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BIOMECHANICAL APPROACHES TO LONG-TERM SPLINTING OF MOBILE TEETH IN PERIODONTITIS

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Abstract. *The article presents a biomechanical approach to splinting that allows to maintain tooth mobility at the physiological level, evenly distribute and dampen the load, involve the periodontal muscle reflex in its regulation, which guarantees the preservation of structural integrity during chewing and treatment.*

The aim of the study was to biomechanically substantiate the splinting of mobile teeth in periodontitis, taking into account the height and inclination of the crowns of the teeth, the degree of their mobility and the type of bite.

Material and Methods. For biomechanical calculations, we considered a model with intact periodontal tissues and typical cases where the crown height is h≥6 mm. The value of this parameter is a necessary component for obtaining reliable data.

Results and discussion. The results of the study showed that in the normal case, the design scheme of the incisor is a rigidly clamped cantilever structure capable of absorbing vertical and horizontal loads arising from biting down on food. As the calculated height of the tooth h, a size is taken that is the sum of the height of the crown part of the tooth and one third of the length of its root.

Conclusions. A mathematical model has been developed and a method of splinting anterior teeth with pathological mobility with the placement of a reinforcing splint element based on an inorganic matrix on the vestibular surface of the tooth has been substantiated, taking into account biomechanical feasibility, degree of tooth mobility, resorption of interdental septa and the height of clinical crowns.

Key words*: periodontitis, tooth mobility, long-term splinting, mathematical model, horizontal and vertical forces of force vectors.*

Introduction.

The most common method of strengthening mobile teeth in periodontitis is splinting them using various types of reinforcement and placement in relation to the splinted teeth [1,2,3,4].

When developing treatment plans with a predictable prognosis for both temporary and permanent splinting, it is necessary to take into account the proportions of the teeth, the ratio of weight and length of the elements that make up the splint, gingival zenith, and periodontal aesthetics [4, 5, 6]. In order to restore the biomechanics of chewing, aesthetics, and durability of the remaining teeth and their periodontium, biofunctionality and harmony between the temporary splint and periodontal tissues are important. In this respect, its design, occlusion and biomaterials are of great importance and should be taken into account when planning

[6, 7, 8]. Noticeable tooth lengthening (which increases the degree of trauma to periodontal tissues) causes certain difficulties in the selection and planning of a type of temporary splinting system and the choice of materials to reduce the functional overload of abutment teeth.

At the same time, with any splinting method, it is of particular importance to determine the optimal (most rational from the point of view of biomechanics) placement for the retention furrow and reinforcement, depending on the height of the tooth crown [4, 8, 9]. The maximum occlusal loads (external force) that occur during chewing depend on the individual physical capabilities of the muscles and the pain threshold [10]. Thus, tooth stability can be increased by reducing the force arm (l), for example, by shortening the tooth, or by increasing the periodontal resistance ($_{RX}$) by splinting adjacent teeth. In order to direct the force to the lower anterior teeth axially, the cutting surface of these teeth should be inclined by approximately^{200} vestibularly. Such modeling of the occlusal surface will minimize the moment of force that overturns the tooth, directing the axial masticatory load [8].

The above indicates the relevance of the biomechanical approach to splinting, which allows to maintain tooth mobility at the physiological level, evenly distribute and dampen the load, involve the periodontal muscle reflex in its regulation, which guarantees the preservation of structural integrity during chewing and treatment, while maintaining high functional and aesthetic qualities of the splint.

The aim of the study is to biomechanically substantiate the splinting of mobile teeth in periodontitis, taking into account the height and inclination of the crowns of the teeth, the degree of their mobility and the type of bite.

Material and methods.

For biomechanical calculations, we considered a model with intact periodontal tissues and typical cases where the crown height is h≥6 mm. The value of this parameter is a necessary component for obtaining reliable data. For the study model, a rod subjected to axial compression was assumed for vertical loads, and a cantilever beam firmly fixed in the sagittal plane was assumed for horizontal loads.

The following main geometric parameters of the abutment teeth were determined from radiographic data: root length, difference between the extraalveolar and interalveolar parts of the tooth. The internal forces of the structure were determined by assessing the effects of the total vertical and horizontal external load components. Based on the determination of the functional stresses of the periodontal tissues of the abutment teeth and their correlation with the minimum and maximum permissible parameters, an algorithm was developed for selecting the location of the splinting structure on the teeth. It was applied taking into account the rational distribution of the chewing load in the biomechanical system "splint - abutment teeth - periodontium".

Results and discussion. The results of the study revealed that, in the normal case, the design scheme of the incisor is a rigidly clamped cantilever structure capable of absorbing vertical and horizontal loads arising during biting off food. The calculated height of the tooth *h is* the size that is the sum of the height of the crown part of the tooth and one third of the length of its root. It should be borne in mind that the teeth in the sockets are in an elastically fixed state and have some mobility [8, 11, 12]. Despite the direction of the force, the dependence of tooth displacement on load is complex. In case of pathological mobility of the I and II degree incisors, the rigidly clamped support becomes a spring-jointed one, and the design scheme becomes a geometrically variable system, when the load is applied to which the latter can be considered as a mechanism. To take the external load of such a scheme, an additional connection is needed, which is the tire fixed to the canines (Figure 1).

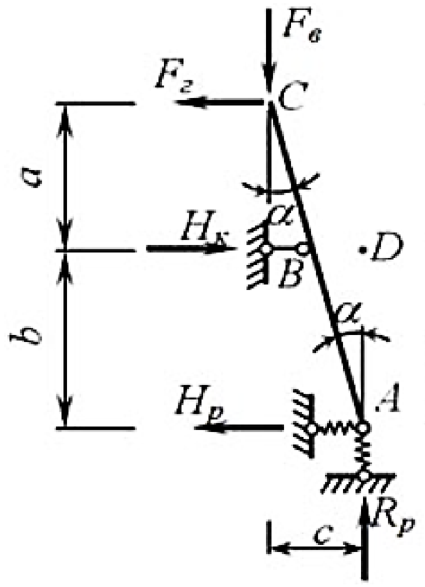

Figure 1 - Design scheme of a moving cutter,
where: ***Fv*** *- vertical component of the external load;* ***Fh*** *- horizontal component of the external load;* ***α*** *is the angle of inclination of the incisors in the frontal area;* ***h*** *is the calculated height of the tooth;* ***hk*** *is the vertical projection of the crown part of the tooth;* ***lk*** *is the vertical projection of the root of the tooth;* ***Hk*** *is the horizontal reactive force perceived by the tire reinforcement;* ***Hp*** *is the horizontal reactive force in the incisor,* ***Rp*** *is the vertical reactive force in the incisor.*

The main criterion for the optimal placement of the retention sulcus in the height of the crown part of the tooth is the force at the root of the incisor and the horizontal force created directly by the splint on the canines under the influence of vertical and horizontal loads on the incisors. The angle of inclination for the central incisors in the anterior region was determined using parallelometry. For this purpose, the resulting F.G. Spee curve was determined on the models for each side. A force *F* acts perpendicularly to the plane formed by these resultant curves.

Thus, if we divide the depth of *the* vestibular surfaces of the mandibular central incisors to the force vector *F* by the length of the crown of the central incisor, we obtain *sin α*, and the ratio of the depth of *the* vestibular surfaces to the vertical projection of the height of the crown of the central incisor $^{hl}{}_k$ is *tg*.

The value of the angle of inclination of the central incisors *α* in the anterior region can be defined as follows:

$$\alpha = arcsin\frac{P_в}{h_k^l}, \text{ or } \alpha = arctg\frac{P_в}{hk}$$

In order to determine the numerical values of the forces transmitted by the tire to the canines and the forces arising in the root of the incisor from the action of the vertical load, the equilibrium equations were used: (1), (2), (3)

$$\sum M_A = 0 \qquad F_g \cdot h + F_v \cdot c - H_\kappa \cdot b = 0 \tag{1}$$

$$H_\kappa = \frac{F_g \cdot h + F_v \cdot c}{b} = \frac{F_g \cdot h + F_v \cdot h \cdot tg\alpha}{b} \tag{2}$$

$$\sum Y = 0 \qquad R_p - F_v = 0 \qquad \Rightarrow \qquad R_p = F_v$$

$$\sum M_D = 0 \qquad F_g \cdot a + F_v \cdot c - H_p \cdot b = 0$$

$$H_p = \frac{F_g \cdot a + F_v \cdot c}{b} = \frac{F_g \cdot a + F_v \cdot h \cdot tg\alpha}{b} \tag{3}$$

From the obtained dependencies (1), (2) and (3), it can be concluded that the values of the reactive forces that occur in the incisors and the forces transmitted to the canines depend on the anatomical dimensions of the crown part of the incisors, their inclination and the position of the splint reinforcement in relation to the tooth height.

Thus, the higher the splint is placed (increasing the size of b in Figure 1), the smaller the horizontal force *Hp* that occurs in the incisor and the force *Hk* transmitted through the splint reinforcement to the canine (since *b* in expressions 1 and 2 is in the denominator).

The values of the horizontal force in the tire and the horizontal reactive force in the incisor depend not only on the value of the horizontal component of the load, but also on the vertical component. In addition, the vertical component of the reactive force in the incisor, according to (2), regardless of the position of the tire, is always equal to the value of the vertical load.

Therefore, according to expressions (1), (2) and (3), the most rational tire position corresponds to the closest possible approach to the cutting edge of the cutters. The location of the retention furrow at a distance of 2-3 mm from the upper cut of the cutter is determined by the tire manufacturing technology and the attempt to change the shape of the inner surface near the cutting edge of the cutters as little as possible.

From the point of view of the transfer of horizontal loads from the incisors through the splint to the canines, the position of the retention furrow in the area of attachment of the reinforcement to the canine should be as low as possible (closer to the lower edge of the crown part of the tooth) to reduce the value of the overturning moment in the canines caused by the horizontal loads transmitted by the splint.

Therefore, the most optimal option for splinting the incisors, from the point of view of biomechanics, is the location of the retention furrow and, accordingly, the working reinforcement in the upper part of the first incisors, followed by a gradual lowering of the reinforcement and retention furrow to the lower edge of the crown part of the canines. It is this arrangement of the reinforcement that should be considered appropriate.

It should be noted that the maximum possible upper position of the reinforcement in a progenitor bite is determined by the occlusal position of the cutting edge of the maxillary incisors. The symmetry of the splinting of the dentition and the applied load allows us to move from the volumetric design scheme to its flat projection, projecting all the applied forces that arise on the sagittal plane (Figure 2).

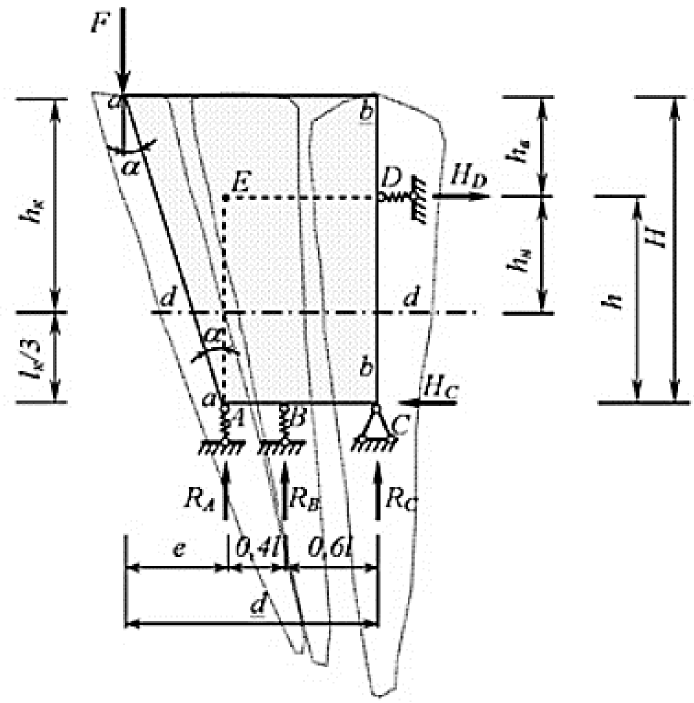

Figure 2 - Design scheme of dental splinting,

*where **hk** is the height of the crown part of the canine; **lk** is the length of the canine root; **F** is the vertical load that occurs during biting on the central incisor, **a-a** is the inclined axis of the central incisor; **α** is the angle of inclination of the central incisors in the anterior region relative to the load; **b-b** - axis of the canine, **e** - eccentricity of the applied force F relative to the central incisors; **d-d** - level of the lower edge of the crown part of the canine; **l** - distance between the centers of resistance of the lower canine and the lower central incisor; R_A - vertical reactive force of the central incisor; R_B - vertical reactive force of the lateral incisor; R_c - vertical reactive force of the canine; H_d - horizontal force transmitted by the tire reinforcement to the canine; H_c - horizontal reactive force arising at the root of the canine, **e** - point of intersection of the lines of action of H_d and R_A forces; **hв** is the distance from the cutting edge of the crown part of the teeth to the axis of the retention furrow; **hн** is the distance from the lower edge of the crown part of the teeth to the axis of the retention furrow; **h** is the distance from the axis of the retention furrow to point A, **n** is the calculated tooth height.*

Thus, as a result of splinting of incisors and canines using reinforcement and polymer, all splinted teeth, from the point of view of mechanics, can be considered a rigid disk (deformations of which can be neglected due to their insignificance), fixed by movable hinge-spring supports along the longitudinal axes of the incisors and at the point of connection of the splint with the canines (points *A*, *B* and *d of Figure* 2) and a hinged-fixed support at point *C*.

The load *F is perceived* as a concentration of the load on one incisor (in the case of small overall dimensions of the food lump not exceeding the width of the incisor) or equally acting from the load distributed along the entire length of the dentition or some part of it (in the case of the size of the food lump exceeding the width of one incisor). A less favorable loading option is the case in which the equivalent load *F is located* between the central incisors.

In this situation, the degree of inclination of the teeth in the frontal area relative to the load is set by the angle *α*, and the degree of resorption and the anatomical size of the teeth are set by the dimensions *hk* and *lk*, respectively .

Taking into account the joint work of all the teeth included in the splint, the vertical load on the incisors has little dependence on the initial degree of mobility of the incisors, and is determined mainly by the mobility of the canines, which receive the load transmitted from the incisors by the splint. When the load F is applied, the hard disk rotates in accordance with the point C (the vertical movement of the canines can be neglected due to the fact that the canine is a support for the entire tire structure), causing reactive forces in the elastic supports that are directly proportional to the distance from the center of rotation *C*. According to Fig. 2, the force *F* causes a reaction of the cutter root *Ra*, which rotates the tire relative to the axis of rotation *C*. During this process, the tire transfers the load *Hd* to the canine. We assume that the reaction force of the canine itself, represented in Figure 2 by the force *Hc*, (due to its high stiffness), is much smaller than the periodontal reaction,

and therefore: $\frac{R_A}{l} = \frac{H_D}{h}$, hence: $R_A = \frac{H_D \cdot l}{h}$.

Similarly: $\frac{R_B}{0{,}6l} = \frac{H_D}{h}$, hence: $R_B = \frac{H_D \cdot 0{,}6l}{h}$.

The dimension *l can be* represented by *H as l = Htga*. The equilibrium equation is used to determine the values of the vertical and horizontal forces that occur in the teeth. Taking into account that when projecting all forces to the sagittal plane, the projections of the reactive forces that occur in the teeth on the right and left sides of the dentition are superimposed on each other (i.e., the number of reactive forces doubles), we have the following indicators (4-7). The obtained indicators (4), (5), (6) and (7) relate the reactive forces arising in the teeth to the values of the external load *F*. The value of the geometric dimension *l* itself *can* be determined using a caliper as the distance from the line connecting the centers of gravity of the cross-sections of the canines, the outer cutting edge of the first incisors *d* minus the value (or approximately the distance between the center of the longitudinal roller of the oral surface of the lower canine and the lingual tubercle of the lower central incisor) that is possible in clinical conditions.

$$\sum M_C = 0 \qquad F(e+l)\cos\beta - FH\sin\beta - 2R_A \cdot l - 2R_B \cdot 0{,}6l - 2H_D \cdot h = 0 \qquad (4)$$

$$H_D = \frac{0{,}5F\cos\beta(H(tg\alpha - tg\beta) + l)\cdot h}{1{,}36l^2 + h^2}$$

$$R_A = \frac{H_D \cdot l}{h} = \frac{0{,}5F\cos\beta(H(tg\alpha - tg\beta) + l)\cdot l}{1{,}36l^2 + h^2}$$

$$R_B = \frac{H_D \cdot 0{,}6l}{h} = \frac{0{,}3F\cos\beta(H(tg\alpha - tg\beta) + l)\cdot l}{1{,}36l^2 + h^2} \quad (5)$$

$$\sum M_A = 0 \quad -F\cdot e\cdot\cos\beta + F\cdot H\cdot\sin\beta - 2R_C\cdot l - 2R_B\cdot 0{,}4l + 2H_D\cdot h = 0 \quad (6)$$

$$R_C = \frac{H_D h - 0{,}4R_B l - 0{,}5FH\cos\beta(tg\alpha - tg\beta)}{l} \quad (7)$$

The value of the maximum load *F can be* determined from expression (4) as:

$$F = \frac{2H_D\ (1{,}36l^2 + h^2)}{\cos\beta\ (H(tg\alpha - tg\beta) + l)\cdot h}$$

where instead of the value of H_d, the maximum permissible value F_g^n of the horizontal force on the canine depending on its clinical condition is substituted

$$H_D = F_g^n \frac{h_к}{h_н}$$

(which was selected from the corresponding table) [12], taking into account the height of the applied force applied

$$F = \frac{2F_g^n\ (1{,}36l^2 + h^2)h_к}{\cos\beta(H(tg\alpha - tg\beta) + l)\cdot h\cdot h_н}$$

Then: (8)

Regardless of the length of the tooth, the ratio of the length of the crown to the root (for all teeth, the average is 1:2). The ratio of the length of the canine crown to the length of its root is more accurately represented by 1:1.5 [11]. However, age-related changes and the possible presence of pathological abrasion make it impossible to consider the height of the crown as a reliable value. Instead, for these purposes, you can use the calculation scheme proposed by L.M. Lomiashvili [15,16]. Thus, the height of the mandibular canine (*Hcor*)*correlates* with the mesiodistal (*Mdcor*) and vestibulo-lingual (*Vlcor*) dimensions of its crown as 1.40:1.00:1.11. Taking into account the variability of pathological abrasion forms, only *Vlcor* can be considered a reliable size for calculation. Therefore, the required length of the canine root can be calculated using the formula:

$$l_к = 2\cdot Hcor = \frac{2\cdot 1{,}4Vcor}{1{,}11} = 2{,}522VLcor$$

Defining all dimensions through *Vlcor* , we get:

$$h_к = \frac{1{,}4Vcor}{1{,}11} = 1{,}261VLcor$$

$$h = h_к + \frac{l_к}{3} - h_в = 1{,}261VLcor + 0{,}631VLcor - h_в = 1{,}829VLcor - h_в,$$

$$H = h_к + \frac{l_к}{3} = 1,261VLcor + 0,631VLcor = 1,829VLcor$$,

$$h_н = h_к - h_в = 1,261VLcor - h_в$$,

and substituting into (8) we have:

$$F = \frac{2,522F_g^n\,(1,36l^2 + (2,102VLcor - h_в)^2)VLcor}{\cos\beta(2,102VLcor(tg\alpha - tg\beta) + l)\cdot(2,102VLcor - h_в)\cdot(1,261VLcor - h_в)} \quad (9)$$

Among the main advantages of expression (9) is that in order to determine the value of the maximum permissible load *F on a* splinted incisor, it is sufficient to determine the vestibulo-lingual dimensions of the canine crown *Vlcor* and the angle of inclination of the central incisors in the anterior region to the line of action of the load. Significant disadvantages of expression (9) are the impossibility of taking into account the clinical height of the crowns of the teeth (only the anatomical dimensions of the crown are taken into account), the magnitude of their possible pathological abrasion and the limit of bone atrophy of the bone tissue of the sockets of the teeth.

Therefore, the use of the calculation scheme (9) is permissible only in cases of complete anatomical restoration of the entire anterior group of teeth. That is why, in practice, the use of expression (8) is more acceptable for calculations. Finally, the value of the maximum permissible load *F on the* splinted cutter is determined as the lesser of two values: obtained by (8) according to [13, 14] and selected from the table of maximum permissible values of vertical forces on abutment teeth depending on their clinical condition.

This method is reliable for clinical cases with pathological mobility of the central and lateral incisors of the I and II degree, with the amount of atrophy less than 2/3 of the socket and the absence of pathological mobility of the canines. In the case of pathological mobility of the canines of the first degree, in order to reduce the values of the loosening moment that occurs in the canine from the load transmitted by the splint, the retention furrow should be placed as low as possible in the height of the crown part of the canine. The maximum value of the load transmitted to the canine by tire incisors is determined by formula (4).

Conclusions.

1. An analytical model has been developed to mathematically substantiate the distribution of the chewing load on the anterior teeth with varying degrees of pathological mobility, taking into account the condition of the abutment teeth and the endurance of periodontal tissues, depending on the conditions in the oral cavity.

2. The method of splinting of anterior teeth with pathological mobility with the placement of a reinforcing splint element based on an inorganic matrix on the vestibular surface of the tooth was substantiated, taking into account biomechanical feasibility, degree of tooth mobility, resorption of interdental septa and the height of clinical crowns.

3) The expediency of the splinting structure, its location in accordance with mathematical calculations, taking into account the height of clinical crowns, tooth inclination and type of bite after a preliminary study of plaster models in a parallelogram, is substantiated.

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