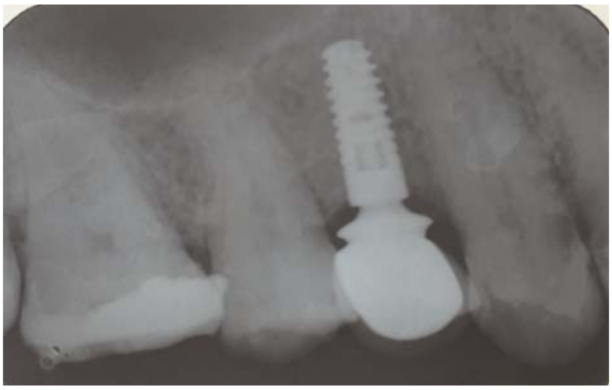

Figure 12. Two year follow- up

Figure 10. Immediate loading and a temporary crown

(xenograft granules). The exudate of PRF was used to hydrate the graft granules. Afterwards, the i-PRF was poured drop by drop onto the bone graft material, in order to avoid overflow of i-PRF from the bone graft (Figure 3).

The extraction was performed completely atraumatically, by using atraumatic elevators (Figure 4). The flapless technique was first described by Landsberg and Bichacho in 1994. This technique does not damage the papillae; they remain attached to the cement of adjacent teeth. Atraumatic extraction was carried out without damaging the surrounding remaining bone and the site was thoroughly debrided by curettes and excessive irrigation in order to remove any granulated tissue. Then, the sticky bone graft material was placed in the post-extraction alveoli with a slight pressure and adaptation (Figure 5). Above the graft, the biological membrane (A-PRF membrane) was applied, whose ends were placed under the previously created underlying places. The edges of the postextraction soft tissue were approximated with stabilization suture using silk suture. (Figure 6,7). After the intervention, anti-inflammatory drugs and analgesics were administered and frequent rinsing with chlorohexidine solution was recommended. The postoperative period was uneventful.

The patient was evaluated after 5 months and an endosseous implant with immediate loading protocol was performed (Figure 8,9,10). Three months after the implantation surgery, the patient was recalled for definite prosthodontic solution (Figure 11, Figure 12).

Discussion

The bone is a living tissue that is constantly remodeling or changing its geometry, density (degree of calcification) and structure (orientation) under different factors such as biomechanical load, metabolic and hormonal effects, nutrition and neuronal influences.

Biomechanical laws defined by Wolff (1892) and Frost (1983) explain that the bone remodeling process depends on different characteristics of the masticatory forces such as the quantum of strength, the change in the size of the force, the number of cycles (mastication cycles) and the change in force distribution[4].

Canullo et al. claim that the degree of resorption is individual and depends on the osteoclast activity and they describe two kinds of individual trends in patients: individual resorptive and individual anabolic trend. The latter responds to dental extraction with intense bone apposition due to individual anabolic constitutions[5].

During the first 3 months after tooth loss, vertical bone resorption is around 2 mm. Horizontal resorption is 3-6 mm in the first 6 months. For a period of 3 years, the bone volume is reduced by 40-60%. Resorption of the vestibular lamina in both jaws is greater[6].

The resorption pathways described by Carl Misch and Randolph Resnik (2017) consider that the extent of bone resorption of the residual ridge is closely related to the time after dental extraction. The loss of tissue contours is greatest in the early postextraction period (the first 6 months). After several years, the maxilla progressively becomes smaller, while the mandibular arch becomes wider. There is a tendency to create a class III intermaxilar ratio. The degree of resorption is individual and depends on the osteoclast activity[7].

The Cologne Classification of Alveolar Ridge Defects (2013) uses three part codes to describe the effect of the alveolar ridge as comprehensively as possible with a view to existing therapeutic options[8]:

Part 1: Orientation of the defect

h: horizontal
V: vertical
C: combined
S (or +S): sinus area

Part 2: Reconstruction needs associated with the defect

1. low: < 4 mm
2. medium: 4-8 mm
3. high: > 8 mm)

Part 3: Relation of augmentation and defect region

i: internal, inside the contour
e: external, outside the ridge contour

The simplest and most predictable way to preserve the width, height, and position of the alveolar ridge is the preservation of the alveolar ridge at the time of extraction[9]. Only two thirds of the alveolar space that spontaneously heals after the extraction will be supplied with new bone[10]. Alveolar ridge preservation is guided bone regeneration (GBR) application at the time of tooth extraction to control bone resorption and to preserve original ridge dimensions and contours (hard and soft tissues)[11].

The first techniques of preserving the alveolar bone were presented in 1980, using a hydroxyapatite in the form of a dental root cone[12,13].

The key to successful alveolar bone preservation was described by Carl Misch that included: atraumatic extraction; evaluation of the walls of the socket and the size of the defect; asepsis and complete removal of granulation tissue; providing adequate blood supply to the graft; correct selection of graft material and ensuring adequate recovery time[14].

Classical technique for socket preservation is carried out in the following order: atraumatic extraction, placement of graft material and primary closure of the postextraction wound. It is recommended to raise the mucoperiosteal flap prior to the extraction. To secure the graft material, a barrier membrane is used, while the closing flap is displaced coronary to allow primary closing[15]. The potential problems could be associated with loss of interdental papilla height if the papillary attachment is involved in incision line, a recession of adjacent teeth, difficulty in coronary displacement of the flap and sequential inability to achieve primary closure, cicatrix formation along the vertical incisions, coronal dislocation of keratinized tissue and reduction of the level of keratinized tissue on the vestibular aspect.

The technique without any flap is also called the flapless technique. In the original procedure described by Landsberg and Bichacho in 1994, a small free autogenous gingival graft with adequate dimensions is stabilized using suture. Once the graft from the donor site has been cut off, there is a minimal shrinkage of the soft tissue graft and a reduction in its primary dimensions[15].

Future therapies with autologous stem cells and recombinant growth factors may have the potential to reduce the need for autologous bone harvesting in the future. However, until now, these therapies are limited to designated medical centers[8].

The various regenerative biomaterials used for socket preservation are bone grafts, membranes, biologic modifiers, and platelet concentrates[16]. Platelet rich plasma (PRP) and plasma rich in growth factors (PRGF) are the first generation of platelet concentrates.

Compared to PRP, PRF has many advantages over PRP. First, PRF can be squeezed to form a membrane and can be used as fibrin bandage serving as a matrix to accelerate the healing of wound edges[16]. Second, PRF does not use bovine thrombin or other exogenous activators in the preparation process[17]. Its natural fibrin architecture seems responsible for a slow release of growth factors and matrix glycoproteins during 7 days[18].Third, the chair side preparation of PRF is quite easy and fast, and simplifies processing without any artificial biochemical modification. Fourth, this produces an inexpensive autologous fibrin membrane in few minutes and eliminates the cost of membrane.

PRF (platelet-rich fibrin) which belongs to a new second generation of platelet concentrates[19,20], and was first developed in France, by Choukroun et al.[21] for specific use in oral and maxillofacial surgery. Fibrinogen is converted into an insoluble fibrin during enzymatic cascades of coagulation in the presence of thrombin, factor XIII, fibronectine, and calcium ions[22]. The polymerized fibrin gel constitutes the first cicatricial matrix of the injured site[23,24].

The biochemical analysis of the PRF composition analyzes that it consists of an intimate assembly of cytokines, glycanic chains, and structural glycoproteins enmeshed within a fibrin network[21]. The PRF matrix enmeshes glycosaminoglycans (heparin, hyaluronic acid) from blood and platelets. Glycosaminoglycans have great capacity to support cell migrations and healing processes[23].

Platelets are discoidal, anuclear structures formed in the bone marrow from megakaryocytes. Activation and degranulation of the platelets releases the cytokines that stimulate the cell migration and proliferation within the fibrin matrix.

PRF platelet cytokines remain trapped in the fibrin meshes, and probably even in the fibrin polymers (intrinsic cytokines)[25]. They stay trapped in the PRF fibrin matrix even after serum exudation, which necessarily implies an intimate incorporation of these molecules in the fibrin polymer molecular architecture. These cytokines have increased lifespan and they will be released at the time of initial cicatricial matrix remodeling (long-term effect).

A newly developed product of fabricating PRF-enriched bone graft matrix (also known as “sticky bone”) using autologous fibrin glue has been introduced. As an alternative to titanium mesh or block bone procedure, sticky bone was introduced in 2010 by Sohn DS[26]. Sticky bone is a bone graft material entrapped in fibrin mesh. Particulate bone powders are strongly interconnected to each other by a fibrin network. Sticky bone has numerous advantages: 1) It is flexible, well adapted over various shape of bony defect; 2) The stability of the grafted bone is granted against any motion and bone loss during the healing period is minimized. Since the volume of augmentation is maintained during the healing period, it reduces the need for ti-mesh membrane; 3) Fibrin network entraps platelets and leukocytes to release growth factors, so bone regeneration and soft tissue healing are facilitated; 4) No chemical additives are needed to fabricate the sticky bone[27].

Fibrin rich gel is known to release slow growth factors[28,29] such as platelet-derived growth factor (PDGF), transforming growth factor-β (TGF-β), fibroblast growth factor (FGF), vascular endothelial growth factor (VEGF) and insulin-like growth factor (IGF), which stimulate cell proliferation, matrix remodeling, and angiogenesis[30].

PRF poor mechanical properties have resulted in promotion of a new entity ”sticky bone” that has found a place in the regenerative field owing to its advantages over the solo use of PRF[31].

The “sticky bone“ acts like a mineral scaffold for orientation and organized migration of the bone forming cells. Moreover, it also contains growth factors necessary for the stimulation, differentiation and migration of cells[32]. The use of bone substitute with fibrin, platelets and leukocytes have shown a better histological evidence of hard bone and soft tissue formation than the use of PRF as a single filling material for the extraction socket[32].

Conclusion

The socket preservation technique conserves the alveolar architecture and prevents hard and soft tissue collapse that minimizes the necessity for further augmentation procedures in implant placement. The use of new innovative PRF autologous products transforms simple socket preservation into a more effective procedure. Using a combination of a sticky bone and PRF membranes for socket preservation is a simple and cost-effective source of growth factors that increase the predictability and success outcome of implant supported prosthodontic solutions.

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UDC: 616.314–76

THE DISTRIBUTION OF OCCLUSAL VERTICAL STRESS IN SHORTENED DENTAL ARCHS WITH CROSS-ARCH DENTAL BRIDGES

ДИСТРИБУЦИЈА НА ОКЛУЗАЛНИ ВЕРТИКАЛНИ СИЛИ КАЈ МАЛКУ СКРАТЕНИ ЗАБНИ НИЗИ СО МОСТОВНИ КОНСТРУКЦИИ

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Abstract

The **aim** of the research is to analyze the distribution of occlusal vertical forces of the abutment teeth in bridge constructions with slightly shortened dental arches. **Material and method.** Subject of research are bridge constructions in slightly shortened dental arches in the mandibula. The Finite Element Method (FEM) was applied, and the analysis was made with simultaneous both-sided loading on the distal three abutment teeth. The simulated loading forces are with strength between 0.5 to 512N. Distributed occlusal vertical forces are measured at the level of the periodontal ligament (PDL). **Results.** The results show a symmetrical distribution of forces on both sides of the bridge structure. The largest forces are distributed on teeth with applied force. The smallest forces are distributed in the apical part of PDL. There was no difference between the total distributed forces on teeth and the distributed forces on the lateral part of the PDL. The measured strength of the forces and the percentage are within the known values in the literature. **Conclusion.** The obtained results of the research are within the level of known functional values of the mastication forces. This means that the biomechanical aspect for bridge constructions with slightly shortened dental arches is not disputable, but the decision to make it should also be based on other individual and clinical conditions. **Keywords:** Occlusal vertical forces, bridge construction, shortened dental arches, finite elements method (FEM), periodontal ligament (PDL).

Апстракт

Цел на трудот е да се направи анализа на дистрибуцијата на оклузални вертикални сили на забите носачи кај мостовни конструкции кај малку скратени забни низи. **Материјал и метод.** Предмет на истражување е мостовна конструкција кај малку скратен забен низ во долна вилица. Применет е метод на конечни елементи (МКЕ) а анализата е направена со симетрично оптоварување на дисталните три заби носачи. Симулираните сили на оптоварување се со јачина од 0.5 до 512N. Дистрибуираните сили се мерени на ниво на пародонталниот лигамент (ПДЛ). **Резултати.** Резултатите покажуваат симетрична дистрибуција на силите и на двете страни на мостовната конструкција. Најголеми сили се дистрибуираат на забите на кои делува аплицираната сила. Најмали сили се дистрибуираат во апикалниот дел на ПДЛ. Не е најдена разлика помеѓу вкупно дистрибуираните сили на забот и дистрибуираните сили на страничниот дел на ПДЛ. Измерените сили по јачина и процент се во рамките на познатите вредности во литературата. **Заклучок.** Добиените резултатите од истражувањето се во ниво на познатите функционални вредности на џвакалните сили. Ова значи дека од биомеханички аспект изработка на мостовни конструкции кај малку скратени забни низи не е спорна, но одлуката за изработка треба да се донесе и врз база на другите индивидуални и клинички услови. **Клучни зборови:** Оклузални вертикални сили, мостовни конструкции, скратени забни низи, метод на конечни елементи (МКЕ), периодонтален лигамент (ПДЛ).

Introduction

Until the seventies of the twentieth century, the goal of dental treatment was the maintenance of complete dental arches with 28 teeth. In 1981, the concept of the shortened dental arch (SDA) promoted by Käyser, suggesting that shortened dental arches with at least four occlusal units, preferably in a symmetrical position, have sufficient capacity to maintain an adequate oral function[1].

This claim caused a series of researches in which the concept of shortened dental arch was studied from all aspects, the functions of the masticatory system, the effect of dental treatment, the quality of life, as well as the economic and social aspects[2, 3, 4, 5, 6].

Based on the results of extensive surveys, the World Health Organization WHO in 1992 set the new goal of dental treatment, which is a healthy, natural, and functional dental arch with at least 20 teeth without the need for prosthesis[7, 8].

Anneloes and associates found that shortened dental arches can stay stable for more than 27 years, which justifies the dental concept for shortened dental arches[9].

However, certain teeth changes can disrupt the stability of the shortened dental arches and in that case, a prosthetic treatment would be needed. The most frequent changes are the migration of teeth by separation, aesthetical and functional needs, and especially the loss of bone support.

According to De Oliveira and associates, teeth in shortened arches show greater movement than teeth in intact dental arches[10].

According to Kourkout and associates, bridge constructions can provide a certain degree of rigidity and enable a more favorable distribution of the masticatory forces of all remaining cases in patients with an advanced degree of progressive changes in the periodont[11].

Measuring the the masticatory forces is important in order to assess the functional state of the masticatory system, but it is a complex problem. The values obtained depend on many factors in the masticatory system, in the body, as well as of the measurement methods. Therefore, we find differences in the values obtained in literature.

In the published results, prevailing data suggest that the occlusal forces in static occlusion range from 100 to 1000N, while the data of the functional masticatory forces range from 3.5 to 350N[12].

According to Waltimo and Kononen, the maximal occlusal forces between Europeans and Americas range from 600 to 750N, while the functional mastication forces are much smaller, around 60-100 N[13].

Veleski measured the maximal masticatory forces in intact dental arches in the lower jaw from 176.8 N to 380.9 N in women and from 193.7 N to 506.9 N in men[14].

Himmlová measured the approximate value of 135 N in masticatory forces in subjects with natural intact dental arches[15].

Laurell L. measured maximal masticatory forces of 320 N in circular dental bridge constructions with a healthy periodont and 264 N with weakened paradont[16].

In his research, Biswas found the mean values of the maximal masticatory forces for the front teeth to be 193N, for the canines 223 N, for the premolars 280 N and for the molars 350 N[17].

The mean value of the occlusal force is between 39-66 N for the premolars and 11-33 N for the front teeth[18].

According to Lundgren and Laurell, the maximal force that occurs during the chewing act is 280 N and the medium functional force is about 100 N. He thinks that, on average, about 37% of the total maximal occlusal force is used in chewing[19].

Sato too believes that the dynamic functional momentum is 35-45% of the measured static forces[20].

By electromyographic analysis of the masticatory muscles, Prochechel and Morneburg found a mean functional masticatory force of 220N[21].

Several authors noted that the strength of the masticatory forces increases in the distal direction of dental arches[16, 22, 23, 24, 25, 26, 27, 28].

Kondo measured higher values of the maximal masticatory force in slightly shortened dental arches and pressure on PDL on second premolars[29].

Guo and associates and André and associates proved that the deformation forces of the periodontal ligament increase in proportion to the increase of the loading[30,31].

According to Apostolov, there are no distinctive differences in the values of the maximal masticatory forces on the left and on the right side of the dental arches[32, 33].

Cai and associates and Zhou Shu-min and associates found out that in the initial teeth loading, a larger amount of the masticatory forces are distributed on the cervical and lateral parts of the periodontal ligament[34, 35, 36].

In Jayam's research, during vestibular, lingual and incisal loading, the distribution of force in the apical zone is from 0.75 to 0.80N[37].

Fratila, Oruć and Je J discovered that the greatest concentration of the forces is distributed at the site of force action[18, 38, 39].

Al-Zarea measured higher values of force on the side of the natural teeth in comparison to the bridge structure side, in same subjects, the difference was statistically significant ($p < 0.05$)[40].

According to literature data, the highest influence on teeth is inflicted by the occlusal vertical forces which are the largest and the base of mastication. They are one of the most important conditions for physiologically optimal occlusion, especially in prosthetic constructions where the tendency during modeling is to reduce the impact of side forces[24].

From this aspect, the interest of this research is the distribution of the occlusal vertical forces of bridge constructions made in small shortened sequences.

Aim of the research

The aim of this research is to analyze the distribution of occlusal vertical dental forces of bridge constructions in slightly shortened dental arches.

Material and methods

The analysis of the distribution of occlusal vertical forces is made by using the finite element method. The research was done on a three-dimensional computer model, the computer analysis and the generation of the finite element network were done with SOFISTIK software package.

The basic model is Kenedy class I edentulous in the mandibula with end teeth 45 and 35, a slightly shortened dental arch (Figure 1.).

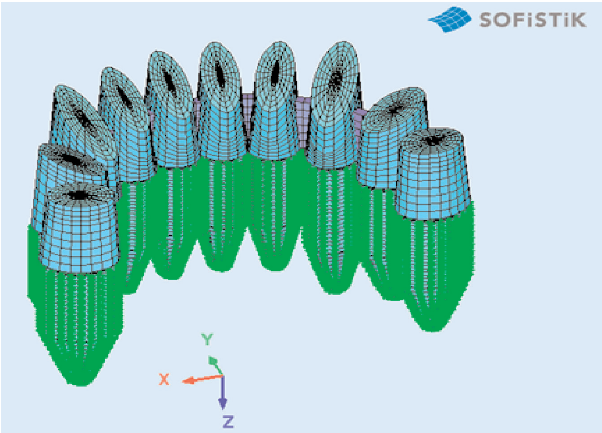

Figure 1. *Model of bridge construction in slightly shortened dental arch*

The discretization of the model is on finite elements with six sides and eight nodes.

The values needed for modeling teeth, periodontal ligament, component materials for bridge structures were taken from literature data.

The analysis was performed by symmetrical loading on the three distal abutment teeth of the bridge construction 45, 44, 43, 42, 41, 31, 32, 33, 34, 35 (Figure 2).

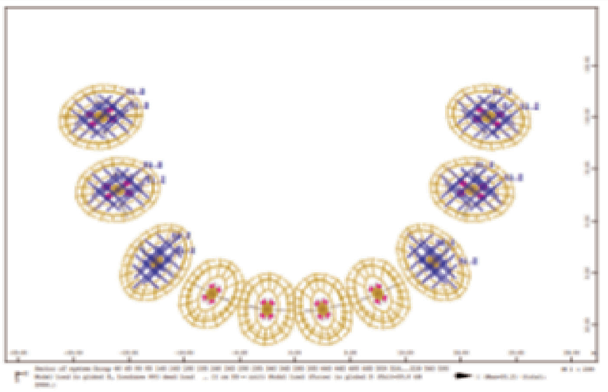

Figure 2. *Symmetrical loading of the three distal teeth*

Simulated vertical occlusal forces with a magnitude of 0.5N to 512N were applied in the research, respectively to the literature data for maximal and minimal masticatory forces.

The duration of the load force is not taken as a factor for the analysis.

The applied finite element method is a recognized and used method in dental researches, especially in dental biomechanics.

In this research, a three-dimensional (3D) finite element method (FME) is applied, based on the deformation method.

It is a numerical method that performs physical discretization of space. The continium (independent of its shape, shape, size) is divided into elements with finite dimensions. These elements are connected to each other in discrete points marked as nodes, and that way, a finite element network is formed. By analyzing the finite elements, actually the analysis of the continuum as a whole is carried out.

The data for teeth, periodontal ligament, materials used for bridge structures are taken from literature[41.42].

The problem being analyzed in this research is nonlinear. Nonlinearity is due to the anisotropic properties of the periodontal ligament. According to Kojima, PDL should be modeled as nonlinear[43].

By using the nonlinear analysis, a real response is obtained for the behavior of bridge structures and the distribution of forces.

Results

By carrying out the foreseen examinations in the research, we obtained the following results:

Table 1 shows the obtained values of the distributed occlusal vertical forces on the abutment teeth during simultaneous both-sided load of the three distal abutment teeth 45 44 43 and 33 34 35 in bridge construction at 45 44 43 42 41 31 32 33 34 35 with the slightly shortened dental arch.

Table 2 shows the percentage distribution of occlusal vertical forces on the abutment teeth during simultaneous both-sided load on the three distal abutment teeth 45 44 43 and 33 34 35 in bridge construction 45 44 43 42 41 31 32 33 34 35 with the slightly shortened dental arch.

Table 3 shows the obtained values of the distributed occlusal vertical forces in the apical part of PDL of abutment teeth during simultaneous both-sided load on the three distal abutment teeth 45 44 43 and 33 34 35 in bridge construction 45 44 43 42 41 31 32 33 34 35 with a slightly shortened dental arch.

Table 4 shows the percentage distribution of occlusal vertical forces in the apical part of PDL of abutment teeth during simultaneous both-sided load on the three distal abutment teeth 45 44 43 and 33 34 35 in bridge construction 45 44 43 42 41 31 32 33 34 35 with a slightly shortened dental arch.

Table 1. Values of the distributed occlusal vertical forces on the abutment teeth during simultaneous both-sided load of the three distal abutment teeth 45 44 43 and 33 34 35

F / Tooth	0.5 N	1 N	2 N	4 N	8 N	1 6N	32 N	64 N	128 N	256 N	512 N
45	-0..17	-0..35	-0..69	-1.39	-2.92	-5.89	-13.58	-24.85	-49.91	-94.30	-186.09
44	-0..13	-0..26	-0..52	-1.05	-1.96	-4.24	-7.20	-18.52	-35.54	-79.09	-160.03
43	-0..10	-0..20	-0..40	-0.80	-1.56	-2.97	-5.53	-t1.27	-25.92	-52.13	-113.78
42	-0.05	-0..11	-0..21	-0.42	-0.84	-1.55	-3.05	-4.74	-10.24	-18.44	-31.18
41	-0.04	-0.08	-0..17	-0.34	-0.70	-1.32	-2.56	-4.09	-6.78	-11.80	-16.31
31	-0.04	-0.08	-0..17	-0.34	-0.69	-1.32	-2.56	-4.09	-6.74	-11.76	-16.28
32	-0.05	-0..11	-0..21	-0.42	-0.84	-1.54	-3.06	-4.74	-10.28	-18.49	-31.33
33	-0..10	-0..20	-0..40	-0.80	-1.56	-2.96	-5.54	-11.18	-25.86	-52.02	-113.56
34	-0..13	-0..26	-0..52	-1.05	-1.96	-4.24	-7.21	-18.49	-35.50	-79.11	-160.04
35	-0..17	-0..35	-0.70	1.39	-2.92	-5.89	-13.60	-24.87	-49.94	-94.37	-186.18
Total	-1.00	-2.00	-3.99	-7.99	-15.98	-31.94	-63.88	-126.83	-256.71	-511.51	-1014.78

Table 2. Percentage distribution of occlusal vertical forces on the abutment teeth during simultaneous both-sided load on the three distal abutment teeth 45 44 43 and 33 34 35

F / Tooth	0.5 N	1 N	2 N	4 N	8 N	1 6 N	32 N	64 N	128 N	256 N	512 N
45	17.40	17.36	17.40	17.37	18.30	18.44	21.26	19.59	19.44	18.44	18.45
44	13.12	13.10	13.12	13.10	12.29	13.29	11.27	14.6.60	13.84	15.46	15.77
43	10.04	10.04	10.03	10.03	9.79	9.31	8.66	8.88	10.10	10.19	11.21
42	5.25	5.27	5.24	5.26	5.27	4.84	4.78	3.74	3.99	3.61	3.07
41	4.20	4.24	4.21	4.24	4.35	4.15	4.01	3.22	2.64	2.31	1.61
31	4.20	4.24	4.20	4.23	4.35	4.14	4.00	3.22	2.63	2.30	1.60
32	5.24	5.26	5.24	5.25	5.27	4.84	4.79	3.74	4.01	3.61	3.09
33	10.03	10.02	10.03	10.02	9.78	9.27	8.67	8.82	10.07	10.17	11.19
34	13.12	13.09	13.13	13.10	12.30	13.27	11.28	14.58	13.83	15.47	15.77
35	17.42	17.37	17.42	17.38	18.30	18.45	21.29	19.61	19.45	18.45	18.35
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

Table 3. Values of the distributed occlusal vertical forces in the apical part of PDL

Tooth \ F	0.5 N	1 N	2 N	4 N	8 N	1 6N	32 N	64 N	128 N	256 N	512 N
45	-0.001	-0.002	-0.003	-0.006	-0.013	-0.026	-0.079	-0.151	-0.270	-0.443	-0.817
44	-0.001	-0.001	-0.002	-0.005	-0.009	-0.019	-0.031	-0.110	-0.205	-0.383	-0.704
43	0.000	-0.001	-0.001	-0.003	-0.006	-0.011	-0.031	-0.048	-0.126	-0.230	-0.429
42	0.000	0.000	-0.001	-0.002	-0.003	-0.006	-0.011	-0.018	-0.047	-0.091	-0.139
41	0.000	0.000	-0.001	-0.001	-0.003	-0.005	-0.009	-0.015	-0.020	-0.053	-0.074
31	0.000	0.000	-0.001	-0.001	-0.003	-0.005	-0.009	-0.015	-0.020	-0.053	-0.074
32	0.000	0.000	-0.001	-0.002	-0.003	-0.006	-0.012	-0.019	-0.049	-0.095	-0.145
33	0.000	-0.001	-0.001	-0.003	-0.006	-0.011	-0.020	-0.047	-0.125	-0.228	-0.425
34	-0.001	-0.001	-0.002	-0.005	-0.009	-0.019	-0.031	-0.110	-0.205	-0.383	-0.704
35	-0.001	-0.002	-0.003	-0.006	-0.013	-0.027	-0.079	-0.151	-0.270	-0.443	-0.818
Total	0.00	-0.01	-0.02	-0.03	-0.07	-0.13	-0.30	-0.68	-1.34	-2.40	-4.33

Table 4. Percentage distribution of occlusal vertical forces in the apical part of PDL on abutment teeth

Tooth \ F	0.5 N	1 N	2 N	4 N	8 N	16 N	32 N	64 N	128 N	256 N	512 N
45	0.08	0.08	0.08	0.08	0.08	0.08	0.12	0.12	0.11	0.09	0.08
44	0.06	0.06	0.06	0.06	0.06	0.06	0.05	0.09	0.08	0.07	0.07
43	0.04	0.04	0.04	0.04	0.04	0.03	0.03	0.04	0.05	0.04	0.04
42	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.01	0.02	0.02	0.01
41	0.02	0.02	0.02	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.01
31	0.02	0.02	0.02	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.01
32	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.01
33	0.04	0.04	0.04	0.04	0.04	0.03	0.03	0.04	0.05	0.04	0.04
34	0.06	0.06	0.06	0.06	0.06	0.06	0.05	0.09	0.08	0.07	0.07
35	0.08	0.08	0.08	0.08	0.08	0.08	0.12	0.12	0.11	0.09	0.08
Total	0.42	0.42	0.42	0.42	0.42	0.42	0.47	0.54	0.52	0.47	0.43

Table 5. Values of distributed occlusal vertical forces on the lateral parts of PDL of abutment teeth during simultaneous both-sided load on the three distal abutment teeth 45 44 43 and 33 34 35

F / Tooth	0.5 N	1 N	2 N	4 N	8 N	1 6 N	32 N	64 N	128 N	256 N	512 N
45	-0.17	-0.35	-0.69	-1.38	-2.91	-5.86	-13.50	-24.70	-49.64	-93.86	-185.27
44	-0.13	-0.26	-0.52	-1.04	-1.96	-4.22	-7.17	-18.41	-35.33	-78.70	-159.32
43	-0.10	-0.20	-0.40	-0.80	-1.56	-2.96	-5.51	-11.22	-25.80	-51.90	-113.35
42	-0.05	-0.10	-0.21	-0.42	-0.84	-1.54	-3.04	-4.73	-10.20	-18.35	-31.04
41	-0.04	-0.08	-0.17	-0.34	-0.69	-1.32	-2.55	-4.07	-6.76	-11.74	-16.23
31	-0.04	-0.08	-0.17	-0.34	-0.69	-1.32	-2.55	-4.07	-6.72	-11.71	-16.20
32	-0.05	-0.10	-0.21	-0.42	-0.84	-1.54	-3.05	-4.72	-10.23	-18.39	-31.18
33	-0.10	-0.20	-0.40	-0.80	-1.56	-2.95	-5.52	-11.13	-25.73	-51.80	-113.14
34	-0.13	-0.26	-0.52	-1.04	-1.96	-4.22	-7.18	-18.38	-35.29	-78.73	-159.33
35	-0.17	-0.35	-0.69	-1.38	-2.91	-5.87	-13.53	-24.72	-49.67	-93.93	-185.36
Total	-1.00	-1.99	-3.98	-7.95	-15.91	-31.80	-63.58	-126.15	-255.38	-509.11	-1010.45

Table 6. Percentage distribution of occlusal vertical forces on lateral parts of PDL in abutment teeth

F / Tooth	0.5 N	1 N	2 N	4 N	8 N	1 6 N	32 N	64 N	128 N	256 N	512 N
45	17.32	17.28	17.32	17.30	18.21	18.36	21.14	19.47	19.34	18.35	18.26
44	13.06	13.04	13.06	13.04	12.24	13.23	11.22	14.51	13.76	15.39	15.70
43	10.00	10.01	9.99	10.00	9.75	9.27	8.63	8.85	10.05	10.15	11.17
42	5.23	5.25	5.22	5.24	5.26	4.82	4.76	3.73	3,97	3.59	3,06
41	4.18	4.23	4.19	4.22	4.34	4.13	3.99	3.21	2.63	2.30	1.60
31	4.18	4.22	4.18	4.22	4.33	4.12	3.99	3.21	2.62	2.29	1.60
32	5.22	5.24	5.22	5.23	5.25	4.82	4.77	3.72	3.99	3.60	3.07
33	9.99	9.98	9.99	9.98	9.74	9.24	8.63	8.78	10.02	10.13	11.15
34	13.06	13.03	13.07	13.04	12.24	13.21	11.23	14.49	13.75	15.39	15.70
35	17.34	17.29	17.34	17.31	18.22	18.37	21.17	19.49	19.35	18.36	18.27
Вкупно	99.58	99.58	99.58	99.58	99.58	99.58	99.53	99.46	99.48	99.53	99.57

Table 5 shows the obtained values of the distributed occlusal vertical forces on the side parts of the PDL on abutment teeth during simultaneous both-sided load on the three distal abutment teeth 45 44 43 and 33 34 35 in bridge construction 45 44 43 42 41 31 32 33 34 35 with a slightly shortened dental arch.

Table 6 shows the percentage distribution of occlusal vertical forces on lateral parts of PDL of abutment teeth during the simultaneous both-sided load on the three distal abutment teeth 45 44 43 and 33 34 35 in bridge construction 45 44 43 42 41 31 32 33 34 35 with a slightly shortened dental arch.

Discussion

OThe obtained results for the distribution of the occlusal vertical forces on the abutment teeth of bridge constructions in slightly shortened dental arches during simultaneous both-sided loading of the three distal abutment teeth 45 44 43 and 33 34 35 (Table 1) have an approximately identical distribution of the applied force to the left and right side. Such results were also obtained by Apostolov[32].

All distributed forces have the same direction of action identical to the direction of action of the loading force.

The distributed force has a tendency to approximately double the rise with the increase in the strength of the applied force. That is in line with the results of Guo and associates and André and associates[30, 31].

For all applied loading forces, the strongest force is distributed to the distal abutment teeth that gradually decrease mesially. Fratila, Oruc and Ye Y. found this kind of force distribution[18, 38, 39].

On teeth not exposed to direct loading forces, smaller forces are distributed that reach values of 31.33 N for the strongest applied force (Table 1).

During the simultaneous both-sided load of the three distal abutment teeth 45, 44, 43 and 33, 34, 35 in bridge structures, there is approximately identical distribution percentage of distributed force on the left and right side. The percentage of distributed forces is approximately identical for small and large forces with a tendency of slight increase by increasing the strength of the applied force. The highest percentage of force is distributed to distal abutment teeth that gradually decrease to the mesial abutment teeth.

On teeth with no force applied, the greatest force is distributed during small loading forces and gradually decreases with the rise of loading force (Table 2).

The strength of the distributed forces on the apical part of the PDL on the abutment teeth is minimal, and is less than 1 N, which is in accordance with Jayam's research.37

The percentage of the distributed forces of the apical parts of the PDL of the teeth carriers is less than 0.5% (Table 4).

Distributed force on the side parts of the PDL on the abutment teeth has the same characteristics as the distributed forces on teeth. This means that the major part of the force is received by the lateral parts of PDL. This is consistent with the results of Cai and Associates and Zhou Shu-min and associates[34, 35, 36].

Over 99.5% of the applied force is distributed to the lateral parts of PDL of the abutment teeth and has the same characteristics as on the entire teeth (Table 6).

The greatest difficulty in this research was that there are many data in the literature, but the results are difficult to compare because different research methods have been used. The published clinical trials are often reduced to periodic analyzes.

Conclusion

Distributed occlusal vertical forces on all abutment teeth have the same direction of action that is identical with the direction of action of the loading force.

For all applied loading forces, the strongest force is distributed to the distal teeth.

The percentage of distributed occlusal vertical forces on teeth is approximately identical for small and large forces.

Distributed occlusal vertical forces on the lateral parts of PDL have the same characteristics as the distributed forces on teeth.

The strength and percentage of the distributed occlusal vertical forces on the apical part of PDL on the abutment teeth is minimal, and is less than 1N or 0.5%.

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