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Analysis of sliding mechanics force degradation during postextraction space closure

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SUMMARY

Introduction Due to its simplicity, sliding mechanism is very often used in clinical practice for post-extraction space closure, however, the efficiency of this method may be reduced due to friction and changes in the properties of the materials used in this method. The most commonly used methods of sliding mechanics are nickel titanium (NiTi) closed coil spring and elastic chain.

The aim of this study was to analyze force degradation in the application of nickel titanium closed coil springs and elastic chains during post-extraction space closure within treatment with fixed orthodontic appliances.

Material and Methods The total sample in this study consisted of 78 post-extraction spaces in patients who were indicated for extraction of first premolars and treatment with fixed orthodontic appliances. Nickel titanium closed coil springs and elastic chains were used to close the post-extraction spaces. Post-extraction spaces were monitored for 6 months with follow up examinations every 4 weeks. Measurements of initial force, at the beginning of mechanism activation and residual force in the observation period were performed during control examinations.

Results Results of this research showed that with both methods of sliding mechanism there was a significant decrease in the observation period. When using NiTi closed coil springs, the value of average initial force at control examination was between 189.00-210.25 g, while residual was in the range of 117.56-133.50 g that NiTi closed coil springs kept an average 61.57% of initial force. The average initial force on the control examinations for elastic chains was between 184.5-205.38 g, while residual force was in range of 100.39-113.00 g, that elastic chains retained an average 53.41% of initial force.

Conclusion There was a significant force degradation between inspections, when sliding mechanics were applied. The loss of force between activation phases of NiTi closed coil springs was smaller compared to the forces produced by elastic chains.

Keywords: sliding mechanics; elastic chain; NiTi closed coil spring; post-extraction space

INTRODUCTION

Optimal orthodontic treatment requires application of mechanics that lead to maximum speed of tooth movement with minimal irreversible damage to root, periodontal ligament and alveolar bone. Optimal force for orthodontic tooth movement is described as the lightest force providing maximum or almost maximum response [1, 2]. Depending on magnitude of the force applied, different types of resorptions may occur in zones of tooth movement. If heavy forces are applied, necrosis of the surrounding tissue and undermining resorption with hyalinization zones can occur and lead to retention in tooth movement. With application of mild continuous forces, there is a uniform movement of teeth with the appearance of the desired form of resorption, that is frontal resorption. In terms of duration, two types of force can be generated with fixed orthodontic appliances: continuous and intermittent. Continuous ones show the same level during 24 hours, and insignificantly decrease between control examinations, while intermittent forces suddenly decrease and at the next checkup, they are equal to zero [2, 3]. More efficient and faster closing of post-extraction space is also influenced by the decrease in force of applied mechanism over time. Orthodontic tooth displacement requires the application of continuous force over a certain period of time, whereby the efficiency increases if the force is maintained for as long as possible [4, 5, 6].

Within treatment with fixed orthodontic appliances, the sliding mechanism is a very simple method for closing post-extraction space and it is therefore most often used in clinical practice. This method performs appropriate application and transmission of force inside the dental arch. Due to occurrence of friction, the efficiency

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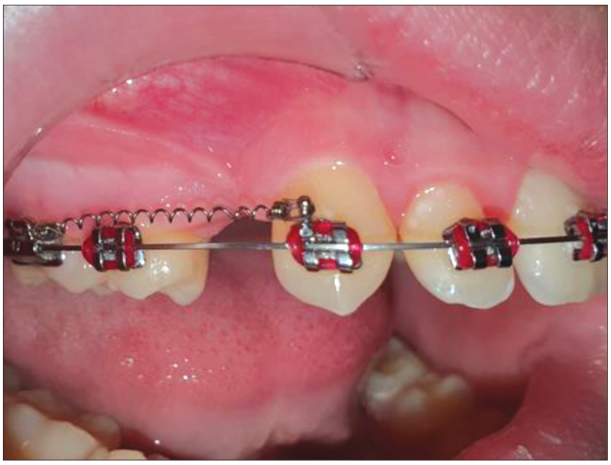

Figure 1. Application of NiTi closed spring
Slika 1. Postavljanje NiTi zatvorene opruge

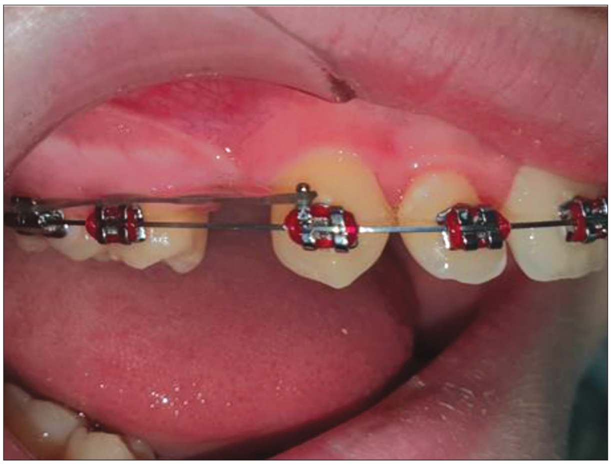

Figure 2. Application of elastic chain
Slika 2. Postavljanje elastičnog lanca

Figure 3. Dynamometer (Force Gauge Dynamometer, White Oak, USA)
Slika 3. Dinamometar (*Force Gauge Dynamometer, White Oak,* USA)

of this method may be reduced. Friction is a force of resistance that occurs between two surfaces and opposes movement. In sliding mechanics, force and resistance to sliding change as the tooth moves, at first inclines, then a biological response occurs, the tooth then straightens, bone remodels around the root, and then inclines again [7]. There are a number of factors that affect the resistance that occurs with the sliding mechanism, and they can be grouped into physical and biological factors. Physical factors are mainly related to the properties and dimensions of orthodontic arches, braces, as well as the type of ligation, while biological factors include the amount and presence of saliva, plaque and food debris [8].

It is necessary to apply such force that can overcome the resistance to sliding of wire arch through the system of brackets and move teeth along the wire arch [9]. It is recommended that the optimal force should be between 100 and 200 g/cm^2, that is considered a biologically acceptable framework. In order to move the canine with the help of a sliding mechanism, a force of 100 g/cm^2 is needed to move the tooth and an additional 100 g/cm^2 to overcome the resistance (friction) [10].

The aim of this study was to analyze force degradation in the application of nickel titanium closed coil springs and elastic chains during post-extraction space closure within treatment with fixed orthodontic appliances.

MATERIAL AND METHODS

Research was conducted at the Faculty of Medicine - study program of dentistry in Banja Luka, with the consent of the Ethics Committee of the Department of Dentistry. At the beginning of this research, a selection of respondents was made among the patients who came for the first examination. After clinical processing of patients (anamnesis, clinical examination, taking impressions, analysis of study models, analysis of orthopantomography and teleradiography), potential subjects were informed about the research and they signed an informed consent. Subjects ranged in age from 12 to 20 years and had no contraindications for orthodontic therapy, as well as other extractions (except first premolars). Subjects excluded from the study were those who did not came to check-ups regularly, had poor oral hygiene and did not follow the instructions given at the beginning of therapy. The total sample in the study was 78 post-extraction spaces in patients who were indicated for extraction of the first premolars in order to conduct orthodontic treatment.

After extraction of first premolars, subjects were fitted with a fixed orthodontic appliance (Dentaurum, Discovery, Roth prescription, slot 0.022 in) and initial leveling was performed with NiTi arches of round and square cross-section, before application of square steel arches. A square steel arch with a cross section of 0.019×0.025 in was left in the slots of brackets for at least 4 weeks, to become passive and nickel titanium closed springs (American Orthodontics, USA) were applied for 40 and elastic chains (American Orthodontics, USA) for 38 post-extraction spaces. Nickel titanium closed coil springs were placed from the hook on the tube of first molar to the hook of bracket on the canine, where springs were not stretched more than 9 mm (Figure 1). If the spring was too short, a ligature wire was used to connect it to hook on the tube on molar. During the therapy, spring was activated at the control examinations. Elastic chain was placed so that it connects hook on the tube of the first molar and hook of the bracket on the canine, whereby it was stretched to approximately twice the initial length, and at the control examinations it was replaced with a new one (Figure 2).

Post-extraction spaces were monitored for 6 months from the beginning of the sliding mechanism application at intervals of one month (T_0-T_6). Control examinations were performed every 4 weeks and it was checked whether there was damage on applied mechanisms and their activation.

Measurements of initial force at the beginning and residual force in the observation period were performed at the control examinations. Force strength was measured with a dynamometer (Force Gauge Dynamometer, White Oak, USA) (Figure 3).

RESULTS

In our research, the effect of applied sliding mechanism activation force at the beginning and residual force at the end was analyzed. The average applied force at the beginning and at the end of each time activation interval was examined. The T test for paired samples showed that applied force significantly differed at the beginning and end of activation in each time interval. In the interval T_1, average force at the beginning was M = 231.02 g, and at the end M = 121.99 g (52.8%). This difference was statistically significant (t = 45.03, df = 117, p = 0.000). In T_2, the average force at the beginning was M = 228.42 g, and at the end M = 120.34 g (52.68%). This difference was statistically significant (t = 42.96, df = 116, p = 0.000). In T_3, the average force at the beginning was M = 230.56 g, and at the end M = 123.70 g (53.65%), this difference was statistically significant (t = 37.99, df = 107, p = 0.000). In T_4 the average force at the beginning was M = 234.93 g, and at the end M = 130.21 g (55.42%), this difference was statistically significant (t = 33.17, df = 71, p = 0.000). In T5 the average force at the beginning was M = 240.73 g, and at the end M = 143.13 g (59.45%), this difference was statistically significant (t = 28.31, df = 47, p = 0.000). In T_6 the average force at the beginning was M = 209.44 g, and at the end M = 140.74 g (67.19%), this difference was statistically significant (t = 12.39, df = 26, p = 0.000) (Table 1).

Table 1. Force applied at the beginning and end of activation
Tabela 1. Primenjena sila na početku i na kraju aktivacije

	N	M	SD	T	Df	P
T_1 Beginning T_1 Početak	78	231.02	39.70	45.035	77	0.000
T_1 End T_1 Kraj	78	121.99	21.72			
T_2 Beginning T_2 Početak	77	228.42	38.31	42.961	76	0.000
T_2 End T_2 Kraj	77	120.34	18.44			
T_3 Beginning T_3 Početak	68	230.56	38.23	37.998	67	0.000
T_3 End T_3 Kraj	68	123.70	20.47			
T_4 Beginning T_4 Početak	52	234.93	39.70	33.173	51	0.000
T_4 End T_4 Kraj	52	130.21	22.00			
T_5 Beginning T_5 Početak	28	240.73	39.88	28.319	27	0.000
T_5 End T_5 Kraj	28	143.13	33.34			
T_6 Beginning T_6 Početak	20	209.44	42.86	12.392	19	0.000
T_6 End T_6 Kraj	20	140.74	38.47			

N – number of subjects; Min – minimum value on the sample; Max – maximum value on the sample; M – arithmetic mean; SD – standard deviation; t – t-test for paired samples; df – degree of freedom; p – statistical significance
N – broj ispitanih prostora; Min – minimalna vrednost na uzorku; Max – maksimalna vrednost na uzorku; M – aritmetička sredina; SD – standardna devijacija; t – t-test za uparene uzorke; df – stepen slobode; p – statistička značajnost

After examining change in force strength, these changes were examined within each method. The average values of force at the beginning and at the end of each activation time interval within NiTi closed spring method were examined. The T test for paired samples showed that applied force differed significantly at the beginning and end of activation in each time interval. In the interval T_1, the average force at the beginning was M = 210.250 g, and at the end M = 121.625 g (57.84%). This difference was statistically significant (t = 33.37, df = 39, p = 0.000). In T_2, the average force at the beginning was M = 201.154 g, and at the end M = 117.564 g (58.44%). This difference was statistically significant (t = 34.90, df = 38, p = 0.000). In T_3, the average force at the beginning was M = 204.242 g, and at the end M = 123.485 g (60.46%), this difference was statistically significant (t = 28.12, df = 32, p = 0.000). In T_4, the average force at the beginning was M = 204.667 g, and at the end M = 122.667 g (59.93%), this difference was statistically significant (t = 19.43, df = 14, p = 0.000). In T_5, the average force at the beginning was M = 205.417 g, and at the end M = 128.750 g (62.67%), this difference was statistically significant (t = 15.77, df = 11, p = 0.000). In T_6 the average force at the beginning was M = 189,000 g, and at the end M = 133,500 g (70.06%), this difference was statistically significant (t = 10.81, df = 9, p = 0.000) (Table 2).

Force was tested at the beginning and at the end of each activation time interval within the elastic chain method. The T test for paired samples showed that the applied force differed significantly at the beginning and at the end of activation in each time interval. In the interval T_1, the average force at the beginning was M = 199.34 g, and at the end M = 100.39 g (50.36%). This difference was statistically significant (t = 39.75, df = 37, p = 0.000). In T_2, the average force at the beginning was M = 204.47 g, and at the end M = 103.82 g (50.77%). This difference was statistically significant (t = 37.17, df = 37, p = 0.000). In T_3, the average force at the beginning was M = 204.58 g, and at the end M = 104.72 g (51.18%), this difference was statistically significant (t = 25.53, df = 35, p = 0.000). In T_4, the average force at the beginning was M = 198.75 g, and at the end M = 109.17 g (54.92%), this difference was statistically significant (t = 26.73, df = 23, p = 0.000). In T_5 the average force at the beginning was M = 205.38 g, and at the end M = 108.08 g (52.02%), this difference was statistically significant (t = 29.64, df = 12, p = 0.000).

Table 2. Applied force at the beginning and end of activation within the NiTi spring mechanism
Tabela 2. Primenjena sila na početku i na kraju aktivacije u okviru mehanizma NiTi opruge

	N	M	SD	T	Df	P
T_1 Beginning T_1 Početak	40	210.250	15.971	33.376	39	0.000
T_1 End T_1 Kraj	40	121.625	13.746			
T_2 Beginning T2 Početak	39	201.154	17.262	34.909	38	0.000
T_2 End T_2 Kraj	39	117.564	13.854			
T_3 Beginning T_3 Početak	33	204.242	16.683	28.126	32	0.000
T_3 End T_3 Kraj	33	123.485	12.959			
T_4 Beginning T_4 Početak	15	204.667	16.526	19.431	14	0.000
T_4 End T_4 Kraj	15	122.667	14.251			
T_5 Beginning T_5 Početak	12	205.417	18.397	15.778	11	0.000
T_5 End T_5 Kraj	12	128.750	14.001			
T_6 Beginning T_6 Početak	10	189.000	10.220	10.810	9	0.000
T_6 End T_6 Kraj	10	133.500	19.444			

N – number of subjects; Min – minimum value on the sample; Max – maximum value on the sample; M – arithmetic mean; SD – standard deviation; t – t-test for paired samples; df – degree of freedom; p – statistical significance
N – broj ispitanih prostora; Min – minimalna vrednost na uzorku; Max – maksimalna vrednost na uzorku; M – aritmetička sredina; SD – standardna devijacija; t – t-test za uparene uzorke; df – stepen slobode; p – statistička značajnost

Table 3. Applied force at the beginning and end of the activation within the elastic chain mechanism
Tabela 3. Primenjena sila na početku i na kraju aktivacije u okviru mehanizma elastičnog lanca

	N	M	SD	T	Df	P
T_1 Beginning T_1 Početak	38	199.34	17.21	39.759	37	0. 000
T_1 End T_1 Kraj	38	100.39	13.48			
T_2 Beginning T_2 Početak	38	204.47	13.79	37.174	37	0. 000
T_2 End T_2 Kraj	38	103.82	11.12			
T_3 Beginning T_3 Početak	36	204.58	19.17	25.532	35	0. 000
T_3 End T_3 Kraj	36	104.72	12.93			
T_4 Beginning T_4 Početak	24	198.75	14.47	26.739	23	0. 000
T_4 End T_4 Kraj	24	109.17	9.74			
T_5 Beginning T_5 Početak	13	205.38	17.97	29.645	12	0. 000
T_5 End T_5 Kraj	13	108.08	8.79			
T_6 Beginning T_6 Početak	10	184.50	27.13	8.106	9	0. 000
T_6 End T_6 Kraj	10	113.00	6.32			

N – number of subjects; Min – minimum value on the sample; Max – maximum value on the sample; M – arithmetic mean; SD – standard deviation; t – t-test for paired samples; df – degree of freedom; p – statistical significance
N – broj ispitanih prostora; Min – minimalna vrednost na uzorku; Max – maksimalna vrednost na uzorku; M – aritmetička sredina; SD – standardna devijacija; t – t-test za uparene uzorke; df – stepen slobode; p – statistička značajnost

In T_6 the average force at the beginning was M = 184.50 g, and at the end M = 113.00 g (61.24%), this difference was statistically significant (t = 8.10, df = 9, p = 0.000) (Table 3).

DISCUSSION

It is very important that applied mechanisms for post-extraction space closure produce continuous forces for orthodontic tooth movement over a period of time, with their efficiency increasing if the force is maintained for as long as possible [11].

Studies on optimal force for canine retraction showed that a force of 150-200 g leads to the most efficient movement. It is believed that light forces do not have such efficiency, while heavy ones can lead to hyalinization of tissues, which results in obstruction of tooth movement process [12]. In our research, forces with an average value of about 200 g were used. The average force at the beginning of activation was 231.02 g, while at the end of activation period, after 4 weeks, this value averaged 121.99 g.

NiTi closed springs showed an increasing trend in clinical use in post-extraction space closure, that is why they are often a subject of research. In our study, NiTi springs were used from the same manufacturer, so that they produce a force of about 200 g. If they would generate too much force during larger stretches, wire ligatures were used to tie hooks of tubes on molars. When using NiTi closed springs, the value of the average initial force on the control examinations ranged between 189.00 g to 210.25 g, while the residual one ranged from 117.56 g to 133.50 g. It can be concluded that NiTi closed springs retained an average of 61.57% of the initial force.

Influence of oral environmental factors on the force degradation in NiTi closed coil springs has been investigated through numerous studies. It has been confirmed that neither food nor liquids found in the mouth, including saliva, affect the force generated by these springs [13, 14, 15]. It has been established that only large temperature differences can lead to changes in the force level [16, 17]. In this research, it was not possible to control these conditions, except that in communication with patients it was found that it is difficult for them to maintain hygiene, as well as retain food on springs, especially at the end of the activation cycle, when the thread gap decreases.

Kishorekumar et al. monitored force degradation of NiTi springs over certain time intervals. Total sample consisted of 30 NiTi springs, 9 mm length from 3 different manufacturers (Lancer orthodontics, Ortho technology, GAC international). Initially, NiTi springs were stretched to produce a force of 150 g. At the end of 4 weeks the force loss for the GAC spring (29.03%) was higher than the Lancer spring (21.61%) and Orthotech (14.62%). The GAC spring showed significant force degradation during most of the interval, although it was exposed to the martensite plateau, it did not achieve the target force in the activation range given by the manufacturer (1-12 mm). With the Lancer spring, there was no significant loss of force during the first 24 hours, while Orthotech springs showed less force degradation throughout the period. Authors recommend stretching the Lancer and Orthotech springs by 1/3 of their length, and for GAC springs by 1/2 to 1/3 of its original length [18].

Maganzini et al. measured initial force of 14 different 9 mm NiTi closed springs from 5 different manufacturers. They found that only 6 of them had a change in intensity of less than 50 g when deactivated, while some springs also had a decrease in force of more than 100 g. Authors believe that such results may be primarily due to the fact that in addition to dimensions of 9 and 12 mm, manufacturers put descriptive names (ultra-light, light, medium, heavy, extra heavy), while others mark the constant force generated by springs (100 g, 150 g and 200 g). Such marking can be misleading to clinicians, especially if we take into account the fact that light models of tested springs from one manufacturer produce a force of 103-120 g, and another from 121-226 g [19]. A similar study was conducted by Conti et al. and it was concluded that it is necessary to measure the force produced by NiTi closed springs during orthodontic treatment, in order to achieve optimal force for moving teeth [20].

In a clinical-laboratory study, Geng et al. examined the level of force produced by NiTi closed springs during post-extraction space closure. This study showed that the loss of maximum force and the decrease of forces on the deactivation plateau did not depend on time. Authors conclude that it should be taken care when the spring is applied to avoid excessive stretching. Thermal cycles from daily food and beverages can contribute in force degradation of these springs, while heat treatment can help return them to their original state [21].

Unlike NiTi closed springs, elastic chains in the oral cavity begin to absorb saliva, can break and permanently deform due to the rupture of internal connections. Over time, exposure to saliva and changes in oral temperature can reduce the ability to maintain the same level of strength. Numerous studies have shown that the composition and method of production can affect the transmission of force, so it has been shown that transparent elastic chains retain a certain level of force longer than colored [22, 23, 24]. Only transparent elastic chains were used in this study. The average initial force on the control examinations was between 184.5 g to 205.38 g, while the residual force ranged from 100.39 g to 113.00 g. It can be concluded that the elastic chains retained an average of 53.41% of the initial force.

Several studies have confirmed that elastic chains change the level of force over time, mostly during the first hours and the first day of application, so that it decreases between 40-50% and degradation continued, but to a lesser extent. After 4 weeks, the average degradation was 50-85% depending on the type of research and the type of elastic chain. Although there is a great loss of force, it is considered that it is still sufficient to continue with movement of canine [25, 26].

Elastic chain is most often applied by connecting a hook on the back teeth, usually molars, and for a specific front tooth or a hook on the canine in order to achieve the desired tooth movement. Balhoff et al. conducted a study comparing different techniques for placing 4 different types of elastic chains. They compared three ways of applying elastic chains: configuration 6-5-3 (first molar, second premolar and canine), configuration 6-3 (first molar and canine) and elastic chain loop (first molar, around the hook on the canine and back to molar). They came to conclusion that directly connecting the hook on the molar and the hook of the bracket on the canine is the most efficient for post-extraction space closure and there is the slightest decrease in force. The force loss for the first configuration (6-5-3) was 42-68%, for the elastic chain loop 39-55% and for the second configuration (6-3) 32-60% [27].

In our research, the same type of memory elastic chain (American Orthodontics memory chain) was used with a force of about 200 g. Miraschemi et al. examined elastic chains with memory technology (memory chain), that has the role of enabling them to maintain their power for as long as possible. They analyzed three types of conventional and three types of new memory elastic chains. Results showed that force degradation in the first hour for conventional averaged 17.93% and 4.83% for the memory group, while after 24 hours, elastic chains from the first group remained 74%, and from the second group 90.7% initial forces. After 4 weeks, the remaining force for conventional elastic chains ranged from 26-40%, and for memory from 60-63%. American Orthodontics memory chain showed the best results. In order to achieve a force of 200 g, memory elastic chains had to be stretched more about the initial length ratio than the conventional ones [28].

Some authors recommend "pre-stretching" in order to achieve moderate and relatively stable force over time. This procedure involves stretching the elastic chain before application in order to apply tensile stress to molecular bonds made of a polymeric material in order to improve the force generated by the elastic chain [29]. Kim et al. examined the effect of the "pre-stretching" method on the force degradation over time and found that it has an effect in the first hour, and later decreases as well as this method is not applied [30].

This research did not use the "pre-stretching" method, but initial force that elastic chain had was applied when it was used for the first time from the spool, so that uneven stretching would not disrupt the uniform mechanical properties specified by the manufacturer.

CONCLUSION

When sliding mechanism is used, there is a significant force degradation between inspections. The loss of force between the activation phases of NiTi closed coil springs is smaller compared to the forces produced by elastic chains. Good knowledge of how different types of sliding mechanism work is crucial for efficient tooth movement in biologically accepted frames.

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Analiza opadanja sile kod kliznog mehanizma pri zatvaranju postekstrakcionog prostora

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KRATAK SADRŽAJ

Uvod Zbog svoje jednostavnosti klizni mehanizam se veoma često primenjuje u kliničkoj praksi za zatvaranje postekstrakcionog prostora. Međutim, efikasnost ove metode može biti smanjena zbog pojave trenja i promene osobina materijala kojima se ova metoda sprovodi. Najčešće korišćene metode klizne mehanike su nikl-titanijumska (NiTi) zatvorena opruga i elastični lanci.
Cilj ovog rada je bio da se analizira opadanje sile kod primene NiTi zatvorenih opruga i elastičnih lanaca prilikom zatvaranja postekstrakcionog prostora u okviru terapije fiksnim ortodontskim aparatima.
Materijal i metode rada Ukupan uzorak u istraživanju činilo je 78 postekstrakcionih prostora kod pacijenata kojima je indikovana ekstrakcija prvih premolara uz primenu fiksnog ortodontskog aparata u cilju sprovođenja terapije. Za zatvaranje postekstrakcionih prostora primenjeni su NiTi opruge i elastični lanci. Postekstrakcioni prostori su praćeni tokom šest meseci sa kontrolnim pregledima svake četiri sedmice. Na kontrolnim pregledima su izvršena merenja inicijalne sile, na početku aktivacije mehanizma i rezidualne sile u opservacionom periodu.
Rezultati Rezultati istraživanja pokazuju da kod obe metode kliznog mehanizma dolazi do značajnog pada u opservacionom periodu. Kod primene NiTi zatvorenih opruga vrednost prosečne inicijalne sile na kontrolnim pregledima je iznosila između 189,00 i 210,25 g, dok je rezidualna bila u rasponu od 117,56 do 133,50 g, odnosno NiTi zatvorene opruge zadržavale su u proseku 61,57% početne sile. Prosečna inicijalna sila na kontrolnim pregledima za elastične lance je iznosila između 184,5 i 205,38 g, dok je rezidualna bila u rasponu od 100,39 do 113,00 g, odnosno elastični lanci su zadržavali u proseku 53,41% početne sile.
Zaključak Kod primene kliznog mehanizma dolazi do značajnog pada sile između kontrolnih pregleda. Gubitak sile između faza aktivacije kod NiTi zatvorenih opruga je manji u odnosu na sile koje proizvode elastični lanci.
Ključne reči: klizni mehanizam; elastični lanac; NiTi zatvorene opruge; postekstrakcioni prostor

UVOD

Optimalna ortodontska terapija zahteva primenu mehanike koja vodi do maksimalne brzine pomeranja zuba uz minimalno ireverzibilno oštećenje korena, parodontalnog ligamenta i alveolarne kosti. Optimalna jačina sile za ortodontsko pomeranje zuba se opisuje kao najlakša sila koja pruža maksimalni ili skoro maksimalni odgovor [1, 2]. Zavisno od veličine sile koja se primenjuje mogu se pojaviti različite vrste resorpcije u zonama pomeranja zuba. Ukoliko se primenjuju jake sile, može doći do nekroze okolnog tkiva i podminirajuće resorpcije sa zonama hijalinizacije i to može dovesti do zadržavanja u pomeranju zuba. Primenom blagih kontinuiranih sila dolazi do ujednačenog kretanja zuba uz pojavu poželjnog oblika resorpcije, odnosno frontalne resorpcije. U odnosu na trajanje, fiksnim ortodontskim aparatima se mogu proizvesti dve vrste sila: kontinuirane i intermitentne. Kontinuirane pokazuju isti nivo u toku 24 sata i trend neznačajnog pada između kontrolnih pregleda, dok intermitentne sile naglo padaju, tako da se pri sledećoj kontroli nalaze na nuli [2, 3]. Na efikasnije i brže zatvaranje postekstrakcionog prostora utiče i opadanje sile primenjenog mehanizma kroz vreme. Za ortodontsko pomeranje zuba potrebna je primena kontinuirane sile kroz određeni period, pri čemu se efikasnost povećava ukoliko se jačina sile održi što duže [4, 5, 6].

U okviru terapije fiksnim ortodontskim aparatima klizni mehanizam predstavlja veoma jednostavnu metodu za zatvaranje postekstrakcionog prostora i zbog toga se najčešće primenjuje u kliničkoj praksi. Ovom metodom se unutar zubnog luka vrši odgovarajuća primena i prenos sile. Zbog pojave trenja efikasnost ove metode može biti smanjena. Trenje predstavlja silu otpora koja se javlja između dve površine i suprotstavlja se kretanju. U kliznoj mehanici, sila i otpor klizanju se menjaju kako se zub pomera, tako da se on prvo naginje, zatim se dešava biološki odgovor, zub se zatim ispravlja, kost se remodeluje oko korena i zatim se ponovo naginje [7]. Postoje brojni faktori koji utiču na otpor koji se javlja kod kliznog mehanizma, a mogu se grupisati u fizičke i biološke činioce. Fizički faktori se, uglavnom, odnose na osobine i dimenzije ortodontskih lukova, bravica, kao i na vrstu ligiranja, dok biološki faktori uključuju količinu i prisustvo pljuvačke, plaka i ostataka hrane [8].

Suština je da je neophodno primeniti takvu silu koja može savladati otpor klizanju žičanog luka kroz sistem bravica i pomeriti zube duž žičanog luka [9]. Preporučeno je da optimalna sila iznosi između 100 i 200 g/cm^2, što se smatra biološki prihvatljivim okvirom. Da bi se pomoću kliznog mehanizma pomerio očnjak, potrebna je sila od 100 g/cm^2 za pomeranje zuba i još dodatnih 100 g/cm^2 da se prevaziđe otpor, odnosno trenje [10].

Cilj ovog rada je bio da se analizira opadanje sile kliznih mehanizama kroz vreme prilikom zatvaranja postekstrakcionog prostora primenom NiTi zatvorenih opruga i elastičnih lanaca u okviru terapije fiksnim ortodontskim aparatima.

MATERIJAL I METODE

Istraživanje je sprovedeno na Medicinskom fakultetu u Banjoj Luci, studijski program Stomatologija, uz saglasnost Etičkog komiteta Zavoda za stomatologiju. Na početku istraživanja izvršen je izbor ispitanika među pacijentima koji prvi put dolaze na pregled. Nakon kliničke obrade pacijenata (anamneza, klinički pregled, uzimanje otisaka, analiza studijskih modela, analiza ortopantomografskog i telerendgenskog snimka), potencijalni ispitanici su bili informisani o istraživanju, nakon čega su potpisali informisani pristanak. Ispitanici su bili uzrasta od 12 do 20 godina i nisu imali kontraindikacije za ortodontsku terapiju, kao ni druge ekstrakcije (osim prvih premolara). Iz istraživanja su isključeni oni ispitanici koji su neredovno dolazili na kontrolne preglede, koji su imali lošu oralnu higijenu i oni koji se nisu pridržavali datih uputstava na početku terapije. Ukupan uzorak u istraživanju iznosio je 78 postekstrakcionih prostora kod pacijenata kojima je indikovana ekstrakcija prvih premolara u cilju sprovođenja ortodontske terapije.

Posle ekstrakcije prvih premolara ispitanicima je postavljen fiksni ortodontski aparat (*Dentaurum, Discovery, Roth preskripcija, slot 0,022 in*), nakon čega je izvršena početna nivelacija sa NiTi lukovima okruglog i četvrtastog preseka, pre postavljanja čeličnih četvrtastih lukova. Četvrtasti čelični luk preseka 0,019 × 0,025 in stajao je u slotovima bravica najmanje četiri sedmice, da postane pasivan, nakon čega su aplicirane NiTi zatvorene opruge (*American Orthodontics, USA*) za 40 i elastični lanci (*American Orthodontics, USA*) za 38 postekstrakcionih prostora. NiTi zatvorene opruge su postavljane od kukice na tubi prvog molara do kukice bravice na očnjaku, pri čemu opruge nisu bile istegnute više od 9 mm (Slika 1). Ukoliko je opruga bila prekratka, korišćena je žičana ligatura za povezivanje sa kukicom tube na molaru. Za vreme terapije opruga je aktivirana na kontrolnim pregledima. Elastični lanac je postavljan tako da povezuje kukicu na tubi prvog molara i kukicu bravice na očnjaku, pri čemu je rastegnut na približno dvostruku početnu dužinu, a na kontrolnim pregledima je zamenjen novim (Slika 2).

Postekstrakcioni prostori su praćeni šest meseci od početka primene kliznog mehanizma u intervalima od mesec dana (T_0–T_6). Kontrolni pregledi su obavljani svake četiri sedmice i na njima je proveravano da li je došlo do oštećenja apliciranih mehanizama i izvršena njihova aktivacija.

Na kotrolnim pregledima su izvršena merenja inicijalne sile na početku i rezidualne sile u opservacionom periodu. Jačina sile je merena dinamometrom (*Force Gauge Dynamometer, White Oak, USA*) (Slika 3).

REZULTATI

U okviru ovog istraživanja analizirano je dejstvo primenjene sile na početku i kraju aktivacije kod kliznog mehanizma. Ispitana je prosečna primenjena sila na početku i na kraju aktivacije svakog vremenskog intervala. T-test za uparene uzorke pokazuje da se primenjena sila statistički značajno razlikuje na početku i na kraju aktivacije u svakom vremenskom intervalu. U intervalu T_1 prosečna sila na početku iznosila je M = 231,02 g, a na kraju M = 121,99 g (52,8%); ova razlika je statistički značajna (t = 45,03, df = 117, p = 0,000). U T_2 prosečna sila na početku iznosila je M = 228,42 g, a na kraju M = 120,34 g (52,68%); ova razlika je statistički značajna (t = 42,96, df = 116, p = 0,000). U T_3 prosečna sila na početku iznosila je M = 230,56 g, a na kraju M = 123,70 g (53,65%); ova razlika je statistički značajna (t = 37,99, df = 107, p = 0,000). U T_4 prosečna sila na početku iznosila je M = 234,93 g, a na kraju M = 130,21 g (55,42%); ova razlika je statistički značajna (t = 33,17, df = 71, p = 0,000). U T_5 prosečna sila na početku iznosila je M = 240,73 g, a na kraju M = 143,13 g (59,45%); ova razlika je statistički značajna (t = 28,31, df = 47, p = 0,000). U T_6 prosečna sila na početku iznosila je M = 209,44 g, a na kraju M = 140,74 g (67,19%); ova razlika je statistički značajna (t = 12,39, df = 26, p = 0,000) (Tabela 1).

Nakon ispitane promene u jačini sile, ispitane su ove promene u okviru svake metode.

Ispitane su prosečne vrednosti sile na početku i na kraju aktivacije svakog vremenskog intervala u okviru metode NiTi opruge. T-test za uparene uzorke pokazuje da se primenjena sila statistički značajno razlikuje na početku i na kraju aktivacije u svakom vremenskom intervalu. U intervalu T_1 prosečna sila na početku iznosila je M = 210,250 g, a na kraju M = 121,625 g (57,84%); ova razlika je statistički značajna (t = 33,37, df = 39, p = 0,000). U T_2 prosečna sila na početku iznosila je M = 201,154 g, a na kraju M = 117,564 g (58.44%); ova razlika je statistički značajna (t = 34,90, df = 38, p = 0,000). U T_3 prosečna sila na početku iznosila je M = 204,242 g, a na kraju M = 123,485 g (60,46%); ova razlika je statistički značajna (t = 28,12, df = 32, p = 0,000). U T_4 prosečna sila na početku iznosila je M = 204,667 g, a na kraju M = 122,667 g (59,93%); ova razlika je statistički značajna (t = 19,43, df = 14, p = 0,000). U T_5 prosečna sila na početku iznosila je M = 205,417 g, a na kraju M = 128,750 g (62,67%); ova razlika je statistički značajna (t = 15,77, df = 11, p = 0,000). U T_6 prosečna sila na početku iznosila je M = 189,000 g, a na kraju M = 133,500 g (70,06%); ova razlika je statistički značajna (t = 10,81, df = 9, p = 0,000) (Tabela 2).

Sila je ispitana na početku i na kraju aktivacije svakog vremenskog intervala u okviru metode elastičnog lanca. T-test za uparene uzorke pokazuje da se primenjena sila statistički značajno razlikuje na početku i na kraju aktivacije u svakom vremenskom intervalu. U intervalu T_1 prosečna sila na početku iznosila je M = 199,34 g, a na kraju M = 100,39 g (50,36%); ova razlika je statistički značajna (t = 39,75, df = 37, p = 0,000). U T_2 prosečna sila na početku iznosila je M = 204,47 g, a na kraju M = 103,82 g (50,77%); ova razlika je statistički značajna (t = 37,17, df = 37, p = 0,000). U T_3 prosečna sila na početku iznosila je M = 204,58 g, a na kraju M = 104,72 g (51,18%); ova razlika je statistički značajna (t = 25,53, df = 35, p = 0,000). U T_4 prosečna sila na početku iznosila je M = 198,75 g, a na kraju M = 109,17 g (54,92%); ova razlika je statistički značajna (t = 26,73, df = 23, p = 0,000). U T_5 prosečna sila na početku iznosila je M = 205,38 g, a na kraju M = 108,08 g (52,02%); ova razlika je statistički značajna (t = 29,64, df = 12, p = 0,000). U T_6 prosečna sila na početku iznosila je M = 184,50 g, a na kraju M = 113,00 g (61,24%); ova razlika je statistički značajna (t = 8,10, df = 9, p = 0,000) (Tabela 3).

DISKUSIJA

Kod zatvaranja postekstrakcionih prostora veoma je važno da primenjeni mehanizmi proizvode kontinuirane sile za ortodontsko pomeranje zuba kroz određeni period, pri čemu se njihova efikasnost povećava ukoliko se jačina sile održi što duže [11].

Studije o optimalnoj sili za retrakciju očnjaka pokazuju da sila od 150 do 200 g dovodi do najefikasnijeg pomeranja. Smatra se da slabije sile nemaju takvu efikasnost, dok jače mogu da dovedu do hijalinizacije tkiva, što za posledicu ima ometanje procesa pomeranja zuba [12]. U ovom istraživanju su korišćene sile sa prosečnim vrednostima oko 200 g. Prosečna sila na početku aktivacije je iznosila 231,02 g, dok je na kraju aktivacionog perioda, posle četiri sedmice, ova vrednost prosečno iznosila 121,99 g.

NiTi zatvorene opruge pokazuju sve veći trend u kliničkoj upotrebi kod zatvaranja postekstrakcionog prostora, zbog čega su veoma često predmet ispitivanja. U ovom istraživanju su primenjivane NiTi opruge istog proizvođača, tako da proizvode silu oko 200 g. Ukoliko bi pri većim rastezanjima generisale preveliku silu, vezivane su preko žičanih ligatura za kukice tuba na molarima. Kod primene NiTi zatvorenih opruga vrednost prosečne inicijalne sile na kontrolnim pregledima iznosila je između 189,00 g do 210,25 g, dok je rezidualna bila u rasponu od 117,56 g do 133,50 g. Iz ovog se može zaključiti da su NiTi zatvorene opruge zadržavale u proseku 61,57% početne sile.

Uticaj faktora oralnog okruženja na opadanje sile kod NiTi zatvorenih opruga je ispitan kroz mnogobrojne studije. Utvrđeno je da ni hrana ni tečnosti koje se nađu u ustima, uključujući i pljuvačku, ne utiču na silu koju generišu ove opruge [13, 14, 15]. Ustanovljeno je da jedino velike temperaturne razlike mogu dovesti do promene nivoa sile [16, 17]. U ovom istraživanju nije bilo moguće kontrolisanje ovih uslova, osim što je u komunikaciji sa pacijentima konstatovano da im je otežano održavanje higijene, kao i zadržavanje hrane na oprugama, posebno na kraju aktivacionog ciklusa, kada se smanji razmak između navoja.

Kishorekumar i saradnici su pratili opadanje sile NiTi opruga kroz određene vremenske intervale. Ukupan uzorak činilo je 30 NiTi opruga od 9 mm od tri različita proizvođača (*Lancer orthodontics, Ortho technology, GAC international*). Na početku su NiTi opruge istegnute kako bi proizvele silu od 150 g. Na kraju četiri sedmice gubitak sile za oprugu *GAC* (29,03%) bio je veći od opruga *Lancer* (21,61%) i *Orthotech* (14,62%). Opruga *GAC* je pokazala značajnu degradaciju sile tokom većine intervala. Iako je bila izložena martenzitnom platou, nije postigla ciljanu silu u opsegu aktiviranja koju je dao proizvođač (1–12 mm). Kod opruge *Lancer* nije došlo do značajnijeg gubitka sile tokom prva 24 sata, dok su opruge *Orthotech* pokazale manju degradaciju sile tokom celog perioda. Autori preporučuju istezanje opruge *Lancer* i *Orthotech* za 1/3 dužine, a za opruge *GAC* od 1/2 do 1/3 njegove originalne dužine [18].

Maganzini i saradnici su merili inicijalnu silu kod 14 različitih NiTi zatvorenih opruga dužine 9 mm od pet različitih proizvođača. Ustanovili su da samo šest od njih pri deaktivaciji ima promenu u intenzitetu manju od 50 g, dok su neke opruge imale i opadanje sile za iznos veći od 100 g. Autori smatraju da do ovakvih rezultata prvenstveno može doći zbog toga što pored dimenzija 9 mm i 12 mm proizvođači uz njih stavljaju i opisna imena (*ultra light, light, medium, heavy, extra heavy*), dok drugi obeležavaju konstantnu silu koju opruge generišu (100 g, 150 g i 200 g). Ovakvo obeležavanje može da zavara kliničare, naročito ako se u obzir uzme činjenica da light modeli testiranih opruga jednog proizvođača proizvode silu od 103 do 120 g, a kod drugog od 121 do 226 g [19]. Sličnu studiju je sprovela Konti sa saradnicima, u kojoj se zaključuje da je neophodno merenje sile koju proizvode NiTi zatvorene opruge tokom ortodontske terapije kako bi se postigla optimalna sila za pomeranje zuba [20].

U kliničko-laboratorijskoj studiji Geng i saradnici su ispitivali nivo sile koju proizvode NiTi zatvorene opruge tokom zatvaranja postekstrakcionih prostora. Ova studija je pokazala je da gubitak maksimalne sile i opadanje sila na deaktivacijskom platou nisu zavisili od vremena. Autori zaključuju da treba obratiti pažnju da prilikom postavljanja opruge ne dolazi do prekomernog istezanja. Termički ciklusi iz dnevne hrane i pića mogu doprineti opadanju sile ovih opruga, dok termička obrada može pomoći da se vrate u početno stanje [21].

Za razliku od NiTi zatvorenih opruga, elastomerni lanci u usnoj šupljini počinju da apsorbuju pljuvačku, mogu da se preboje i trajno deformišu zbog kidanja unutrašnjih veza. Kroz duži period izloženost pljuvački i promenama oralne temperature može da smanji mogućnost održavanja istog nivoa sile. Brojnim studijama je utvrđeno da sastav i način proizvodnje mogu da utiču na prenos sile, pa se tako pokazalo da bezbojni elastični lanci duže zadržavaju određeni nivo sile u odnosu na obojene [22, 23, 24]. U ovoj studiji su korišćeni isključivo bezbojni elastični lanci. Prosečna inicijalna sila na kontrolnim pregledima iznosila je između 184,5 g do 205,38 g, dok je rezidualna bila u rasponu od 100,39 g do 113,00 g. Iz ovog se može zaključiti da su elastični lanci zadržavali u proseku 53,41% početne sile.

U nekoliko studija je potvrđeno da elastični lanci menjaju nivo sile kroz vreme, i to najviše tokom prvih sati i prvog dana primene, tako da ona opada između 40 i 50%, nakon čega se opadanje nastavilo ali u manjem iznosu. Posle četiri sedmice prosečna degradacija je iznosila od 50 do 85% u zavisnosti od tipa istraživanja i vrste elastičnog lanca. Iako dolazi do velikog gubitka sile, smatra se da je ona i dalje dovoljna da nastavi da deluje na pomeranje očnjaka [25, 26].

Elastični lanac se najčešće primenjuje spajanjem kukice na bočnim zubima, obično molarima, za određeni prednji zub ili kukicu na očnjaku kako bi se postiglo željeno pomeranje zuba. Balhoff i saradnici su sproveli studiju u kojoj su poredili različite tehnike postavljanja četiri različite vrste elastičnih lanaca. Poredili su tri načina aplikacije elastičnih lanaca: konfiguracija 6–5–3 (prvi molar, drugi premolar i očnjak), konfiguracija 6–3 (prvi molar i očnjak) i omča od elastičnog lanca (prvi molar, oko kukice na očnjaku i nazad na molar). Došli su do zaključka da je direktno povezivanje kukice na molaru i kukice bravice na očnjaku najefikasnije kod zatvaranja postekstrakcionog prostora, kao i da dolazi do najmanjeg opadanja sile. Gubitak sile za prvu konfiguraciju (6–5–3) iznosio je 42–68%, za omču od elastičnog lanca 39–55% i za drugu konfiguraciju (6–3) 32–60% [27].

U ovom istraživanju je korišćena ista vrsta memorijskog elastičnog lanca (*American Orthodontics memory chain*) uz primenu sile od oko 200 g. Mirashemi i saradnici su ispitivali elastične lance sa memorijskom tehnologijom (*memory chain*) koja ima ulogu da im omogući što duže održavanje sile kroz vreme. Analizirali su tri vrste konvencionalnih i tri vrste novih memorijskih elastičnih lanaca. Rezultati pokazuju da je opadanje sile u prvom satu za konvencionalne u proseku iznosilo 17,93%, a 4,83% za memorijsku grupu, dok je posle 24 sata elastičnim lancima iz prve grupe preostalo 74%, a iz druge grupe 90,7% početne sile. Posle četiri sedmice preostala sila za konvencionalne elastične lance se kretala u rasponu 26–40%, a za memorijske 60–63%. Najbolje rezultate je pokazao memorijski elastični lanac *American Orthodontics memory chain.* Da bi se postigla sila od 200 g, memorijski elastični lanci su se morali više istegnuti u odnosu na početnu dužinu u odnosu na konvencionalne [28].

Neki autori preporučuju „pre-stretching“ kako bi se postigla umerena i relativno stabilna sila kroz vreme. Ovaj postupak podrazumeva da se pre aplikacije elastični lanac rastegne kako bi se primenio stres istezanja na molekularne veze iz polimernog materijala u cilju poboljšanja sile koju generiše elastični lanac [29]. Kim i saradanici su ispitivali uticaj metode „pre-stretching“ na opadanje sile kroz vreme i ustanovili da ona ima efekat u prvom satu, a kasnije opada kao i kad se ova metoda ne primenjuje [30].

U ovom istraživanju nije korišćena metoda „pre-strechinga“, nego je primenjena inicijalna sila koju elastični lanac ima kad se prvi put upotrebi iz koluta, kako nejednakim istezanjem ne bi došlo do narušavanja uniformnih mehaničkih osobina koje određuje proizvođač.

ZAKLJUČAK

Kod primene kliznog mehanizma dolazi do značajnog pada sile između kontrolnih pregleda. Gubitak sile između faza aktivacije kod NiTi zatvorenih opruga manji je u odnosu na sile koje proizvode elastični lanci. Dobro poznavanje načina delovanja različitih vrsta kliznog mehanizma je ključno za efikasno pomeranje zuba u biološki prihvatljivim okvirima.