Review Article

Force degradation of orthodontic elastomeric chains: A literature review

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Abstract: Background: Elastomeric chains are used to generate force in many orthodontic procedures, but this force decays over time, which could affect tooth movement. This study aimed to study the force degradation of elastomeric chains. Data and Sources: An electronic search on Cochrane Central Register of Controlled Trials (CENTRAL), MEDLINE, LILACS, and PubMed was made, only articles written in English were included, up to January 2022.Study selection: Fifty original articles, systematic reviews, and RCTs were selected. Conclusion: Tooth movement, salivary enzymes, alcohol-containing mouthwash, whitening mouthwash, and alkaline and strong acidic (pH <5.4) solutions all have a significant impact on elastomeric chain force degradation. The force level of elastomeric chains degrades rapidly over time; however, the force degradation rate is slower in thermoset chains than in thermoplastic ones. An efficient tooth movement could be achieved by using a thermoset chain type with monthly replacement. Ethylene oxide and gamma sterilization methods are preferred to avoid the risk of cytotoxicity.

Keywords: Orthodontic, Elastomeric chain, Force degradation, Tooth movement.

Introduction

Elastomeric chains are polyurethane-based polymers synthesized through chemical reactions between polyether or polyester with bi-functional iso-cyanates (1). They have been introduced in orthodontic treatment since the 1960s. A variety of forms is available depending on the distance between the rings. Since they are reasonably hygienic, affordable, simple to use, and don't require patient cooperation, they are widely used (2). However, there are some disadvantages to consider including the time-limited mechanical efficiency which necessitates their regular replacement. This efficiency is affected by both internal and external influences, which determine their permanent deformation. Material composition, production methods, and physical morphology are all internal influences, while temperature, pH, and moisture absorption are external influences (3).
This review investigated the effects of the internal and external influences on force degradation in orthodontic elastomeric chains.

Effect of time

Several authors (4-16) showed that the tested elastomeric chains were incapable of generating continuous force over time. According to their research, the greatest amount of force degradation (20 50% depending on the study and chain type) happened on day one (particularly the first hour), followed by a considerably slower rate of degradation over the next four weeks, providing an average degradation of 50 to 85% (5,7,9-16). Andreasen and Bishara (4) advocated additional chain extension to produce a higher initial force to compensate for this rapid force degradation. However, this led to enormous patient discomfort and could lead to complications like root resorption (17).

Hershey and Reynolds [5] increased the study time to six weeks and included simulated tooth motions at a rate of 0.25 and 0.5 mm per week. After four weeks, all modules sustained an average of 40% of their initial force, and a similar level after six weeks was recorded. The rate of force loss increased as the teeth were moved about in a virtual environment. Only 33% of the initial force persisted after four weeks at a rate of 0.25 mm, while 25% remained at a rate of 0.5 mm over the same period.

More recently, Evans et al. [18] have published a clinical trial that tested elastomeric chain (3M) ability to produce sufficient force for orthodontic tooth movement over 16 weeks. This study had a split-mouth design, with the chain being removed after four weeks on one side but kept in for the entire 16 weeks on the other side. They found a difference in the rate of space closure between the altered and unaltered sides which was insignificant statistically. Clinically the chains were capable of moving teeth after 16 weeks although the generated force was 86 gm (the minimum suggested force level is 100 gm).

Effect of internal factors

The method of manufacturing may affect the mechanical properties of the material. Hershey and Reynolds [5], in an *in vitro* setting, found that die-cut stamped elastomers maintained higher levels of force than the injection-molded ones. However, clinical findings in canine retraction for both types were similar with no statistically significant difference [2,8].

Different elastomeric chain configurations are available depending on the distance between the rings in their passive state. Generally, the continuous chains were reported to deliver greater initial force and less deterioration than the chains with a longer distance between the rings [19]. The amount of force generated by the elastomeric chain varies from one brand to another. Rock et al. [20] found that the initial force generated by different brands of closed elastomeric chains stretched to 100% was 403 to 625 gm. They considered this a high amount of force and recommended extending the elastomeric chain to only 50-75% of its original length (regardless of the number of links) to achieve the desired force of approximately 300 gm. Aldrees et al. [12] studied 19 clear elastomeric chains with different varieties (closed, short, and long) from eight manufacturers (Ormco/Sybron, 3M/Unitek, Dentaurum, Dentsply/GAC, Ortho-Organizers, American Orthodontics, Rocky Mountain Orthodontics, and TP Orthodontics) and found significant differences in the mean percentage of force degradation between them. In light of these variations, a cautious practitioner should use a force gauge to define the needed initial force level compatible for efficient tooth movement.

In 1985, Killiany and Duplessis [7] conducted a study about the new elastomeric chain (Energy Chain) from Rocky Mountain Orthodontics and compared it to the conventional elastomeric chain (thermoplastic) from American Orthodontics. At the time, it was not known that the Rocky Mountain elastomeric chain was a thermoset type. Force degradation testing revealed that the American Orthodontics plastic chain initially applied 375 gm of force, whereas the Rocky Mountain Orthodontics chain produced 330 gm of force. After four weeks, the Rocky Mountain Orthodontics chain retained 65.8% of its initial force, while the American Orthodontics chain retained 33.4% only. In an in-situ stetting, Baratieri et al. [21] discovered that only thermoset type maintained force levels over 100 gm after three weeks. Masoud et al. [22] investigated two types of elastomeric chains (thermoset and thermoplastic). They tested one of each type from American Orthodontics and ORMCO. They came to the conclusion that thermoset chains generated lower initial force and degraded at a much slower rate than thermoplastic chains, prompting them to recommend that a clear distinction should be made between the two during application. Additionally, Subroto et al. [23] found that the thermoset elastomeric chain color stability is superior to the thermoplastic type.

Thermoset elastomeric chains are marketed under various brand names that imply memory or low force decay [14]. These elastics have grown in favor of other materials in recent years as a result of manufacturer claims regarding their "memory," a reduced force deterioration with time, a lighter initial force, and ease of usage; and being compliance-free, smooth, and more affordable than NiTi springs (24). Khanemasjedi et al. (25) reported that by using a thermoset elastomeric chain and replacing it every month, the canine can be retracted at speeds comparable to those achieved with a NiTi coil spring. However, thermoset chains needed more stretching than thermoplastic chains to achieve the desired forces (12).

Cheng et al. (3) attempted to enhance the physical properties of elastomeric chains by nanoimprinting their surface during manufacturing. Nanopillars are nanostructures created on the surface of elastomeric chains as a part of the treatment. The results were promising, as this procedure transformed them from hydrophilic to hydrophobic, reducing the problems associated with these force-generating auxiliaries.

The effect of external factors (environmental factors)

David et al. (6) evaluated the effects of thermo-cycling on the force degradation pattern. They found that the thermo-cycled group (15-45°C) had significantly lower force degradation than the group maintained at a constant temperature of 37°C. However, this difference was reported as only 7-10 gm after three weeks of elastomeric chain stretching.

Sulaiman et al. (26) tested the effect of temperature on the elastomeric chain by immersing them in artificial saliva at different temperatures (4°C, 23°C, 37°C, 55°C) for 210 minutes. The force degradation of the elastomeric chain stored at 23°C was statistically significantly higher, while other groups have a similar value of force degradation (no statistically significant difference).

There is a controversy in literature when evaluating the effects of artificial saliva on force degradation versus water. Von Fraunhofer et al. (27) found that elastomeric chains in artificial saliva needed more stretching to achieve the desired force, while other researchers (4,19) reported no statistically significant difference between the two. However, the condition is different in the oral cavity as enzymes (especially esterase) in saliva can contribute to polyurethane degradation (28). Andhare et al. (29) reported higher force degradation *in vivo* studies than *in vitro* studies in a systematic review and meta-analysis.

Ramazanzadeh (30), Javanmardi and Salehi (31), and Mirhashemi et al. (14) investigated the effects of fluoride on elastomeric chains. They concluded that using sodium fluoride (NaF) on a daily basis did not affect the force delivery capabilities of orthodontic elastomeric chains.

Behnaz et al. (15,16) evaluated the effect of whitening kinds of toothpaste and mouthwash on the elastomeric chain force delivery. It was concluded that ordinary toothpaste (from Crest) had a lower negative impact on chains than whitening toothpaste and that regular toothpaste had the least negative influence on chains when compared to Sensodyne toothpaste (15). On the other hand, it was found that both fluoridated and whitening mouthwash might produce force degradation, with a stronger effect for the whitening mouthwash (16).

The effect of different chlorhexidine concentrations on the force delivery of elastomeric chains was studied by Pithon et al. (10), who found a nonsignificant effect after four weeks. Their findings were in agreement with Mirhashemi et al. (14). In contrast, Omidkhoda et al. (13) reported a significant effect of chlorhexidine on the force degradation of the elastomeric chain, which could be attributed to ethanol content (13.65%) of the studied mouthwash; as the deleterious effect of alcohol on the elastomeric chains force delivery was reported by Larrabee et al. (9) and Mahajan et al. (32).

Teixeira et al. [33] evaluated the effect of phosphoric acid, citric acid, light Coke®, and artificial saliva on the elastomeric chain. Following three weeks of immersion, there was no statistically significant difference in force degradation pattern when compared to immersion in artificial saliva. Lacerda dos Santos et al. [34] had the same conclusion for weak acidic and neutral pH (5.0, 6.0, and 7.5 pH). In contrast, other studies [35, 36] found that Coke® [35] and citric acid [36] resulted in an increased force degradation of elastomeric chains, while Ferriter et al. [37] reported that the acidic fluoride environment improved force delivery of elastomeric chains. Pureprasert et al. [38] found that exposure to Sodium Hydroxide (NaOH), a strong alkaline solution, lowered the maximum forces and delivery forces of various elastic bands. Sufarnap [39] reported that polyurethane material can be hydrolyzed when exposed to a strongly acidic pH (pH <5.4) or alkaline pH (pH >8.0).

The effect of Sterilization

Traditional sterilization procedures (like dry heat sterilization) are not feasible due to the heat-sensitive nature of elastomeric chains, and autoclaving them resulted in force deterioration [40].

When elastomeric chains were immersed in glutaraldehyde-containing solutions for 30 minutes (disinfection protocol), force degradation was found to be non-significant, until immersion time was increased up to 10 hours (sterilization protocol) when the effect became significant [41, 42]. Immersion in 0.12% chlorhexidine for 10 minutes (disinfection protocol) and peracetic acid for 30 minutes was found to be non-significant [11].

Pithon et al. [43] analyzed the effect of different methods of sterilization (70% alcohol, glutaraldehyde, ethylene oxide, autoclave, microwave, ultraviolet (UV), and gamma rays) on the cytotoxicity of elastomeric chains. They found that sterilizing elastics with ethylene oxide, UV, and gamma rays had no effect on their cytotoxicity; nevertheless, cytotoxicity was raised by autoclaving, glutaraldehyde, 70% alcohol, and microwaving. One of the significant flaws in this study is that they did not examine the mechanical impacts of these sterilization techniques. So, Pithon et al. [44] in 2015 studied the mechanical influence of these sterilization methods; they found no significant effect on elastomeric chain force delivery. They also reported that the UV is not completely efficient for the sterilization of elastomeric chains.

Effects of pre-stretching

Kim et al. [17] studied the effect of pre-stretching on transparent closed elastomeric chains (from Ormco company). They compare experimental group being pre-stretched to 100% of their initial length with non-stretched control group. The initial force was significantly lower in pre-stretched group; one hour later, both experimental and control groups had similar readings. The rate and pattern of force degradation were very similar from one hour to four weeks. Baty et al. [19] concluded in their literature review that the improvements were minor (although statistically significant) and unlikely to be clinically relevant, given that the pre-stretching resulted in a 5% less force degradation at three weeks. With a force reduction of 50 to 75%, a 5% change is unlikely to be clinically significant. A similar conclusion was reached by Halimi et al. [40] in a systematic review. However, Chang et al. [45] reported that the pre-stretching has no disadvantages like permanent deformation of the elastomeric chain, which could affect its force recovery ability, and considered it a beneficial technique that should be practiced.

Clinical efficacy of elastomeric chains

Andrew L. Sonis [46] compared NiTi coil springs to elastic. He sought to avoid the initial force degradation of elastics by using a material that delivers selectable tooth moving forces with the desired effects. This study showed that NiTi coil springs were superior to elastomeric chains as they delivered a constant force over a wide range of lengths without permanent deformation, which nearly produced twice the rate of tooth movement. Santos et al.[47] and Pires et al. [48], in *in vitro* studies, concluded that NiTi closed coil springs are more suitable for dental movement than elastomeric chains. However, a more recent study (as mentioned earlier) by Khanemasjedi et al. [25] reported that monthly replacement of thermoset elastomeric chain gave a comparable speed of tooth movement to that with NiTi coil spring; this is consistent with earlier studies done by Nightingale and Jones [49], and Bokas and Woods [50]. In a split-mouth trial, Barsoum et al. [51] reported no significant difference in canine retraction when employing elastomeric chins, other than the patient experiencing increased pain for longer days. On the other hand, another study by Evans et al. [18] found that elastomeric chains were capable of producing efficient tooth movement for nearly up to 16 weeks, as compared to those changed every four weeks. This shows a considerable improvement in the manufacturing process as well as the continued development of the chain material.

Conclusions

1. Generally, the force level of elastomeric chains degrades rapidly over time, with the majority of degradation occurring during the first 24 hours, after which the rate reduces by time.
2. Differences in elastomeric chains configurations, manufacturer, and especially their types (either thermoset or thermoplastic) affect their initial force and degradation pattern over time, so a clear distinction between them is recommended.
3. The initial force and force degradation rate is lower in thermoset type than the thermoplastic ones.
4. It may be recommended to stretch the thermoplastic elastomeric chains to 50-75% of their original length to achieve an initial force around 300 gm, whereas the thermoset type needs more stretching, to achieve the same force.
5. The pre-stretching to decrease force degradation appears to be of minimal clinical value; however, no clinical disadvantages are present.
6. Environmental factors like tooth movement, salivary enzymes, alcohol-containing mouthwash, whitening mouthwash, and alkaline and strong acidic pH (<5.4) all have a significant impact on elastomeric chain force degradation, whereas sodium fluoride and chlorhexidine mouthwashes (in different concentrations) and temperature changes within the oral cavity (4-55°C) have no negative impact.
7. Cold disinfection protocol is recommended. Ethylene oxide and gamma rays are preferred to avoid the risk of cytotoxicity.

Conflict of interest: None.

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العنوان: تضاؤل قوة السلاسل المرنة التقويمية: مراجعة النتاج الفكري

الباحثون: علي رحمن عيسى , عمار سالم كاظم

الملخص

اهداف البحث: تُستخدم السلاسل المرنة لتوليد القوة في العديد من إجراءات تقويم الأسنان، لكن هذه القوة تتضاءل بمرور الوقت، مما قد يؤثر على حركة الأسنان. هدفت هذه الدراسة إلى دراسة تضاؤل القوة في السلاسل المرنة.
البيانات والمصادر: تم إجراء بحث إلكتروني في قواعد البيانات الالكترونية (PubMed ،LILACS ،MEDLINE ،CENTRAL) وتم تضمين المقالات المكتوبة باللغة الإنجليزية فقط، حتى يناير 2022.
اختيار الدراسة: تم اختيار خمسين مقالة أصلية ومراجعات منهجية وتجارب عشوائية سريرية.
الاستنتاجات: حركة الأسنان، والإنزيمات اللعابية، وغسول الفم المحتوي على الكحول، وغسول الفم المبيض، ومحاليل عالية القلوية أو العالية الحمضية كلها لها تأثير كبير على تضاؤل القوة في السلاسل المرنة. يتضاءل مستوى قوة السلاسل المرنة بسرعة بمرور الوقت؛ ومع ذلك فإن معدل تضاؤل القوة أبطأ في السلاسل المتصلبة بالحراراة منه في السلاسل اللدنة بالحرارة. يمكن تحقيق حركة أسنان فعالة باستخدام السلاسل المتصلبة بالحرارة مع الاستبدال الشهري. يفضل استخدام طرق التعقيم بأكسيد الأثيلين واشعة غاما لتجنب المخاطر السمية الخلوية.