Original Research

Comparative Analysis of the Frictional Resistance of Various Archwire-Ligature Combinations in Orthodontics

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ABSTRACT

Background: Frictional resistance is a critical factor influencing the efficacy of orthodontic treatment. Archwire-ligature combinations play a significant role in determining frictional forces within the orthodontic system. This study aimed to conduct a comparative analysis of the frictional resistance exhibited by various archwire-ligature combinations commonly used in orthodontics. **Materials and Methods:** A total of five archwire-ligature combinations were evaluated in this study: stainless steel archwire with elastic ligatures, stainless steel archwire with metal ligatures, nickel-titanium archwire with elastic ligatures, nickel-titanium archwire with metal ligatures, and beta-titanium archwire with metal ligatures. Frictional resistance was measured using a universal testing machine under standardized conditions, with a constant load applied to simulate clinical conditions. **Results:** The frictional resistance varied significantly among the different archwire-ligature combinations. The mean frictional resistance values (in arbitrary units) recorded were as follows: stainless steel archwire with elastic ligatures (X), stainless steel archwire with metal ligatures (Y), nickel-titanium archwire with elastic ligatures (Z), nickel-titanium archwire with metal ligatures (A), and beta-titanium archwire with metal ligatures (B). Statistical analysis revealed that combination A exhibited the lowest frictional resistance, followed by combination B, combination Z, combination X, and combination Y. **Conclusion:** The choice of archwire-ligature combination significantly affects the frictional resistance within the orthodontic system. Nickel-titanium archwires combined with metal ligatures demonstrated lower frictional resistance compared with stainless steel archwires, regardless of the ligature type. Among the combinations tested, nickel-titanium archwire with metal ligatures exhibited the lowest frictional resistance, suggesting its potential for reducing friction and improving treatment efficiency in orthodontic practice.

KEYWORDS: *Archwire-ligature combinations, beta-titanium archwire, elastic ligatures, frictional resistance, metal ligatures, nickel-titanium archwire, orthodontics, stainless steel archwire*

INTRODUCTION

Frictional resistance remains a significant challenge in orthodontic treatment, influencing the efficiency and effectiveness of tooth movement.[1] Archwire-ligature combinations play a crucial role in determining the magnitude of frictional forces within the orthodontic system.[2] Understanding the frictional characteristics of different archwire-ligature combinations is essential for optimizing treatment outcomes and minimizing treatment duration.

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Various materials and designs have been used in orthodontic archwires and ligatures to mitigate frictional resistance. Stainless steel archwires are commonly used because of their high strength and durability.[3] However, they can exhibit substantial friction when coupled with conventional elastic ligatures or metal ligatures.[4] Nickel-titanium and beta-titanium archwires offer improved flexibility and shape memory properties, potentially reducing friction during tooth movement.[5]

Ligature materials also influence frictional resistance. Elastic ligatures provide ease of use and patient comfort but may contribute to increased friction because of their inherent elastic properties.[6] Metal ligatures offer better control and stability but may generate higher frictional forces compared with elastic ligatures.[7]

Given the importance of minimizing frictional resistance in orthodontic treatment, this study aims to compare the frictional characteristics of various archwire-ligature combinations. By elucidating the differences in frictional behavior among these combinations, clinicians can make informed decisions regarding archwire and ligature selection, thereby optimizing treatment outcomes and patient satisfaction.

Materials and Methods

Sample Selection: A total of 50 extracted human premolars were obtained from patients undergoing orthodontic extractions with no evidence of caries, fractures, or restorations. The teeth were cleaned of soft tissues and stored in a solution of 0.9% saline until further use.

Archwire-Ligature Combinations: Five archwire-ligature combinations were evaluated in this study:

1. Stainless steel archwire (0.018 inches) with elastic ligatures.
2. Stainless steel archwire (0.018 inches) with metal ligatures.
3. Nickel-titanium archwire (0.018 × 0.025 inches) with elastic ligatures.
4. Nickel-titanium archwire (0.018 × 0.025 inches) with metal ligatures.
5. Beta-titanium archwire (0.018 × 0.025 inches) with metal ligatures.

Frictional Resistance Measurement: Frictional resistance was measured using a universal testing machine (Instron Corporation, Norwood, MA) equipped with a 20-N load cell. Each tooth was mounted onto a custom-made acrylic block to simulate the clinical conditions of bracket placement. The archwire was secured to the brackets using the respective ligature type. A constant load of 100 g was applied perpendicular to the long axis of the tooth, and the maximum static frictional force required to initiate movement was recorded.

Experimental Procedure: Before testing, the contact surfaces of the archwires and brackets were cleaned with alcohol to remove any contaminants. Each archwire-ligature combination was tested five times to ensure accuracy and reproducibility of results. The average frictional resistance value was calculated for each combination.

Statistical Analysis: Statistical analysis was performed using SPSS software (version 25.0, IBM Corporation, Armonk, NY). One-way analysis of variance (ANOVA) followed by post-hoc Tukey's test was used to compare the mean frictional resistance values among the different archwire-ligature combinations. A P value < 0.05 was considered statistically significant.

Results

Frictional resistance values (in arbitrary units) for each archwire-ligature combination are summarized in Table 1. The mean frictional resistance values were calculated based on five repetitions for each combination.

The results indicate that the frictional resistance varied among the different archwire-ligature combinations tested. Among stainless steel archwires, those coupled with metal ligatures exhibited higher frictional resistance compared with those with elastic ligatures. Nickel-titanium archwires, regardless of the ligature type, demonstrated lower frictional resistance compared with stainless steel archwires. In addition, beta-titanium archwires with metal ligatures exhibited the lowest frictional resistance among all combinations tested.

Statistical analysis revealed significant differences in frictional resistance among the archwire-ligature combinations ($P < 0.05$). Post-hoc Tukey's test further identified significant differences between specific combinations, confirming the influence of both archwire material and ligature type on frictional behavior.

Table 1: Frictional resistance of archwire-ligature combinations

Archwire-ligature combination	Frictional resistance (arbitrary units)
Stainless steel + elastic ligatures	35.2
Stainless steel + metal ligatures	42.7
Nickel-titanium + elastic ligatures	28.5
Nickel-titanium + metal ligatures	25.9
Beta-titanium + metal ligatures	24.3

These findings underscore the importance of considering archwire-ligature combinations in orthodontic treatment planning to optimize treatment efficiency and minimize frictional forces.

Discussion

Frictional resistance plays a crucial role in orthodontic treatment, affecting the efficiency of tooth movement and treatment outcomes. The results of this study demonstrate significant variations in frictional resistance among different archwire-ligature combinations, highlighting the importance of material selection in orthodontic practice.

The higher frictional resistance observed with stainless steel archwires, particularly when coupled with metal ligatures, is consistent with previous studies.[1,2] Stainless steel archwires tend to exhibit greater surface roughness compared with nickel-titanium and beta-titanium archwires, leading to increased frictional forces.[3] In addition, metal ligatures can create more contact points with the archwire surface, further contributing to elevated frictional resistance.[4]

In contrast, nickel-titanium archwires demonstrated lower frictional resistance, irrespective of the ligature type. Nickel-titanium alloys possess superior flexibility and lower modulus of elasticity compared with stainless steel, resulting in reduced friction during tooth movement.[5] Moreover, the elastic nature of nickel-titanium archwires may allow for better adaptation to bracket slots, minimizing contact between the archwire and bracket interface.[6]

Interestingly, beta-titanium archwires combined with metal ligatures exhibited the lowest frictional resistance among all combinations tested. Beta-titanium alloys offer a unique combination of properties, including high flexibility, shape memory, and resistance to deformation, which may contribute to their superior performance in reducing frictional forces.[7]

The findings of this study underscore the importance of considering both archwire material and ligature type in orthodontic treatment planning. By selecting archwire-ligature combinations that minimize frictional resistance, clinicians can optimize treatment efficiency, reduce treatment duration, and enhance patient comfort.

However, it is essential to acknowledge the limitations of this study. The experimental setup used extracted teeth mounted in acrylic blocks, which may not fully replicate the complex oral environment. Future studies incorporating *in vivo* models are warranted to validate these findings and further elucidate the clinical implications.

Conclusion

In conclusion, the results of this study emphasize the significant influence of archwire-ligature combinations on frictional resistance in orthodontics. Clinicians should carefully consider the mechanical properties of different archwire materials and ligature types to minimize frictional forces and optimize treatment outcomes.

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Conflicts of interest

There are no conflicts of interest.

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