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Original Article

Dentistry Section

Evaluation and Comparison of Moment-to-Force Ratio of a New "PRP Loop" with that of Opus Loop and L Loop-A Finite Element Method Study

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ABSTRACT

Introduction: Extraction space closure is one of the most challenging procedures in the field of orthodontics which requires a robust understanding of biomechanics. There are two commonly used methods of space closure, one involves friction, also called sliding mechanics, and the other is frictionless. The advantages of frictionless mechanics are that there is no force loss due to friction and low anchorage taxing. The preferred method for the retraction of teeth is loop mechanics, which ensures controlled tooth movement.

Aim: To evaluate and compare the Moment-to-Force (M/F) ratio of PRP loop with that of the Opus loop and L loop using the Finite Element Method (FEM).

Materials and Methods: An in-vitro study was conducted by using FEM analysis at DMIHER University with technical assistance from the Department of Mechanical Engineering VNIT Nagpur. Computer models of the loop designs were prepared on Analysis of Systems (ANSYS) version 10 (V10) software. Opus loop, L loop and PRP loop were modeled as SOLID 64 beam elements. Different pre-activation bends were given to the models in α and β nodes of the loop. Statistical analysis was performed using the Statistical Package for Social Sciences (SPSS) version 27.0 software to compare the means of all three loops.

Results: A total of 36 FEM models were studied. PRP loop showed a greater M/F ratio than the Opus and L loop with 15°α and 25°β pre-activation bends in both 0.017×0.025 and 0.019×0.025-inch Titanium Molybdenum Alloy (TMA) wire, i.e., 9.09 and 9.12, respectively. On comparison of the M/F ratio of PRP loop, Opus loop and L loop prepared with 0.017×0.025 and 0.019×0.025 TMA wire, at 15°α and 25°β pre-activation bend in 0.019×0.025 TMA, PRP loop showed the highest M/F ratio of 9.12 as compared to 0.017×0.025 TMA wire.

Conclusion: The study concluded that the PRP loop is an efficient retraction loop with an ideal moment force ratio for translatory movement of tooth. PRP loops had a higher M/F ratio than the Opus loop and L loop, indicating that PRP can be used for translatory movement of teeth in wires of different materials. Therefore, for the proper utilisation of PRP loop, it must be prepared with either 0.017×0.025 inch TMA or 0.019×0.025 inch TMA wire.

Keywords: Finite element analysis, Friction mechanics, Loop mechanics, Retraction force

INTRODUCTION

Closure of the extraction space is the most challenging procedure in orthodontics [1]. The skill required to close spaces, especially those caused by the extraction of teeth, is highly desirable during treatment. The two methods of space closure are sliding or friction mechanics and frictionless or loop mechanics [2,3]. In sliding mechanics, friction is produced between the bracket and archwire when teeth slide along the base archwire. The disadvantages are that, the force magnitude cannot be readily determined and friction slows the movement of the teeth along the archwire [4].

In frictionless mechanics, loops and springs are preferred for the retraction of teeth, which ensures controlled tooth movement. Statistically quantified force is produced with an archwire which is under the operator's control. The advantage of the non-frictional approach is that there is no force loss due to friction and low anchorage taxing [5].

An ideal loop used for space closure should possess certain desirable characteristics, like: i) a high moment-force ratio for translatory tooth movement; ii) a smaller Force-Deflection (F/D) rate for maintaining the ideal force system; iii) a large range of activation; iv) the perfect size for fitting into the vestibule; and v) should be comfortable for the patient [6-9]. Different types of loops are used in space closure, such as Opus loop, mushroom loop, L loop, vertical loop, T loop, teardrop loop, omega loop, K SIR loop, etc. A loop used for space closure must have a high M/F ratio, i.e., close to 10:1, and a low force-to-deflection rate [4].

To make the retraction loop invariably acceptable, a thorough understanding of its biomechanical properties is required. A blend of Opus loop and L loop was introduced by Dr. Pallavi Daigavane in the Department of Orthodontics and Dentofacial Orthopaedics, Sharad Pawar Dental College, in the form of PRP loop [2]. PRP loop is an open loop and its design is similar to that of Opus loop and T loop. The M/F ratio of the PRP loop has not been analysed. This study was therefore conducted to determine the M/F ratio of a new loop called the PRP loop and compare it with the Opus loop and T loop. FEM was used for this study in which a 3-dimensional model of all three loops was generated and the moment force ratio generated by loop geometries in 3-dimensional spaces was studied. The research protocol of this study has already been published [2].

MATERIALS AND METHODS

A cross-sectional study was conducted from 1st July 2022 to 1st December 2022. The study was carried out after approval from the Ethical Committee of Datta Meghe Institute of Higher Education & Research (DMIHER), Wardha, Maharashtra, India. (Ref. no. DMIMS(DU)/IEC/2020-21/9399 Dated 24/12/2020).

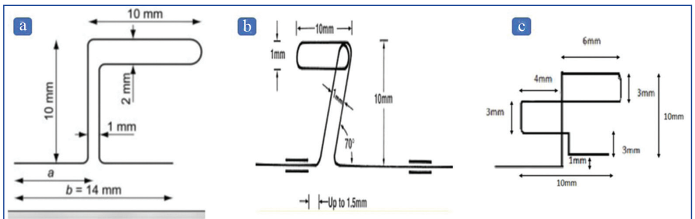
Loop models were fabricated in 0.017×0.025-inch and 0.019×0.025-inch wire dimensions in TMA wires [2]. Loop mechanics favour full slot engagement between the wire and bracket interface to prevent loss of torque during retraction. In 0.022-inch slot, 0.019×0.025-inch wire was preferred and in a 0.018-inch slot, 0.017×0.025-inch wire was preferred [2].

Procedure

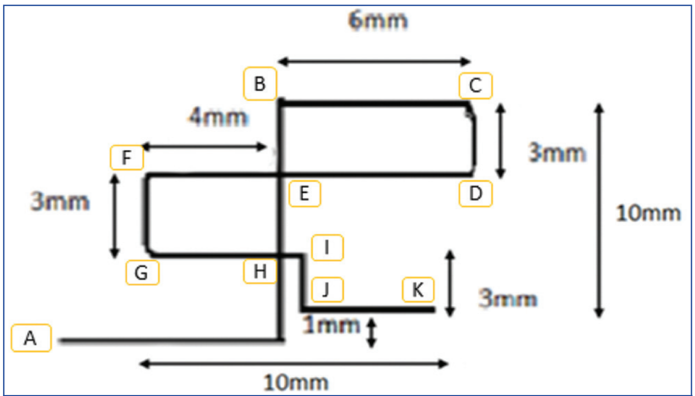
Methodology: The initial modelling was done using Ansys workbench 16 software. The finite element analysis was conducted using ANSYS as the pre and post-processor and the Ansys Direct solver was loaded on the International Business Management (IBM) platform. The dimensions of the loop models were based on the prescriptions given by their respective authors. L loop was first described by Stoner MM in 1960 [10] and the Opus loop was described by Siatkowski RE in 1977 [11]. A total of 36 finite element models were constructed for the study. The horizontal length of all the loop models (distance between the anterior and the posterior node) were kept 13 mm, considering the inter-bracket distance from the mid-point of second premolar to the mid-point of the canine.

L loop- The occluso-gingivally height was kept 10 mm and mesio-distally it extended to 10 mm [2,10]. Opus loop- Occluso-gingivally height was kept 10 mm and mesiodistally it extended to 10 mm [2,11].

PRP loop was designed by Dr. Pallavi Daigavane. The dimensions included occluso-gingival height of 10 mm and mesio-distal extension of 10 mm [Table/Fig-1a-c] [2]. The loop was named PRP based on its structure which resembles the three alphabets P, R, and P. When the clinicians start fabricating the loop, they bend the wire in the shape of P, then they further extend the wire and make the reverse P. Finally, the wire is bent to create an R shape [Table/Fig-2].



[Table/Fig-1]: Figures of (a) L loop; (b) Opus loop; (c) PRP loop.



[Table/Fig-2]: Explanation of the structure defining the name PRP loop. 1) Starting with A, the authors make the first loop as A, H, E, B, C, D, E as first P. 2) Extending E, to make second P loop as D, E, F, G, H (reverse P). 3) Extending point H to form R shape as H, I, J, K.

Different pre-activation bends were applied to all three loops on alpha side (towards canine bracket) and beta side (towards premolar bracket) and models were prepared accordingly. A total of thirty-six loop models were prepared with and without pre-activation bends for the study [Table/Fig-3,4].

0.017×0.025 and 0.019×0.025 TMA wire		
PRP loop	L loop	Opus loop
0° α and 0° β	0° α and 0° β	0° α and 0° β
0° α and 25° β	0° α and 25° β	0° α and 25° β
0° α and 35° β	0° α and 35° β	0° α and 35° β
10° α and 45° β	10° α and 45° β	10° α and 45° β
15° α and 25° β	15° α and 25° β	15° α and 25° β
30° α and 0° β	30° α and 0° β	30° α and 0° β

[Table/Fig-3]: Loop models of PRP loop, L loop and Opus loop.

Methodology for analysis:

i. For loops without pre-activation bends: After modelling of the loops, a fixed point was determined on the alpha position (towards the canine bracket). The terminal node on the beta side (towards the premolar bracket) was displaced by 1 mm. Force and moment was produced on the terminal node towards the alpha side (towards the canine bracket).

ii. For loops with pre-activation bends:

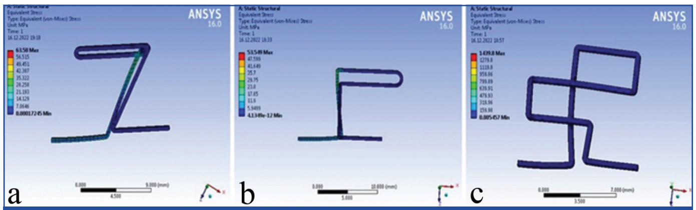
Methodology for analysis of loops with pre-activation bends:

Step 1: Loops were prepared with pre-activated bends and imported to ANSYS for analysis [Table/Fig-4a-c].

Step 2: The terminal β node towards the premolar was fixed and α segment towards the canine was displaced.

Step 3: The displacement was between 0.1-1 mm. At each displacement moment and force were noted on terminal nodes.

Step 4: Subsequently, the terminal node on the beta side towards premolar bracket was displaced by 1 mm, after which the force and the moment produced on the terminal node was recorded.



[Table/Fig-4]: FEM model of: (a) Opus loop; (b) L loop; (c) PRP loop without pre-activation bends.

STATISTICAL ANALYSIS

The statistical analysis was carried out using IBM SPSS version 27.0 software. To compare the performance of the three loops (PRP Loop, Opus Loop, and L Loop), the one-way Analysis of Variance (ANOVA) test and group descriptive function of the software was utilised to compare the means and to find out group descriptive.

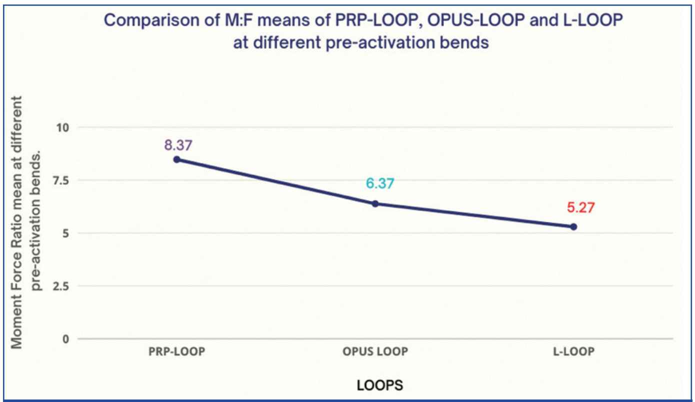
RESULTS

A total of 36 FEM models were studied to evaluate the M/F ratio, and the maximum force generated by the respective Loop Models after their activation. Statistical analysis revealed that the M/F ratio mean at different pre-activation bends of PRP loop was 8.37, Opus loop was 6.37 and L loop was 5.26. Therefore, according to [Table/Fig-5,6] PRP had the highest value of M/F ratio mean in comparison of other two loops.

In 0.017×0.025 TMA wire without pre-activation bend at 0°α and 0°β bend with displacement of 0.1 to 1 mm, the M/F ratio of PRP loop was 8.30, opus loop was 6.84 and L loop was 5.60. PRP loop exhibited greater M/F ratio than Opus and L loop with 0° pre-activation bends [Table/Fig-7,8]. After increasing pre-activation bend with displacement of 0.1 to 1 mm, the PRP loop had higher M/F ratio than opus and L loop. At pre-activation bend of 15°α and 25°β bend; the PRP loop showed highest M/F ratio of 9.09, while the opus loop showed 6.55 and L loop showed 4.85. This indicates that at 15°α and 25°β bend, the PRP loop has more bodily or translatory movement as compared to the opus loop and L loop [Table/Fig-7,8].

Type of loop	N	Mean of M/F ratio	Standard deviation	Standard error	95% Confidence interval for mean Lower bound	95% Confidence interval for mean Upper bound	Minimum	Maximum
PRP loop	6	8.47	0.45	0.18	8.0	8.94	7.77	9.09
OPUS loop	6	6.37	0.60	0.24	5.73	7.00	5.36	7
L loop	6	5.26	0.78	0.32	4.44	6.09	4.63	6.72

[Table/Fig-5]: Means of M/F ratio of PRP loop, Opus loop, and L loop.



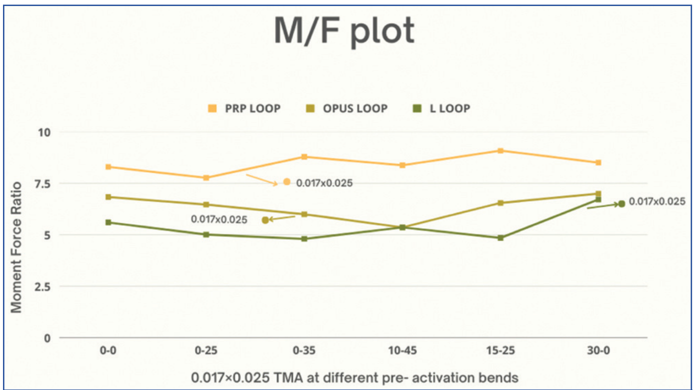
[Table/Fig-6]: Graphical representation of a comparison of M/F means of PRP loop, Opus loop and L-loop at different pre-activation bends.

bend with displacement of 0.1 to 1 mm, PRP loop had higher M/F ratio than Opus and L loop. At pre activation bend of 15°α and 25°β bend PRP loop showed highest M/F ratio of 9.12 whereas Opus loop showed 6.61 and L loop showed 5.04. This indicated that at 15°α and 25°β bend, PRP loop had more bodily or translatory movement [Table/Fig-9,10].

On comparison of M/F ratio of all three loops prepared with 0.017×0.025 and 0.019×0.025 TMA wire without pre-activation bend M/F ratio of PRP loop was 8.30, Opus loop was 6.84 and L loop was 5.60. The PRP loop had highest M/F ratio compared to the opus and L loops [Table/Fig-11]. At 15°α and 25°β pre-activation bend in 0.019×0.025 TMA, the PRP loop showed highest M/F ratio of 9.12 as compared to 0.017×0.025 TMA wire [Table/Fig-11,12].

0.017×0.025	PRP loop			OPUS loop			L loop		
TMA	Force (N)	Moment (N-mm)	M:F	Force	Moment	M:F	Force	Moment	M:F
0-0	0.428	3.554	8.30	0.01	1.35	6.84	0.15	0.85	5.60
0-25	1.396	10.86	7.77	0.14	0.94	6.47	0.20	1.01	5.01
0-35	1.02	8.78	8.79	0.14	0.87	6.0	0.21	1.03	4.80
10-45	1.77	14.92	8.38	0.15	0.81	5.36	0.22	1.04	4.63
15-25	1.18	10.78	9.09	0.14	0.95	6.55	0.20	0.98	4.85
30-0	1.03	8.77	8.51	0.19	1.37	7.0	4.47	30.10	6.72

[Table/Fig-7]: M/F ratio of PRP loop, Opus loop and L loop in 0.017×0.025. TMA at different pre-activation bends.



[Table/Fig-8]: M/F ratio of PRP loop, Opus loop and L loop in 0.017×0.025 TMA at different pre-activation bends.

In the 0.019×0.025 TMA wire without pre-activation bend at 0°α and 0°β bend with displacement of 0.1 to 1 mm, M/F ratio of PRP loop was 8.30, Opus loop was 6.84 and L loop was 5.60. PRP loop showed greater M/F ratio than Opus and L loop with 0° pre-activation bends [Table/Fig-9,10]. After increasing pre-activation

DISCUSSION

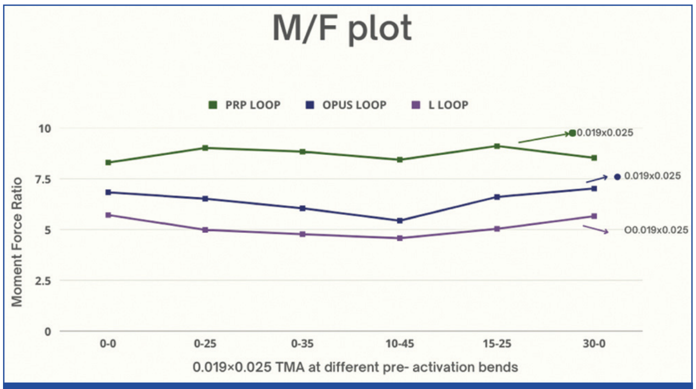
The result showed that the inherent M/F ratio produced by PRP loop prepared in TMA wire with dimensions 0.019×0.025-inch and 0.017×0.025-inch without pre-activation bend, that is 0° α and β bend, is not adequate to impart translatory movement of the dentition. To increase the M/F ratio close to 8-10, gable pre-activation bends were applied. PRP loop models prepared in TMA wire with 0.017×0.025-inch and 0.019×0.025-inch dimension needs a pre-activation bend to produce an ideal M/F ratio in the range of 8-10 which is very important for translatory movement of the dentition.

M/F ratio for all the PRP loop models was in the range of 7-10 in the present study. This is an important characteristic of any retraction loop. M/F ratio of any retraction loop is closely related to the centre of rotation of the dentition. As the M/F ratio changes, accordingly the centre of rotation will change and this will cause inconsistent distribution of stress along the periodontium which is not ideal condition during the process of space closures [7].

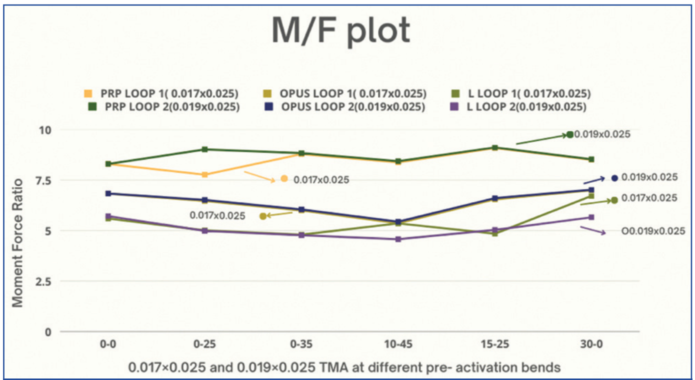
In the present study, L loop with 0.017×0.025 TMA and 0.019×0.025 TMA wire showed M/F ratio of 5.60 at 0° pre-activation bend which

0.019×0.025	PRP loop			OPUS loop			L loop		
TMA	Force (N)	Moment (N-mm)	M:F	Force	Moment	M:F	Force	Moment	M:F
0-0	1.42	11.83	8.30	0.27	1.85	6.84	0.015	0.08	5.60
0-25	1.62	14.69	9.02	0.20	1.309	6.52	0.28	1.40	4.99
0-35	1.91	16.96	8.84	0.19	1.2	6.05	0.30	1.43	4.77
10-45	2.439	20.609	8.44	0.20	1.13	5.44	8.55	39.22	4.58
15-25	1.638	14.955	9.12	0.20	1.32	6.61	7.84	39.52	5.04
30-0	1.432	12.221	8.53	0.27	1.92	7.03	5.95	33.75	5.66

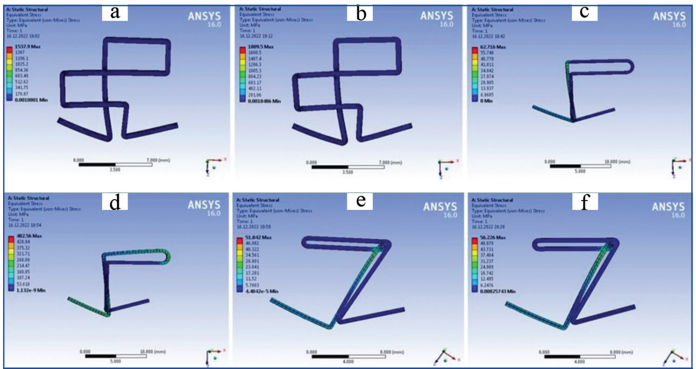
[Table/Fig-9]: M/F ratio of PRP loop, Opus loop and L loop in 0.019×0.025 TMA at different pre-activation bends.



[Table/Fig-10]: M/F ratio of PRP loop, Opus loop and L loop in 0.019×0.025 TMA at different pre-activation bends.



[Table/Fig-11]: M/F ratio of PRP loop, Opus loop and L loop in 0.017×0.025 and 0.019×0.025 TMA at different pre-activation bends.



[Table/Fig-12]: FEM models of: (a) 0.017×0.025 TMA PRP loop at 15ºα and 25ºβ pre activation bend; (b) 0.019×0.025 TMA PRP loop at 15ºα and 25ºβ pre-activation bend; (c) 0.017×0.025 TMA L loop at 15ºα and 25ºβ pre-activation bend; (d) 0.019×0.025 TMA L loop at 15ºα and 25ºβ pre-activation bend; (e) 0.017×0.025 TMA Opus loop at 15ºα and 25ºβ pre-activation bend; (f) 0.019×0.025 TMA Opus loop at 15ºα and 25ºβ pre-activation bend.

was similar to a study conducted by Safavi MR et al., [12]. The author compared four different loops that is T loop, L loop, Opus loop and vertical helical, closing loop prepared with 0.016×0.022 SS wire with different pre-activation bends with the help of FEM study and found that M/F ratio of L loop was 4.6 at 0º pre-activation bend and for Opus loop were 7.6 at 1 mm displacement. The reading for Opus loop obtained in the present study at 1 mm displacement was 6.84. This variation might be because of difference in wire material or dimension of wire. TMA wire is more resilient and less stiff than stainless steel wire. TMA produces less force for a longer duration whereas stainless steel wire produces more force for shorter duration. The M/F ratio of TMA is higher than that of stainless steel, indicating that TMA can produce more bodily or translatory movement [12].

In the present study, the M/F ratio of the Opus loop was between 5-7 in 0.017×0.025-inch and 0.019×0.025-inch TMA wire. The M/F ratio of Opus loop was between 8.5-9.3 at 0-degree pre-activation with displacement of 0-2 mm reported by Techalertpaisarn P and Versluis A, in his study [13]. The authors compared the opus loop with the T loop and L loop fabricated in a 0.016×0.022-inch stainless steel wire. Opus loops and L-loops exhibited the highest M/F ratio (8.5-9.3) on the canine bracket when the loop was centred. The difference in M/F ratio between both studies might be because of the different wire material or different softwares used for FEM study.

The M/F ratio of L loop was in the range of 4-6 in the present study which was similar to study conducted by Cai Y [14]. The author evaluated and compared the M/F ratio of vertical, L and T loops in both TMA and stainless-steel arch wires and concluded that TMA generated M/F ratio of vertical loop was 3.235 mm, L loop was 4.768 mm, and T loop was 6.95.

There is limited research about properties of L loop, but according to Savafi MR et al., Siatkowski RE; this loop had higher values of force and moment, without angular bend [11,12]. When angular bend was given, moment, force, and M/F of the L loop decreased similar to other loops, but by enhancing activation range, its moment increased greater than other loops. Studies by Burstone CJ and Koenig HA; Faulkner MG et al., Menghi C et al., Chen J et al., and Thiesen G et al., increasing the wire length and adding a helix can cause reduction in force [6,15-18].

In the present study, the M/F ratio of the opus loop was 6.84 at a 0º pre-activation bend. A similar FEM study conducted by Rao PR et al., evaluated and compared the snail loop with opus loop and tear drop loop. They found that at 0º pre-activation bend M/F ratio of opus loop was 9.8 in 0.019×0.025-inch TMA wire [19]. This difference might be because of difference in software used in FEM study [19].

After evaluating and comparing the M/F ratio of the opus loop, L loop, and PRP loop, the authors can conclude that the PRP loop has a clear advantage over the L loop in terms of the M/F ratio. Additionally, compared to the opus loop, the PRP loop offers distinct advantages. By incorporating gable bends, the PRP loop efficiently delivers the desired M/F ratio within an ideal range. Furthermore, the PRP loop exhibits better shape morphology, which helps prevent tissue impingement. Moreover, the fabrication time of the PRP loop is significantly shorter compared to the opus loop.

Limitation(s)

The study only evaluated M/F ratio. F/D rate can also be evaluated before clinical application of the PRP loop.

CONCLUSION(S)

After evaluating the M/F ratio of the PRP loop, opus loop and L loop, it can be concluded that the PRP loop is an efficient retraction loop with an ideal M/F ratio for translatory movement of teeth. The PRP loop, opus loop and L loop showed insufficient M/F ratios without pre-activation bend. As the pre-activation bend increased, the M/F ratio also increased in both 0.017×0.025 inch and 0.019×0.025-inch TMA wires. PRP loops had a higher M/F ratio than the opus loop and L loop, indicating that PRP can be used for translatory movement of teeth in both wires. On comparing the 0.017×0.025 inch and 0.019×0.025 inch PRP loop, 0.019×0.025 inch TMA wire had a higher M/F ratio. Further clinical trials are recommended for frictionless closure of extraction space. The results obtained must be further substantiated by experimental investigation and clinical study. The study evaluated the M/F ratio and the F/D rate can also be evaluated before the clinical application of the PRP loop.

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PLAGIARISM CHECKING METHODS: [Jain H et al.]
- Plagiarism X-checker: Feb 09, 2023
- Manual Googling: Apr 07, 2023
- iThenticate Software: Apr 20, 2023 (16%)

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- Was informed consent obtained from the subjects involved in the study? NA
- For any images presented appropriate consent has been obtained from the subjects. NA

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