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RESEARCH ARTICLE

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Stability and failure rate during 3 years of fixed retention: A follow-up of an randomized clinical trial on adolescents with four different lingual retainers

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Abstract

Objective: To evaluate stability outcomes and failure rates associated with four types of lingual retainers: (1) dead-soft wire, (2) multistrand stainless steel (SS) wire, (3) CAD/CAM nitinol, and (4) connected bonding pads (CBPs) after 3 years of retention.

Methods: This study enrolled 96 patients (66 females, 30 males) with a median age of 19 years with four types of lingual retainers: (1) 0.016 × 0.022-inch dead-soft wire, (2) 0.0215-inch five-strand SS wire, (3) 0.014 × 0.014-inch CAD/CAM nitinol wire, and (4) CBPs. The irregularity index, intercanine distances, and arch lengths were obtained and used to evaluate mandibular stability. Failure rates were also assessed during this study. Data were statistically analysed.

Results: Irregularity increased, whereas intercanine width and arch length decreased after 3 years of retention. The greatest irregularity was associated with the CBPs and the least with the CAD/CAM retainers. Changes in stability measurements were significantly higher in the dead-soft wire and CBPs than those in the CAD/CAM nitinol and multistrand SS wires. Parallel to these changes, the frequency of failure yielded similar results with the same significance between the groups. The failure rate of CBPs, in contrast to the CAD/CAM nitinol and multistrand SS wires, was significantly higher in the right quadrant ($P < .05$).

Conclusion: After taking the 3-year results into consideration, CAD/CAM nitinol and multistrand SS wires were found to be more successful than the others in maintaining mandibular stability. The most failures were observed with CBPs after 3 years of retention.

KEYWORDS
failure, retainer, stability

1 | INTRODUCTION

Fixed retainers (FRs) are necessary in many cases to maintain the outcomes of orthodontic treatment for life.[1] Most FRs are made of stainless steel (SS) wire with different thicknesses and configurations for greater flexibility and strength.[2] Based on long-term experience, a five-strand 0.0215-inch diameter SS wire has been proposed as the gold standard.[3] However, Zachrisson[3] emphasized that it should be carefully shaped and bonded in an entirely passive position to prevent instability, which will cause unexpected side effects in the long

term. Dead-soft wire has also been used for FRs due to its high adaptability. However, Shaughnessy et al.[4] reported that it is likelier to break than other wires, and breakage will result in loss of alignment. Alternatively, bondable mesh-base pads are available in different sizes for clinical use. The manufacturer claims that the tooth-shaped pads allow maximum retention strength.[5] Despite their low thickness for perfect adjustment to the lingual surfaces, the connected structure may prevent passive adaptation during retainer bonding.

In light of recent developments regarding computer-aided design and computer-aided manufacturing (CAD/CAM) technology, customized CAD/CAM nitinol has been introduced to overcome the aforementioned drawbacks. The CAD/CAM retainer offers some advantages, such as the non-requirement of bending, individualized placement, precision fit, tighter interproximal adaptation, and better patient comfort.[6] Moreover, researchers have highlighted the benefits associated with its position accuracy and positive effects on periodontal health.[7,8]

According to a recent systematic review and meta-analysis, the retainer failure rate has ranged from 7.3% to 50%, regardless of FR type.[9] Hence, this issue is still regarded as a major problem in the current literature. Regarding CAD/CAM retainers, their short-term results (6 or 12 months) have been observed to be satisfactory in terms of stability and failure in recent years.[10–15] However, there is insufficient data about their long-term stability and failure rates. This study thus aimed to investigate the changes in the stability and failure rates of four FR types (CAD/CAM nitinol, multistrand SS wire, dead-soft wire, and connected bonding pads [CBPs]) after 3 years of retainer bonding. The null hypothesis was that there would be no significant differences between the four FR types in terms of long-term stability and failure rate.

2 | MATERIALS AND METHODS

2.1 | Study design and ethical approval

This study was approved by the Ethics Committee of Pamukkale University (17.05.2022/07). All the participants in the previous randomized clinical trial (RCT) were recalled after 3 years of retainer bonding. Written informed consent was obtained among them who were willing to participate in the present study.

2.2 | Participants

The previous RCT[13] was carried out on 132 patients who had completed the active phase of fixed orthodontic treatment between November 2018 and January 2019 at the Department of Orthodontics, Faculty of Dentistry of Pamukkale University.

The study sample described by (R.A.A.) et al. was enrolled based on the same eligibility criteria as follows: (1) moderate mandibular anterior crowding (4–6 mm) based on Little's irregularity index (LII);[16] (2) good oral hygiene; and (3) absence of caries. The participants were excluded if they had a history of periodontal problems requiring retainer debonding.

2.3 | Retention protocol

One of the following FR types was directly bonded to all mandibular anterior teeth after bracket debonding: (1) dead-soft wire, (2) multistrand SS wire, (3) CAD/CAM nitinol wire, and (4) CBPs. In group 1, a 0.016 × 0.022-inch eight-strand braided dead-soft wire (Bond-A-Braid, Reliance Orthodontic Products) was adapted passively via dental floss (Figure 1A). In group 2, a 0.0215-inch five-strand SS wire (Pentaflex, GC Orthodontics America Inc.) was bent on a plaster model and transferred using a silicone transfer tray. The canines were the first to be bonded, and after tray removal, the incisors followed (Figure 1B). In group 3, a 0.014 × 0.014-inch CAD/CAM nitinol wire (Memotain, CA-Digital; Figure 1C) was applied as in group 2. In group 4, a 0.012-inch CBPs (Leone SpA) was directly applied using a hand instrument (Figure 1D). During the bonding procedure, the enamel surfaces were etched with 37% phosphoric acid (Etch-Royale, Pulpdent), and then adhesive primer (Transbond XT Primer, 3 M Unitek) was applied and slightly air thinned. All retainers were bonded with Transbond LR composite paste (3 M Unitek) by the same investigator (R.A.A.). After retainer bonding, the patients were assessed during clinic visits every three months in the first year and every six months thereafter, even if there was no problem. During the pandemic, as the patients could not go to the clinic, they were interviewed over the telephone. Vacuum-formed retainers were used in the maxilla as retention appliances, and the full-time wear was gradually reduced after a 1-year follow-up period.

2.4 | Data collection

The primary outcomes were the changes in stability measurements, and the secondary outcomes were the failure rates after 3 years of retainer bonding. The stability measurements were performed with analysis software (OrthoAnalyzer, 3Shape) on the digital models. The LII was calculated as the sum of the distances between the anatomic contact points from the mesial aspect of the left canine to the corresponding point on the other side. The intercanine distance was measured between the cusp tips of the canines. The arch length was determined by calculating the sum of the right and left distances from the mesial anatomic contact points of the first molars to the contact points of the central incisors.[17]

Retainer failure was considered when the FR was detached from one or more bonding sites or when the wire broke. For failure assessment, the numbers of detached teeth and failures per patient were recorded for each group. In addition, detachment was recorded as that per tooth. When there was no wire breakage or deformation, the adhesive remnants were removed, and the retainers were repaired. Unlike conventional bending wires and prefabricated CBPs, it would take approximately 10 days for the manufacturing

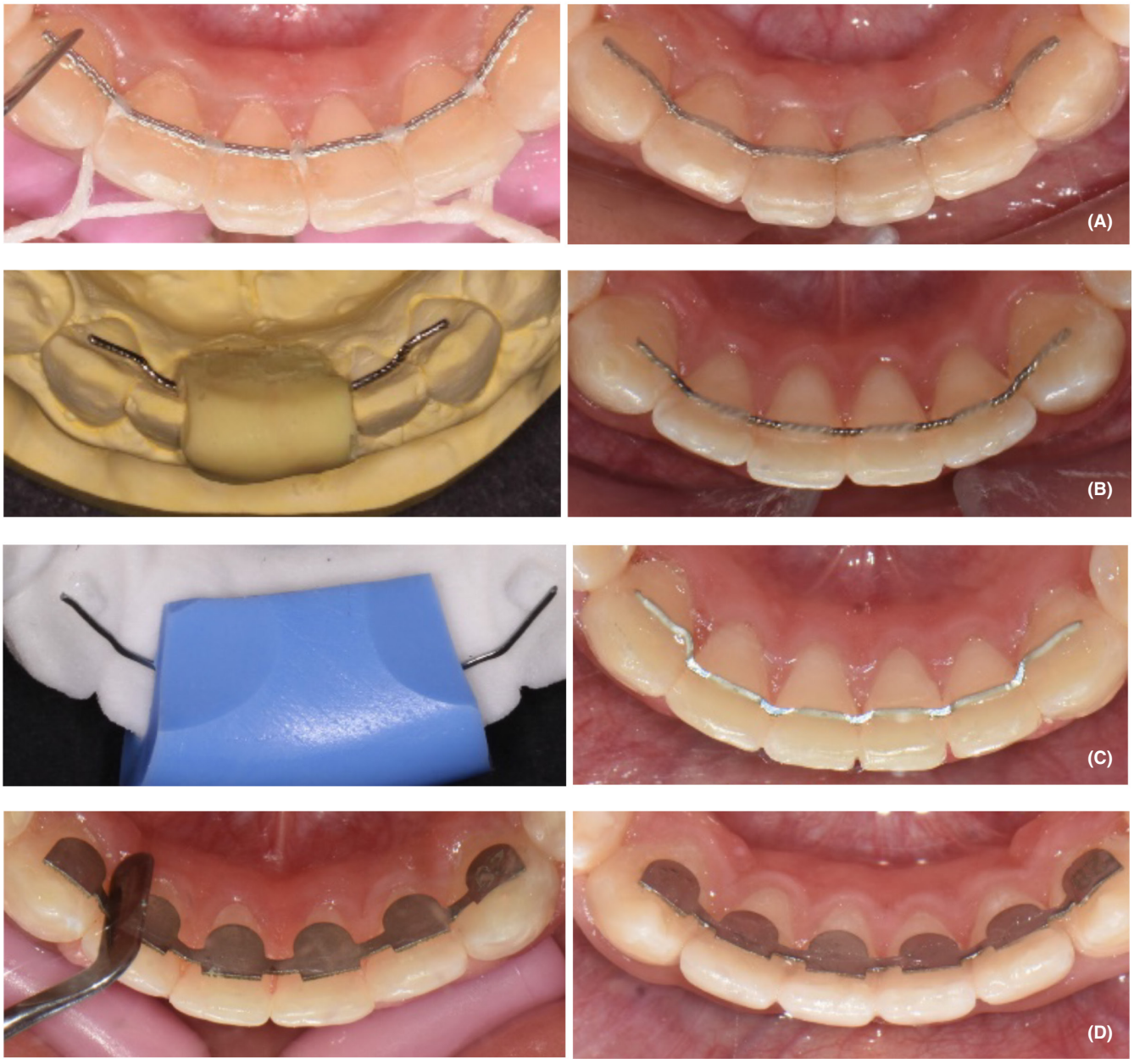


FIGURE 1 The application of different types of fixed retainers (A) Dead-soft wire; (B) Multistrand stainless steel; (C) CAD/CAM nitinol; (D) Connected bonding pads.

and shipping of the CAD/CAM retainer. Considering that stability would be affected by FR replacement, cases of total retainer loss were excluded from the statistical analysis. Due to the differences in the appearance of retainers, the investigators could not be blinded during the follow-up period and outcome assessment. However, the data analyst was blinded to the type of retainer in each group.

2.5 | Measurement error

The stability measurements were separately evaluated by two researchers (S. Ç. and M. Ç.). The digital models of 24 patients were randomly selected and measured by the same researchers after 4 weeks to determine intra- and inter-examiner reliability using the intraclass correlation coefficient (ICC) in this study.

2.6 | Sample size calculation

The post hoc power analysis (G*Power version 3.1.9.7; Franz Faul, Kiel University) was conducted on the data that had been collected in the present study. Because the number of participants decreased at the end of the 3-year follow-up despite our attempts to reach all participants. Based on the LII data from the initial RCT,[13] the power analysis showed that the effect size value of 0.35 with $\alpha = 0.05$ resulted in 80% statistical power according to 23 patients in each group.

2.7 | Statistical analysis

The data were analysed using SPSS software (version 23; IBM). The Kolmogorov Smirnov test was performed to determine the statistical distribution of the data. Descriptive parameters were analysed with Kruskal-Wallis and one-way ANOVA tests. The chi-square test was used for categorical variables. The Friedman test was used for intragroup comparisons of LII data, followed by the Wilcoxon test for pairwise comparisons. The Kruskal-Wallis test was used for intergroup comparison, followed by the Mann–Whitney U test. The repeated-measure ANOVA test was applied for intra-group comparison of other normally distributed stability variables, and the one-way ANOVA test was compared between the groups. Failure rates were presented as frequency (n, %), and the chi-square and Mann–Whitney U tests were used to compare the differences between groups. The statistical significance was evaluated as $P < .05$.

3 | RESULTS

3.1 | Descriptive data

Of the 132 patients, 36 (27.2%) were excluded from the data analysis. Among the 30 patients, 14 declined to participate due to concerns regarding regular clinic visits during the pandemic, 10 were unable to be contacted, and six moved to another city. In addition, five patients had a total loss or replaced their retainers, and one retainer was removed as a result of a periodontal problem. Therefore, the data were obtained from 96 patients (66 female and 30 male) aged between 16 and 21, with a median age of 19 (Table 1). The patients followed up for a mean of 3.47 ± 0.39 years. There were a minimum of eight visits for each group during this study. The retainer groups were homogeneous regarding age, gender, malocclusion type, and baseline LII values.

3.2 | Reliability analysis

Both researchers showed excellent agreement for repeated measurements, with intra-examiner ICC values of 0.998 (95% confidence interval [CI] = 0.998–0.999) for researcher I and 0.999 (95% CI = 0.999–1.000) for researcher II. The inter-examiner agreement values were also excellent, with ICC values of 0.998 (95% CI = 0.997–0.998) and 0.998 (95% CI = 0.998–0.999) for the stability measurements.

3.3 | Stability measurements

The retainer groups were similar in terms of stability measurements after debonding. The most irregularity (median, 1.05 mm; interquartile range, 1.21 mm) was observed in the CBPs group after 36 months of retention. The changes in stability measurements over time for each group are demonstrated in Figure 2A-C, considering the results of the previous RCT.[13]

The intragroup evaluation showed that irregularities significantly increased in all groups ($P < .05$, Figure 2A). Conversely, the intercanine distance was significantly decreased, except for the CAD/CAM nitinol group. The intercanine distance remained almost unchanged in the CAD/CAM nitinol group. The arch length statistically decreased in the dead-soft wire group after 1 year of retention. In the CBPs group, a slight increase was found between T0 and T1 time points, while significant decreases were determined in T1–T2 and T0–T2 time intervals ($P < .05$, Figure 2C).

The comparisons of stability measurements between groups are demonstrated in Table 2. Intergroup comparison of irregularity showed a significant difference at T2 ($P < .05$). However, there were no significant differences between the groups in terms of intercanine distance and arch length at the same time point. The median changes in the irregularity of the dead-soft wire (an increase of 0.77 mm) and CBPs groups (an increase of 0.93 mm) were greater

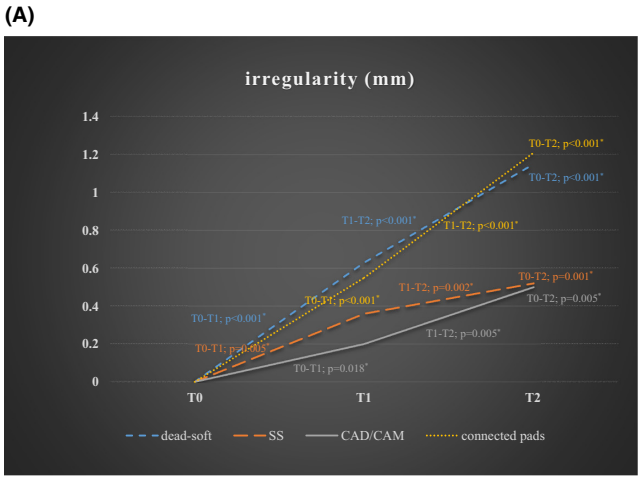
TABLE 1 Descriptive characteristics of the study sample.

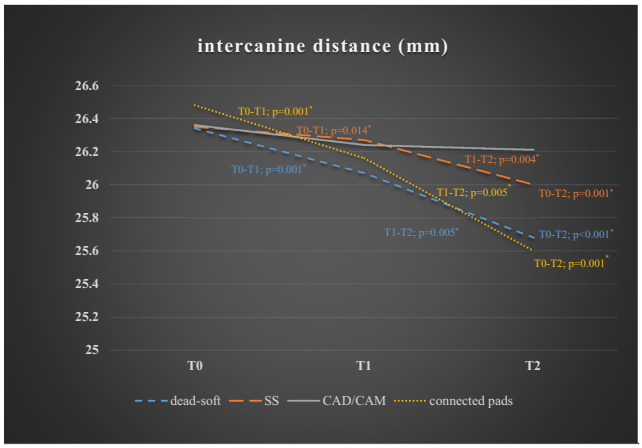
	Group dead-soft wire (n = 24)	Group multistrand stainless steel wire (n = 25)	Group CAD-CAM nitinol wire (n = 24)	Group connected bonding pads (n = 23)	*P*
Age, median (IQR)	19 (4)	18 (4)	19 (5)	19 (5)	.548[a]
Sex, n (%)					
Female	20 (83.3)	16 (64)	14 (58.3)	16 (69.6)	.277
Male	4 (16.7)	9 (36)	10 (41.7)	7 (30.4)	
Malocclusion, n (%)					
Class I	11 (45.8)	10 (40)	10 (41.7)	10 (43.5)	.971
Class II	10 (41.7)	12 (48)	12 (50)	9 (39.1)	
Class III	3 (12.5)	3 (12)	2 (8.3)	4 (17.4)	
Baseline irregularity (mm), mean (SD)	4.23 (0.31)	4.78 (0.26)	4.83 (0.23)	4.6 (0.23)	.356[b]

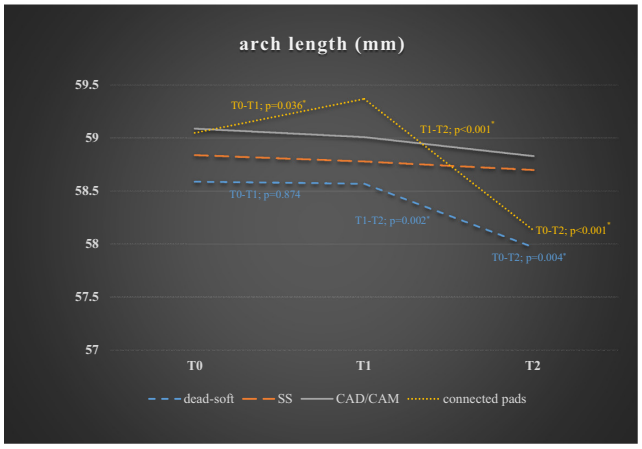
Abbreviation: IQR, interquartile range.

[a]*P* value for comparison of group by Kruskal-Wallis.

[b]One-way ANOVA tests or differences in proportions by Chi-square test.







than those in the multistrand SS and CAD/CAM nitinol wire groups. The intercanine distance significantly decreased by 0.66 mm (95% CI, −0.94 to −0.38 mm) and 0.89 mm (95% CI, −1.31 to −0.47 mm) in the dead-soft wire and CBPs groups, respectively, compared to the multistrand SS and CAD/CAM nitinol wire groups ($P < .05$; Table 2).

FIGURE 2 (A) The changes in irregularity over time within each group[a] (* Indicates $P < .05$). (B) The changes in intercanine width over time within each group[b] (*Indicates $P < .05$ except for CAD/CAM nitinol group). (C) The changes in arch length over time within each group[c] (*Indicates $P < .05$ except for multistrand stainless steel and CAD/CAM nitinol groups). T0: Retainer placement after debonding; T1: 12 months after debonding; T2: 36 months after debonding. [a]Values are presented as interquartile range; *P* values with Wilcoxon signed rank test (intragroup comparison); [b,c]Values are presented as mean; *P* values with repeated-measure ANOVA test (intragroup comparisons).

Similar findings were found in terms of the mean changes in arch length measurements during the 3-year follow-up period.

3.4 | Failure rates

Three patients had retainer failure in the CBPs group during the previous RCT. Four bonding pads were detached from their correspondence. However, no failure of other retainer wires occurred in any patient during the 1-year follow-up period.

A total of 54 failures occurred in 25% of 96 patients during the 3-year follow-up period. However, there were no repeated failures among the 24 patients. The number of patients with failures was significantly higher in the CBPs group than those in the multistrand SS and CAD/CAM nitinol wire groups ($P < .05$; Table 3). Similar findings were found in terms of detached teeth. The failure rates were 13.9% with dead-soft wire, 4.7% with multistrand SS wire, 2.1% with CAD/CAM nitinol, and 17.4% with the CBPs group. Besides, there were significant differences between groups in terms of the distribution of failures per tooth. The failure rates were significantly higher for the right central, lateral, and canine bonded with the CBPs compared to multistrand SS and CAD/CAM nitinol wires ($P < .05$; Table 4).

4 | DISCUSSION

The cause of post-orthodontic relapse has been variable and unpredictable.[18] However, the risks raised from retainer configuration should be minimized when orthodontists choose FRs for a retention procedure. This study was carried out to examine the long-term stability and failure rates of four different FRs. To our knowledge, this was the first study that assessed long-term stability considering CAD/CAM nitinol retainer and investigated whether different retainer types led to different failure rates in this respect.

According to stability results, the first part of the null hypothesis was rejected because the long-term changes demonstrated that CAD/CAM nitinol and multistrand SS wires were more effective than the dead-soft wire and CBPs retainers in maintaining mandibular incisor alignment. The clinical significance of these differences has been questioned. Renkema et al.[19] reported that an LII score of less

TABLE 2 Intergroup comparison of stability measurements at T0 (after debonding) and T2 (3-year follow-up) and changes between T0 and T2.

	Group dead-soft wire	Group multistrand stainless steel wire	Group CAD-CAM nitinol wire	Group connected bonding pads	*P*
Irregularity at T0 (mm)	0 (0)	0 (0)	0 (0)	0 (0.20)	.164†
Irregularity at T2 (mm)	0.78 (1.15)^{A}	0.16 (0.52)^{B}	0 (0.50)^{B}	1.05 (1.21)^{A}	<.001†,*
Difference T2-T0	0.77 (0.23–1.29)^{A}	0.16 (0–0.52)^{B}	0 (0–0.50)^{B}	0.93 (0.50–1.67)^{A}	<.001†,*
Intercanine distance at T0 (mm)	26.34 ± 1.21	26.35 ± 1.32	26.36 ± 0.89	26.48 ± 1.16	.969‡
Intercanine distance at T2 (mm)	25.68 ± 1.16	26.0 ± 1.36	26.21 ± 0.84	25.60 ± 0.83	.180‡
Difference T2-T0	−0.66 (−0.94 to −0.38)^{a}	−0.35 (−0.51 to −0.18)^{b}	−0.15 (−0.32–0.03)^{b}	−0.89 (−1.31 to −0.47)^{a}	.001‡,*
Arch length at T0 (mm)	58.59 ± 2.08	58.84 ± 2.96	59.09 ± 3.27	59.05 ± 2.05	0.922‡
Arch length at T2 (mm)	57.97 ± 1.80	58.70 ± 2.89	58.83 ± 3.18	58.13 ± 2.62	0.591‡
Difference T2-T0	−0.60 (−0.99 to −0.21)^{a}	−0.14 (−0.30–0.02)^{b}	−0.18 (−0.31 to −0.05)^{b}	−0.92 (−1.23 to −0.62)^{a}	<0.001‡,*

Note: T0 and T2 values are presented as mean ± standard deviation or median (IQR).

Difference values are presented as mean (95% confidence interval) or median (Q1-Q3).

Kruskal Wallis test or One-way ANOVA test.

No difference is indicated with the same uppercase (A, B) and lowercase (a, b) letters between groups based on a pairwise comparison with Mann–Whitney U test and post-hoc Tukey test, respectively.

*$P < .05$.

TABLE 3 Comparison of retainer failures between groups during the 3-year follow-up.

Groups	No. of subjects	Failure		*P*[a]	No. of teeth bonded	No. of detached teeth/ Frequency of retainer failure (%)	*P*[a]
		n	%				
Dead-soft wire	24	7	29.2^{A,B}	.010*	144	20/13.9^{A}	<.001*
Multistrand stainless steel wire	25	4	16^{B}		150	7/4.7^{B}	
CAD/CAM nitinol	24	2	8.3^{B}		144	3/2.1^{B}	
Connected bonding pads	23	11	47.8^{A}		138	24/17.4^{A}	

Note: Frequency of retainer failure (%) is calculated as number of failures/total number of bonded teeth in each group.

No difference is indicated with the same uppercase letter (A, B) between groups.

[a]Indicates Chi-Square test.

*$P < .05$.

TABLE 4 The distribution of failures per each tooth and comparison between groups for the 3-year follow-up period.[a]

	Group dead-soft wire	Group multistrand stainless steel wire	Group CAD/CAM nitinol wire	Group connected bonding pads	
	n (%)	n (%)	n (%)	n (%)	*P*[b]
LR-1	5 (9.3)^{A,B}	1 (1.9)^{B,C}	0 (0)^{C}	6 (11.1)^{A}	.015*
LR-2	2 (3.7)^{A,B}	1 (1.9)^{B}	0 (0)^{B}	6 (11.1)^{A}	.012*
LR-3	3 (5.6)^{A,B}	0 (0)^{B}	1 (1.9)^{B}	7 (13)^{A}	.005*
LL-1	4 (7.4)	2 (3.7)	0 (0)	3 (5.6)	.221
LL-2	2 (3.7)	2 (3.7)	1 (1.9)	0 (0)	.535
LL-3	4 (7.4)	1 (1.9)	1 (1.9)	2 (3.7)	.341

No difference is indicated with the same uppercase letter (A-C) between groups.

LL, Lower left; LR, Lower right.

[a]Data are provided as number (percentage). Failure rate (percentage) is calculated as number of failures/total number of failures.

[b]Chi-square test.

*$P < .05$.

than 1 mm was clinically ignorable. Conversely, orthodontic treatment was considered when LII reached 1 mm for a central incisor.[20] Based on the findings from a systematic review and meta-analysis,[21] the irregularities that were about 1 mm in the dead-soft wire and CBPs retainers were found to be clinically acceptable during 3 years of fixed retention in the present study. However, it should be noted that the LII changes should be considered clinically significant when misalignment is restricted to a single tooth. Moreover, it should be emphasized that the calculation of LII from the sum of five measurements is to be a limitation to distinguish this clinical importance.

The intercanine distance decreased with time in all FRs, but there was almost no change in CAD/CAM nitinol, thus contributing to the stability. In addition, the statistical difference revealed that intercanine distance was better preserved in CAD/CAM nitinol and multistrand SS retainers than in dead-soft wire and CBPs after 3 years of retention. In the same manner, the changes in arch length were assumed to be relatively stable in the former two groups. As expected, the arch length decreased with one exception, in which there was a slight increase in CBPs after 1 year of retention. The increase could be explained by the unexpected tooth movements that originated from active forces acting on incisors when pushing on the pads with a hand instrument during the retainer adaption.[22] Because the incisor inclination was not evaluated, and LII did not reflect the labiolingual angulation, the reason for this change could not be explained.

The failure results indicated that the most frequently recorded failure was in CBPs, while the least occurred in CAD/CAM nitinol retainer group. For CBPs, the greatest irregularity was related to the highest failure rates. Due to the complex connected structure, the adaptability of CBPs was more difficult than the other retainer types. The challenging adjustment of bondable mesh-pads to the lingual contours of tooth surfaces may have caused the undesirable results. Similar to CBPs retainers, dead-soft wire was found to be more prone to failure because it was more likely to break.[4] This supports previous findings reported by Baysal et al.[23] In the present study, a higher failure rate was recorded in dead-soft wire compared with 0.0215-inch five-multistrand SS wire. Therefore, the second part of the null hypothesis was also rejected. This requires the clinician to pay close attention to the higher failure rates of dead-soft wires and CBPs. Because the patients might not notice the detachments, resulting in a greater degree of irregularity during the extended retention period.

In addition, the failure rate of CBPs was significantly higher than that of CAD/CAM nitinol and multistrand SS wires in the right quadrant. This could result from patient-related factors such as chewing habits and forces. Another reason for the statistical difference between retainer types was operator-related factors affecting the seating position of retainers. Consistent with the findings reported by Taner et al.,[24] the failure rate was higher for dead-soft wire in the same quadrant, and the most affected tooth was the lower right central incisor. In terms of CBPs, the highest failure was observed in the lower right canine. One possible explanation could be the type of transfer during retainer placement. The tooth-shaped pads were consecutively bonded with finger pressure, starting from the left canine to the right, based on the operator's handedness. However, Kim and Baek[25] recommended the use of a jig to avoid retainer deformation during bonding. Parallel to this, CAD/CAM nitinol and multistrand SS wire retainers showed significantly lower failure rates, contributing to stability.

According to the results, no significant differences were found between CAD/CAM nitinol and multistrand SS wire retainers that supported the stability and failure results of short-term studies.[10–15] The CAD/CAM nitinol retainer may be replaced as a gold standard, considering stability and frequency of failure. Even so, the high cost of CAD/CAM nitinol retainers may be a critical issue when routinely used in clinical practice. Although the plan was to perform the follow-up every 6 months after the first year, pandemic conditions limited this study due to the lack of regular clinical visits. Despite this limitation, a per-protocol design was followed, which was a strength as the drop-out rate was only over 25 percent. Another drawback was that the exact data for the first-time failure of the retainer was not recorded in this study. But that information was of interest as the patients commonly paid no attention to retainers' detachments or failures, and they noticed the irregularity in terms of stability. Therefore, the examination of whether the effects of different types of fixed retainers on patient satisfaction are similar would be necessary for further studies.

5 | CONCLUSIONS

- CAD/CAM nitinol and multistrand SS wires were more effective at maintaining mandibular anterior alignment with fewer failure rates (2.1% and 4.7%, respectively).
- The dead-soft wire retainer group showed significantly more mandibular irregularity and failure (13.9%) than those in the two abovementioned groups.
- The CBPs showed the greatest mandibular irregularity and the highest failure rate (17.4%).
- The changes in mandibular intercanine distance and arch length were judged to be clinically acceptable for all retainer types.

AUTHOR CONTRIBUTIONS

We declare that all authors have contributed significantly to this study and that all authors are in agreement with the manuscript.

CONFLICT OF INTEREST STATEMENT

The authors declare that they have no conflict of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available on request from the corresponding author.

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