Original Article

Comparing patient-centered outcomes and efficiency of space closure between nickel-titanium closed-coil springs and elastomeric power chains during orthodontic treatment: *A two-center, randomized clinical trial*

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ABSTRACT

Objectives: To compare patient-reported pain, discomfort, and difficulty in maintaining proper brushing between nickel-titanium closed-coil springs (CS) and elastomeric power chains (PC) when used for space closure. The secondary aims were to compare plaque control and efficiency of space closure between these two force delivery systems.

Materials and Methods: A total of 48 patients who required extractions of upper first premolars and distal movement of upper canines had the CS randomly allocated to either the right or left side. Blinding was applied at data collection and analysis. Primary outcomes were pain intensity measured on visual analog scale, pain onset and duration, discomfort, and difficulty in maintaining proper brushing from the start of canine retraction at baseline and at 6 and 12 weeks thereafter. Secondary outcomes were plaque scores and the rate of space closure.

Results: No significant differences in mean pain scores, pain onset, and duration at different time intervals between CS and PC were observed. The CS side was significantly less comfortable than the PC ($P < .0001$) and more difficult to keep clean ($P = .008$). No significant differences in plaque scores were observed between CS and PC groups at any time interval. CS produced a faster rate of space closure than did PC ($P = .008$).

Conclusions: CS were less tolerated than PC by patients but produced an average of 0.5 mm more movement than did the PC during the 12-week study period. (*Angle Orthod.* 2022;92:471–477.)

KEY WORDS: Patient-centered outcomes; Plaque scores; Ni-Ti coil springs; Elastomeric power chain; Canine retraction

INTRODUCTION

Space closure in orthodontics is the second stage in comprehensive fixed appliance treatment and can be accomplished by either sliding mechanics or loop mechanics. Nickel-titanium closed-coil springs (CS) and elastomeric power chains (PC) are the most common force delivery systems used in space closure. In vitro studies of the properties of PC showed that they lose force much more rapidly than springs over time.[1,2] In addition, environmental factors and temperature have greater effects on the properties of PC than on CS.[3]

Few clinical trials compared the efficiency between PC and CS in terms of the rate of space closure,[4–7] with conflicting findings. The results of a meta-analysis reported medium quality evidence that CS are more efficient at closing spaces than PC; on average, CS

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were 0.2 mm per month faster at closing spaces than PC.[8] Samuels et al.[9] compared the efficiency of space closure using CS with three different force levels and found that the 150- and 200-g CS were faster at space closure than the 100-g springs.

Most studies compared the efficiency of CS and PC in closing spaces but failed to address other important factors such as patients' comfort, pain perception, or plaque control. In patients with fixed orthodontic appliances, predilection sites for plaque accumulation are found surrounding the bracket base. Many indexes have been used for the assessment of oral hygiene but the most clinically applicable index to use in fixed appliance treatment would most likely be an index that measures plaque surrounding the brackets because this is the most common site for decalcification. The Orthodontic Plaque Index[10] scores plaque accumulation on each tooth surface adjacent to the bracket base (mesial, distal, occlusal/incisal, and cervical).

Pain and discomfort experienced by patients has been widely explored during certain orthodontic procedures, such as separator placement,[11] archwire placement, and activations,[12] but not during space closure with CS and PC.

The primary aims of this study were to compare patient-reported pain, discomfort, and ease of cleaning. Secondary aims were to compare the plaque scores and efficiency of space closure between two force delivery systems used for orthodontic space closure. The null hypothesis was that there would be no difference between CS (intervention) and PC (control) in terms of patient-reported outcomes (pain, discomfort, and ease of cleaning), plaque control (plaque scores), and rate of space closure.

MATERIALS AND METHODS

Trial Design

This was a two-center, split-mouth, randomized clinical trial with an allocation ratio of 1:1 between the two quadrants. Ethical approval was obtained from the institutional review board at Jordan University Hospital (JUH; no. 75/2019/502) and the Ministry of Health (no. MOH REC 1900056). The sample was recruited from patients attending the orthodontic clinics at JUH and the Ministry of Health. Recruitment started in April 2019 and ended in September 2020. This trial was not registered, and the protocol was not published before trial commencement.

Participant, Eligibility Criteria, and Settings

Patients who fit the following eligibility criteria were included: indicated for extraction of upper first premolars on both sides, upper first permanent molars present, no hypodontia, and no craniofacial anomalies or systemic diseases and are not on any medication that would affect orthodontic tooth movement or pain perception. Patients with severe skeletal discrepancies were excluded from the study. Consent was obtained from the patients (and the guardian of minor patients) before their recruitment.

Interventions

All patients were treated with the same conventional preadjusted orthodontic appliance (Mini Master Series, 0.022-inch MBT prescription; American Orthodontics, Sheboygan, Wis). The same protocol was followed for all patients. An 0.019 $\times$ 0.025-inch stainless steel working archwire was left in place for at least 4 weeks. Before starting canine retraction (T0), the working archwire was removed and wiped clean, patients were asked to brush their teeth, and the archwire was retied and traction initiated.

Closed-space PC (Generation II power chain; Ormco, Orange, Calif) and medium-force, 9-mm, CS (Global Orthodontics, Mc Lean, Va) were the two force delivery systems employed for space closure in this study. To establish reproducibility at each time period, the PC and CS were attached at one end to the hook on the molar tube and stretched using a force-gauge (Correx; Dentaurum, Ispringen, Germany) until a force of 200 g was recorded. The other end was attached to the canine hook.

The distance from the tip of the canine to the mesiobuccal cusp of the first molar was measured in each quadrant at T0 and at 6 weeks (T1) and 12 weeks (T2) after initiation of space closure using a Vernier caliper, accurate to 0.1 mm. Plaque index was similarly measured at all three time points. The Orthodontic Plaque Index proposed by Beberhold et al.[10] was employed in this study; plaque accumulation on each side of the bracket (mesial, distal, occlusal, and gingival) was assessed and a score of 0–4 was given. A score of 0 indicated the absence of plaque deposits on any surface adjacent to the bracket base. Scores of 1, 2, 3, and 4 indicated the presence of plaque deposits on 1, 2, 3, and 4 tooth surfaces adjacent to the bracket base, respectively. All measurements were performed by an investigator blinded to the method of space closure. Patients were asked whether they were right- or left-handed to assess the effect of this variable on plaque control.

The visual analog scale (VAS) was used for assessing both pain and difficulty of cleaning after placement of PC and CS at each subsequent visit for each side separately. Patients who reported pain were subsequently asked to record the onset of pain and its duration. To compare which method felt more uncom-

fortable (either annoying or irritating), patients were asked to choose between the right and left sides while explaining to them that discomfort could include irritation or trauma to soft tissues but excluded pain perception.

All patients were given the same oral hygiene instructions: a YouTube video (https://youtu.be/iWzccidNPVQ) and verbal and written instructions.

Outcomes

Primary outcomes were patient-reported pain, discomfort, and ease of cleaning. Secondary outcomes were plaque scores and efficiency of space closure. There were no outcome changes after trial commencement.

Sample Size Calculation

This was a split-mouth randomized control trial. Sample size was calculated using the G*Power program[13] (version 3.1.9.7; Heinrich-Heine University, Dusseldorf) following a priori analysis depending on *t*-test family. Assuming an effect size of 0.5 with an α significance level of 0.05, a total sample size of 36 patients was needed to achieve 90% power for this paired design. Assuming an overall attrition rate of 20%, initial recruitment targeted a total of 43 patients.

Randomization

Randomization was accomplished with a computer-generated list of random numbers. The allocation sequence was concealed in sequentially numbered, opaque, sealed envelopes before the intervention. Each patient was asked to pick a sealed envelope to assign the CS to either the right or left side.

Blinding

Blinding of patients and orthodontists was not possible. However, the research assistants carrying out the measurements were blind to the space closure method used. Both the CS and PC were removed at each visit by the operator before carrying out the measurements. Analysis of the results was accomplished by an author who was also blind to the method of space closure.

Statistical Analysis

The data were analyzed using SPSS (version 22; IBM, Chicago, IL.). Descriptive statistics for all variables were calculated. A paired-sample *t*-test was used to compare CS and PC. Statistical significance was predetermined at $P \leq .05$.

Interexaminer reproducibility for plaque score measurement was assessed using Cohen's κ. The κ value was 0.831. Intraexaminer reliability for intraoral measurement of canine to molar distance was tested in a pilot study on six patients by repeating the measurements after 2 weeks. The reliability coefficient (Cronbach's α) was 0.997. In addition, distance on the study models of those same six patients was performed to assess the reliability of intraoral measurements. Pearson correlation coefficient was used to investigate the relationship between intra- and extraoral measurements. A positive correlation existed between the two measurement methods ($r = 0.991$; $P < .001$). Therefore, intraoral measurement was adopted as the method of assessing the efficiency of space closure.

RESULTS

Participant Flow

A total of 48 patients were randomly assigned to receive CS on either the left or the right side and PC on the other side. One patient did not receive the allocated intervention because he was complaining of pain in a molar tooth and had to be referred to the restorative department for assessment. Two patients were lost to follow-up. Therefore, data for 90 sites in 45 participants were analyzed (Figure 1). At baseline, plaque scores and distance from molars to canines were similar for the two intervention groups ($P > .05$; Table 1).

Numbers Analyzed for Each Outcome

The mean pain scores and pain onset and duration were not significantly different between the two interventions (Table 2). However, pain duration was less after the second activation within the PC group but not the CS group (Table 3).

Approximately one-third of patients reported initial pain 1 hour following activation of the CS and PC. Pain lasted for 1–3 days for the majority of patients in both groups.

Being right- or left-handed did not have any significant effect on plaque control; therefore, the data were pooled. Patients reported that it was more difficult to maintain proper brushing when the CS were in place (Table 2). Similarly, CS caused more discomfort than PC ($P < .0001$; Table 4). Table 5 shows the mean plaque scores at each time point for the two study groups.

Table 6 presents the distance from canine to molar for the two study groups at T0, T1, and T2. From baseline to week 6, the distance was reduced by an average of 2.49 mm for the CS group and 1.97 mm for the PC group. From week 6 to week 12, however, the rate of distance reduction was less and almost similar for both groups (Table 6).

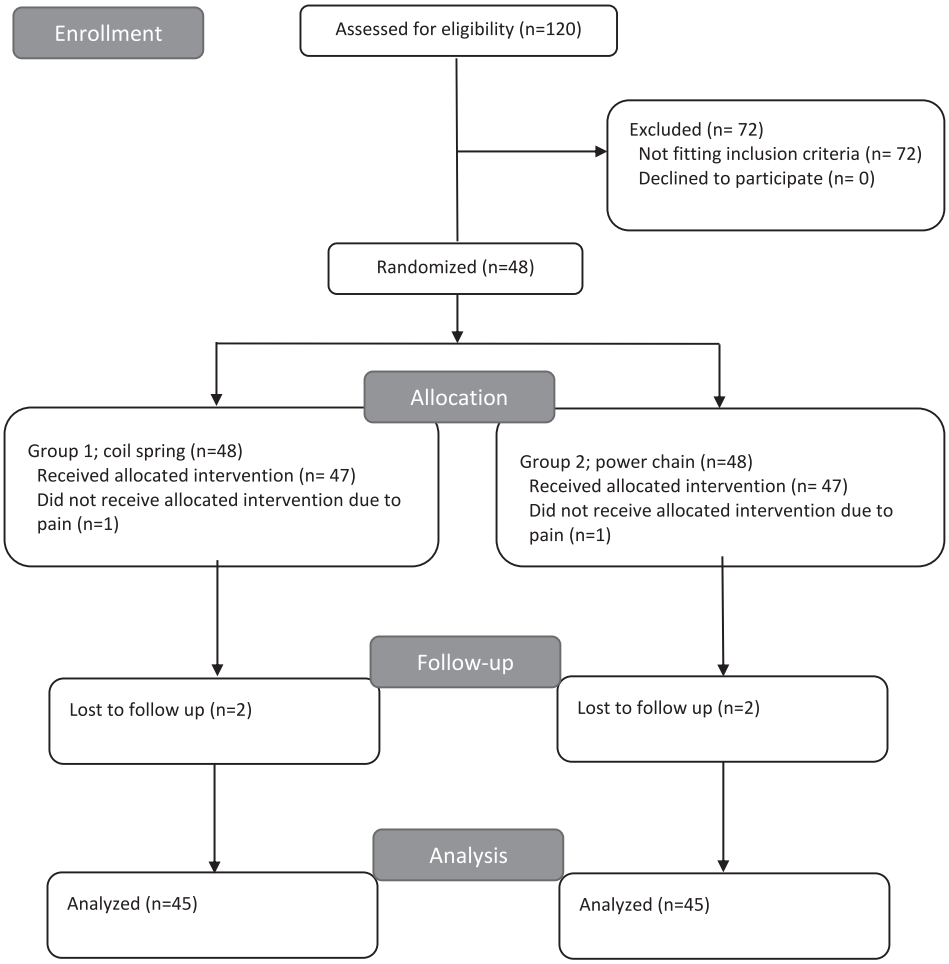

Figure 1. CONSORT diagram showing the flow of patients during the trial.

DISCUSSION

This study attempted to compare two commonly used force delivery systems, CS and PC, in terms of patient outcome measures and experiences, plaque control, and efficiency of space closure. A split-mouth design was selected to eliminate biologic variability, thus reducing variance and sample size requirements.

Patients with underlying systemic conditions or on medications were excluded to eliminate any potential influence on outcome measures. Certain drugs could affect the rate of tooth movement such as corticosteroids, bisphosphonates, and incessant use of nonsteroidal anti-inflammatory drugs. In addition, pain perception is influenced by some of these drugs and any analgesics, which is why patients on analgesics, or with any underlying medical or dental problems, were excluded from the study.

Table 1. Baseline Characteristics of Patients in Each Group[a]

	CS (n = 45)	PC (n = 45)
Demographic characteristics		
Mean age ± SD, y	17.5 ± 4.1	17.5 ± 4.1
Sex		
Male, n (%)	12 (26.7)	12 (26.7)
Female, n (%)	33 (73.3)	33 (73.3)
Clinical characteristics		
Mean plaque score (SEM)	2.67 (0.28)	2.71 (0.37)
Distance from canine to molar ± SD, mm	20.3 ± 1.8	20.4 ± 1.8

[a] SD indicates standard deviation; SEM, standard error mean.

A plaque index that scores plaque adjacent to all four sides of the brackets was chosen because it was considered more valid for the purpose of the study. Using other plaque indexes could be misleading because they rely either on measuring the amount of plaque coverage on the whole labial surface of the crown on certain teeth in each quadrant[14] or by recording plaque dichotomously on six sites per tooth and calculating it as percentage of total tooth surfaces.[15]

Studies on pain reported that initial pain was perceived at 2 hours and peaked at 24 hours during orthodontic treatment with fixed appliances and decreased by days 3 to 5.[12,16,17] Pain intensity was similar

Table 2. Differences Between the CS and PC Groups in Pain and Difficulty in Cleaning After the First and Second Activations[a]

	PC, Mean (SD)	CS, Mean (SD)	Mean Difference (95% CI)	*P* Value[b]
Pain score (VAS)				
After first activation	4.57 (2.42)	4.64 (2.34)	0.077 (−0.688 to 0.843)	.840
After second activation	3.27 (2.36)	3.76 (2.39)	0.497 (−0.343 to 1.337)	.239
Pain onset (hours)				
After first activation	2.76 (2.05)	2.86 (1.81)	0.104 (−0.393 to 0.602)	.675
After second activation	2.34 (1.80)	2.59 (1.93)	0.244 (−0.292 to 0.779)	.364
Pain duration (days)				
After first activation	2.93 (2.06)	2.89 (1.83)	−0.045 (−0.489 to 0.399)	.838
After second activation	2.26 (1.69)	2.56 (1.65)	0.298 (−0.191 to 0.786)	.226
Cleaning difficulty (VAS)				
After first activation	3.63 (2.50)	4.21 (2.79)	0.574 (−0.263 to 1.411)	.174
After second activation	2.73 (2.04)	3.86 (2.54)	1.139 (0.312 to 1.966)	.008

[a] First activation at baseline; second activation at week 6. CI indicates confidence interval.
[b] Using paired-samples *t*-test.

Table 3. Paired-Samples *t*-Test for Differences in Pain and Difficulty in Cleaning Within Each Intervention Group (n= 45 Participants, 90 Sides)[a]

	Paired Differences							
				95% CI of the Difference				
Pairs	Mean	SD	SEM	Lower	Upper	*t* Statistic	*df*	*P* Value[b]
CS group								
Pain scores: first activation − second activation	0.880	3.242	0.483	−0.094	1.854	1.821	44	.075
Pain onset time: first activation − second activation	0.277	2.296	0.342	−0.413	0.966	.809	44	.423
Pain duration: first activation − second activation	0.329	2.080	0.310	−0.296	0.954	1.061	44	.294
Cleaning difficulty: first activation − second activation	0.343	2.961	0.441	−0.547	1.232	.776	44	.442
PC group								
Pain scores: first activation − second activation	1.300	2.866	0.427	0.439	2.161	3.042	44	.004
Pain onset time: first activation − second activation	0.416	2.191	0.327	−0.242	1.074	1.275	44	.209
Pain duration: first activation − second activation	0.672	1.926	0.287	0.093	1.251	2.341	44	.024
Cleaning difficulty: first activation − second activation	0.907	2.811	0.419	0.063	1.752	2.165	44	.036

[a] First activation at baseline; second activation at week 6. *df* indicates degree of freedom.
[b] Two-tailed value.

Table 4. Differences Between the CS and PC Groups in Reported Discomfort After the First and Second Activations[a]

Reported Discomfort	PC, n (%)	CS, n (%)	χ^2 Test	*P* Value
After first activation	13 (28.9)	32 (71.1)	32.9	<.0001
After second activation	11 (24.5)	34 (75.5)	162.7	<.0001

[a] First activation at baseline; second activation at week 6.

between the two groups. Approximately one-third of patients experienced pain after 1 hour of placing CS or PC. Pain lasted from 1 to 3 days for the majority of patients in both groups. Similar findings were reported by another study;[7] duration of pain, however, was significantly less in the CS group in that study. This could be attributed to the subjective nature of pain. The split-mouth design of this study eliminated the effect of different biologic responses.

Table 5. Plaque Scores Between the CS and the PC Groups From Baseline to Weeks 6 and 12

	PC, Mean (SEM)	CS, Mean (SEM)	Mean Difference (95% CI)	*P* Value[a]
Plaque score				
T0	2.71 (0.37)	2.67 (0.28)	−0.044 (−0.614 to 0.525)	.876
T1	6.60 (0.39)	6.09 (0.40)	−0.511 (−1.083 to 0.060)	.078
T2	6.40 (0.28)	6.56 (0.31)	0.159 (−0.338 to 0.656)	.522

[a] Using paired-samples *t*-test.

In the current study, CS were significantly less comfortable than PC. After the initial and second activations, approximately 71% and 75%, respectively, of the patients reported more discomfort from the CS, whereas only 29% and 24% reported more discomfort from the PC.

In addition, patients found it more difficult to maintain proper brushing when CS were in place. It has been inferred that CS are associated with hygiene problems.[18] There is a lack of clinical trials that investigated patient-reported hygiene problems with CS.

Plaque scores on the CS side were not significantly greater than on the PC side. Plaque scores significantly increased from baseline to 6 weeks for both

Table 6. Rate of Space Closure Between the CS and the PC Groups From Baseline to Weeks 6 and 12

	PC, Mean (SD), mm	CS, Mean (SD), mm	Mean Difference (95% CI)	*P* Value[a]
Distance from canine to molar				
T0	20.45 (1.71)	20.38 (1.738)	−0.077 (−0.524 to 0.370)	.731
T1	18.48 (1.67)	17.89 (1.97)	−0.590 (−0.984 to −0.196)	.004
T2	16.69 (2.07)	16.14 (2.17)	−0.549 (−0.935 to −0.164)	.006
Change in distance from canine to molar				
T0 − T1	1.97 (1.46)	2.49 (1.38)	0.513 (0.171–0.855)	.004
T1 − T2	1.79 (1.16)	1.75 (0.99)	−0.041 (−0.286 to 0.204)	.740
T0 − T2	3.77 (2.08)	4.24 (1.69)	0.472 (0.133–0.812)	.008

[a] Using paired-samples *t*-test.

interventions, but did not significantly increase from 6 weeks to 12 weeks. These findings reflect the cooperation of patients in maintaining good oral hygiene, which was not affected by the type of force delivery system used.

Interestingly, space closure was significantly higher in the CS group after the first, but not the second, activation. One possible explanation is that the CS were reactivated at the second visit, whereas the PC were replaced with new PC. This may have resulted in force decay after 6 weeks of use, thus reducing the efficiency of the CS in space closure after 6 weeks.

However, CS resulted in significantly faster space closure than did PC during a period of 12 weeks. In another clinical trial,[4] the rate of space closure achieved by CS was greater than PC, but the difference was not statistically significant. The overall rate of space closure at 4 months in that study was 3.23 mm for CS and 2.33 mm for PC. Both were less than the space closure achieved in the current study (4.24 mm for CS and 3.77 mm for PC). However, they took measurements only at two times: just before space closure and at 4 months (or earlier if space closure was completed). Therefore, the exact rate of space closure could not be determined accurately because in some patients the spaces closed before the time of the second measurement.

The difference in the rate of space closure between PC and CS reported in clinical trials ranged from 0.05 to 0.25 mm/mo.[4–9,18–20] In the current study, the difference was only 0.05 mm/mo, which can hardly be considered as clinically significant. The same difference was reported in another recent clinical trial.[7]

The amount of activation was standardized in the current study. CS were activated every 6 weeks, and the PC were changed every 6 weeks to achieve a force of 200 g. Laboratory studies reported a force decay of PC ranging from 50% to 70% during a period of 21 days.[21,22] Force decay of CS, however, was much less.[23] Although CS did not deliver constant forces when used intraorally, they still resulted in space-closure rates of approximately 1 mm per month.[23]

It is not clear whether this force decay would significantly affect tooth movement intraorally over time. If patients were to be left more than 6 weeks, the PC may undergo more force decay than the CS, which would result in slower tooth movement when the PC are used.

The limitations of the study were that most of the patients were girls and anchorage loss was not accounted for during space closure.

Generalizability

Perception of pain and discomfort differs between patients. The use of a split-mouth design eliminated this confounding variable, thus strengthening the generalizability of the results. This study, however, was carried out in two centers by two clinicians in public clinics.

CONCLUSIONS

- Patients complained of more discomfort from CS than from PC.
- Patients reported that it was more difficult to maintain proper brushing when the CS were in place compared with the PC.
- The level of pain was similar between the two groups and lasted from 1 to 3 days for the majority of patients.
- CS produced faster space closure than did PC by 0.5 mm in 3 months.

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