AJDS ALAZHAR Al-Azhar Journal of Dental Science
Vol. 23- No. 3- 217:225- July 2020
Record 1110-2624 | the ISSN Portal
portal.issn.org

MANDIBULAR ARCH DIMENSIONAL CHANGES SUBSEQUENT TO UTILIZING NICKEL-TITANIUM AND NICKEL – FREE ORTHODONTIC ARCH WIRES: A PROSPECTIVE CLINICAL STUDY

Ahmed Talaat Hussein,* Ahmed Mohammed Abouelnour,** Farouk Ahmed Hussein***

ABSTRACT

Objective: This clinical study investigated mandibular arch dimensional changes of three different aligning arch wires during initial orthodontic leveling and alignment. **Materials and methods:** Thirty patients, 15 females and 15 males with a mean age of 17.81±1.96 years were randomly allocated into three equal groups: A, single strand nickel titanium (NiTi) arch wires; B, Niobium-titanium-tantalum-Zirconium (nickel-free Gummetal) arch wires; and C, multi-strand NiTi arch wires. All had moderate anterior crowding treated via non-extraction approach. 3D digital models were taken before and after 3 months. Mandibular arch dimensional changes determined by calculating the amount of changes. **Results:** The inter-canine width was significantly increased after 12 weeks observation period with both single strand and multi-strand NiTi arch wires by an average 0.98 mm and 1.12 mm. While, the inter-1stpremolar width was significantly increased in patients treated with single strand NiTi arch wire by an average 1.86 mm. However, the inter-molar width was insignificantly changed with the three investigated arch wires. **Conclusion:** Both single strand and multi-strand NiTi arch wires resulted in greater mandibular arch expansion especially in the inter-canine region during leveling and alignment stage. While, the Gummetal arch wire revealed insignificant changes in transverse mandibular arch dimensions

KEYWORDS: Mandibular arch dimensions, Niobium-titanium-tantalum-Zirconium (Nickel-Free Gummetal), Multi-strand NiTi Arch Wires.

INTRODUCTION

Mandibular anterior crowding is one of the most prevalent forms of malocclusion, which has deleterious squeals on the aesthetics, dental health, periodontal health and the social wellbeing. Along the orthodontic history, transverse mandibular dental arch dimensions have been claimed as the main cause of lower anterior segment mal-alignment [1-3].

Therefore considerations should be given to the treatment modality which increases the arch perimeters rather than decreasing the teeth mass where mal-alignment is due to smaller arch rather than larger teeth [4-6]. As alignment in non-extraction situations relay on increasing the arch width transversely and the arch length anteriorly by tipping the incisors away from the molars without changing the arch form. The initial arch wire should provide a light continuous force level to get the most efficient tipping tooth movement with the minimum side effects [7,8].

The Nickel Titanium (NiTi) arch wires are commonly used as the initial wires in orthodontic treatment because of their advantageous properties

* Demonstrator, MSc student, Department of Orthodontics, Faculty of Dental Medicine (Boys), Al-Azhar University, Cairo, Egypt. E-mail: AhmedAli.209@azhar.edu.eg

** Lecturer, Department of Orthodontics, Faculty of Dental Medicine (Boys), Al-Azhar University, Cairo, Egypt.

*** Associate Professor & Acting Chairman, Department of Orthodontics, Faculty of Dental Medicine (Boys), Al-Azhar University, Cairo, Egypt.

such as high elastic limit, high resilience, and low modulus of elasticity [9]. However, there are certain restrictions to these arch wires in certain situations such as patients who suffer from nickel sensitivity. In these conditions, appropriate alternative arch wires are needed [10]. A relatively recent variety of wire was proposed that is a niobium-based titanium arch wire, with a chemical formula of Niobium-Titanium-Tantalum-Zirconium (TiNbTaZr) and a traditional name of Gummetal[11]. This wire is nickel-free, shape formable, and supposed to produce light-continuous forces. Currently, several laboratory and experimental studies tested properties, safety, and allergenicity of titanium niobium alloys [12]. However, consistent with available literature, very little clinical information regarding the efficiency of Gummetal arch wire is available[13].

Another limitation of the conventional singlestrand NiTi arch wire that in some cases there could be a difficult wire engagement without its permanent deformation. Presently, multi-stranding of arch wires was advocated to gain mechanical advantages such as increased flexibility and reduced load deflection rate. This had been successfully attempted with stainless steel arch wires [14,15]. Other attempts have been undertaken regarding NiTi category where multistrand, sometimes called Supercable or coaxial, NiTi arch wires were introduced. It was suggested that these wires could be advantageous because of greater spring back, increased resistance to deformation, and low force delivery. In addition, multistrand NiTi arch wires proposed to engage a relatively large distance at the start of treatment, so greater degrees of up-righting, leveling, and rotational control could be achieved compared with other aligning arch wires [16].

Unfortunately, however, few clinical studies[13,16,17] are existing that investigated the effect of these the above-mentioned arch wires on the arch dimensions during initial orthodontic stage. According to the current knowledge, no clinical reports are available that compared singlestrand and multistrand NiTi arch wires with the nickel-free Gummetal one. Accordingly, it appeared valuable to evaluate and compare the clinical effect of these arch wires on the arch dimensions during the orthodontic leveling and alignment phase.

SUBJECTS AND METHODS

The study protocol was reviewed and approved by Institutional Review Board and the Ethical Research Committee of Faculty of Dental Medicine (Boys), Al-Azhar University, Egypt and registered on ClinicalTrials.gov (ID: NCT04387578). This prospective study was carried out from September 2018 to September 2019 on a total sample of 30 patients, 15 females and 15 males, ranged 15 to 20 years with a mean age of 17.81 ± 1.96 years and were randomly selected from outpatient clinic, Department of Orthodontics, Faculty of Dental Medicine (Boys), Al-Azhar University, Cairo, Egypt. All participants and/or their parents who accepted to participate in this study signed an informed consent form before treatment initiation that allowed their data to be used for scientific purposes.

Based on a previous clinical study, [17] a sample size calculation was undertaken with G*power version 3.1 statistical software based on the following pre-established parameters: an 80% power, sample size for unpaired t-test, significance level (alpha) = 0.05 (two-tailed). With an alpha risk of 0.05, a sample size of 27 subjects (9 in each group) was required to detect a difference of 1 mm in tooth movement with a power of 0.80. A difference of 1.0 mm in tooth movement was chosen because any differences of less than 1.0 mm could not be considered clinically meaningful. It was decided to increase the sample size to 30 patients to compensate for any possible drop-outs or missing patients during the investigation period.

The sample included patients who fulfilled the following criteria: complete permanent dentition (third molars not included); moderate mandibular anterior crowding treated without extractions in the mandibular arch; no tooth size, shape or root abnormalities visible on the patient's radiographic records; no spaces in the mandibular arch; no blocked out tooth that did not allow for placement of the bracket at the initial bonding appointment; and no treatment with inter-maxillary elastics, interproximal stripping, open NiTi springs, and removable or extra-oral appliances.

The following exclusion criteria were used: previous orthodontic treatment; severe dental crowding that requires an extraction approach, abnormal antero-posterior and vertical relationships, patients with cleft lip and palate, anomalies, and syndromes; radiographic signs of periodontal diseases or periapical lesions and resorption; history of trauma or periodontal problems that required massive periodontal therapy which could affect the labial and/or lingual bone support of the mandibular anterior teeth; and regular medications that could interfere with orthodontic tooth movement.

All patients received Roth preadjusted metallic brackets (3M Unitek, Monrovia, Calif)) with a 0.022×0.028 inch slot and had treatment by the same researcher (A.T.H). Patients were randomized to one of three arch wire groups. A restricted randomization process was employed, where patients were randomized in blocks of 10 to ensure equal allocation of patients to the treatment groups. Randomization was performed using computer-generated numbers. The patients groups were divided as follow:

Group A: in which 10 patients (5 males and 5 females a mean age was 17.27±1.95 years) were treated with round singlestrand NiTi (Ortho Organizer Super Elastic Nitanium Arch wires, USA) arch wires in a sequence of 0.012, 0.014, and 0.016 inch.

Group B: in which 10 patients (6 males and 4 females a mean age was 17.33±2.42) were treated with niobium-titanium-tantalum-Zirconium (Gummetal) arch wires (Rocky Mountain Morita Corporation, Tokyo, Japan) in a sequence of 0.014, 0.016, and 0.018 inches according to manufacturer's recommendations.

Group C: in which 10 patients (4 males and 6 females with a mean age was 18.70 ± 1.49) were treated with multistrand NiTi arch wires (Speed System Orthodontics, Ontario, Canada) in a sequence of 0.016, 0.018, and 0.020 inch according to manufacturer's recommendations.

The process of randomization and group allocation was undertaken via a computerized simple online generated randomization plan using online software found at the website: https://www.graphpad.com/quickcalcs/randomize2/. A list of numbers was kept by another investigator (A.M.A.) who on the day of bracket's bonding assigned them to the appropriate group, so the treating clinician was not involved.

In each group, these arch wires were utilized for leveling and alignment of the mandibualr arch as a part of their comprehensive orthodontic treatment plan. Each arch wire type was ligated, without modifications, with figure-of-eight elastomeric modules (Oramco Corporation, CA) to achieve complete engagement wherever clinically possible. All patients were examined before treatment (T0) and after 12 weeks (T3) observation intervals. Next, all patients completed their comprehensive treatment and orthodontic objectives were achieved.

Study measurements and data collection

The outcome of the present study was to evaluate and compare the mandibular arch dimensional changes among the three investigated arch wires.

Routine orthodontic records were obtained for each patient before treatment. Additionally, orthodontic study models were scanned to obtain 3D digital models. An alginate impression (Cavex CA37, Holland BV, Haarlem, Netherlands) of the mandibular arch was taken and poured immediately with white extra-hard dental stone. The resultant

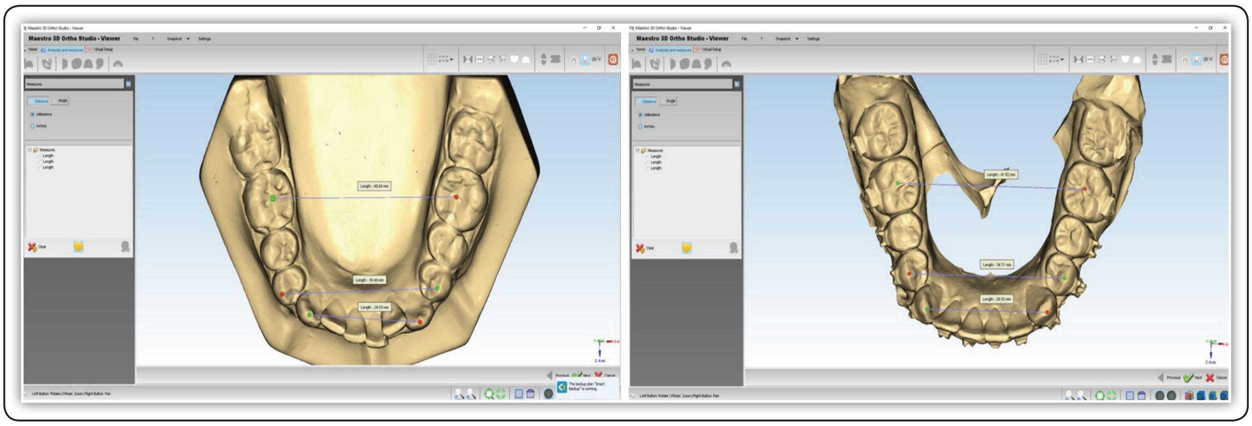

FIG (1) Measurement of mandibular arch dimensions before treatment and after three months observation period on 3D scanned digital model using Maestro 3D software.

study cast was scanned with laser scanner (Hangzhou Shining 3D Tech Co China) to create 3D models that were uploaded to a software (Maestro 3D Dental Studio, Pisa, Italy). The following transverse mandibular arch dimensions were evaluated before and after three months of alignment stage:

The inter-canine width was measured as the distance from cusp tip of one lower canine to the cusp tip of the contralateral one, the inter 1stpremolar width was measured as the distance from the tip of buccal cusp of one lower first premolar to the contralateral one and the inter-molar width was measured as the distance from the central fossa of one lower first permanent molar to the contra lateral one [13]. These changes were measured by the software (Fig. 1) for each patient in the 3 groups at T0 and T3 intervals [13].

STATISTICAL ANALYSIS

All the study variables were collected, coded and analyzed with the Statistical Package for Social Science software (SPSS, Version 23, Inc., Chicago, III, USA). Data were statistically described in terms of means, standard deviations, standard error, mean difference, and percent (%) of changes of variables. Distribution of quantitative data was tested by Kolmogorov-Smirnov and Shapiro-Wilk tests of normality. The results show that the measurements are normally distributed and parametric tests were used for comparison between variables. However, extracted data such as amount and percentage of changes were not normally distributed. So, non-parametric tests were used for their statistical evaluation. Kruskall-Wallis test was used to assess the difference among the three groups. Also, paired t-test was used to assess differences between variables before treatment and after 12 weeks within each group. Confidence interval was set to 95% and the margin of error accepted was set to 5%. The significance level was set at $p \leq 0.05$.

RESULTS

Participant flow, dropout and loses:

The current sample initially conducted on 30 patients. However, during the course of the study, 2 males' patients in Gummetal arch wire group were dropped out due to missed appointments. However, the remaining 28 patients had completed the course of the study.

Error analysis (Reliability of measurements):

The assessment of intra-examiner reliability was undertaken by remeasuring arch dimensions (mm) of 8 randomly selected 3D scanned models from each group after 4 weeks from the 1st measurement. To investigate the reproducibility of the measurements, paired t-test was performed for each variable and no statistically significant differences were found between first and second measurements ($p> 0.05$) that indicated a very good intra-observer agreement.

I) Descriptive statistics and comparison of the changes (mean differences) in the mandibular arch dimensions (mm) after three months observation period within each investigated arch wires group:

It is important to note that comparison of the mandibular arch dimensions (mm) at pretreatment/baseline (T0) among 3 investigated groups using ANOVA test revealed no significant difference ($p>0.05$).

Table 1 show descriptive statistics and comparison of the changes (mean differences) in the mandibular arch dimensions (mm) after three months observation period within singlestrand, multistrand NiTi and nickel-free Gummetal arch wires groups using paired t-test. In singlestrand NiTi group, There are no significant change in the inter-molar width after three months observation period ($p>0.05$). However, there are significant changes in the inter-first premolar width and inter-canine width after three months observation period by averages 1.86 mm and 0.98mm increase in the inter-first premolar and inter-canine widths, respectively.

Regarding Gummetal arch wire group, There are no significant change in the inter-molar width, inter-first premolar width and inter-canine width after three months observation period ($p>0.05$). In multistrand NiTi arch wire group, There are no significant change in the inter-molar width and inter-first premolar width after three months observation period ($p>0.05$). However, there is a significant change in the inter-canine width after three months observation period by an average 1.12mm increase of the inter-canine width ($p\leq0.05$).

TABLE (1): Descriptive statistics and comparison of the changes (mean differences) in the mandibular arch dimensions (mm) after three months observation period within singlestrand, multistrand NiTi and nickel-free Gummetal arch wires groups using paired t-test.

Arch Wire group	Arch dimension	Mean	SD	SE	Mean	SD	SE	Mean difference (changes)	t-value	p-value	Sig.
Single strand NiTi (n=10)	IMW0-IMW3	41.74	2.55	0.77	41.70	2.34	0.70	0.03	0.117	0.909	NS
	IPW0-IPW3	33.96	2.72	0.82	35.82	2.59	0.78	1.86	-4.136	0.002	S
	ICW0-ICW3	25.56	1.18	0.35	26.54	1.44	0.43	0.98	-4.745	0.001	S
Gummetal (n=8)	IMW0-IMW3	41.38	1.46	0.60	41.55	1.49	0.61	0.17	-0.66	0.54	NS
	IPW0-IPW3	33.70	1.38	0.56	34.58	1.93	0.38	0.88	1.94	0.08	NS
	ICW0-ICW3	25.97	1.86	0.76	26.91	1.08	0.44	0.94	-1.42	0.21	NS
Multistrand NiTi (n=10)	IMW0-IMW3	40.62	2.56	0.81	40.42	3.03	0.96	-0.20	0.72	0.491	NS
	IPW0-IPW3	33.34	1.20	0.38	33.64	1.45	0.46	0.30	-1.03	0.330	NS
	ICW0-ICW3	25.05	1.46	0.46	26.17	0.90	0.29	1.12	-2.39	0.041	S

NiTi=Nickel Titanium, n=Number, SD= Standard deviation, SE= standard error, p=probability level, IMW0= Inter-molar width at T0, IPW0= Inter-first premolar width at T0, ICW0= Inter-canine width at T0, IMW3= Inter-molar width after 3 months, IPW3= Inter-first premolar width after 3 months, ICW3= Inter-canine width after 3 months, Sig= Significance, NS= Non-significant p0.05>, S= Significant ($p\leq0.05$), mm= millimeter

II) Comparison of amount (mm) and percentage (%) of changes (T0-T3) in mandibular arch dimensions among three investigated arch wire groups:

Table 2 shows comparison of amount (mm) and percentage (%) of changes (T0-T3) in mandibular arch dimensions among three investigated arch wire groups using Kruskall-Wallis test. There are no significant differences of the changes in both inter-molar and inter-canine widths after three months observation period among the three investigated groups (p>0.05).On the other hand, there are significant differences regarding changes in the inter-first premolar width (p<0.05). These changes (increases) are more pronounced in the singlestrand NiTi group than the two other wire groups.

TABLE (2): Comparison of amount (mm) and percentage (%) of changes (T0-T3) in mandibular arch dimensions among three investigated arch wire groups using Kruskall-Wallis test.

Mandibular arch dimensions (mm)	Singlestrand NiTi group (n=10)		Gummetal group (n=8)		Multistrand NiTi group (n=10)		Comparison of mean difference(change)			Comparison of % of change		
	Mean diff. ± SD	% of change	Mean diff. ± SD	% of change	Mean diff. ± SD	% of change	Test value	P-value	Sig.	Test value	P-value	Sig.
IMW0=IMW3	0.03 ± 0.90	0.02	0.17 ± 0.62	0.41	-0.20 ± 0.87	-0.54	1.20	0.55	NS	1.20	0.55	NS
IPW0-IPW3	1.86 ± 1.49	5.64	0.88 ± 1.68	2.61	0.31 ± 0.94	0.93	7.98	0.02	S	7.93	0.02	S
ICW0-ICW3	0.98 ± 0.68	3.80	0.94 ± 1.62	3.95	1.12 ± 1.48	4.74	0.03	0.99	NS	0.06	0.97	NS

n= Number, SD= Standard deviation, P= Probability level, IMW0= Inter-molar width at T0, IPW0= Inter-first premolar width at T0, ICW0= Inter-canine width at T0, IMW3= Inter-molar width after 3 months, IPW3= Inter-1st premolar width after 3 months, ICW3= Inter-canine width after 3 months,T0= Before treatment, T3= After 3 months treatment, NS= Non-significant p>0.05, S= Significant p≤0.05, NiTi= Nickel Titanium, diff. = Difference, Sig. = Significance, mm= Millimeter.

DISCUSSION

Crowding of mandibular arch is very common in patients with class I malocclusion. Its extent is a decisive factor in choosing the line of treatment whether extraction or non-extraction. With non-extraction treatment; the resolution of crowding could be achieved by distal movement of posterior teeth, proclination of anterior teeth or expanding the dental arch transversely [4].

Different arch wires forms and alloys have been utilized for leveling and alignment phase. NiTi arch wires have commonly used as the initial wire since they have a high elastic limit and resilience with a low modulus of elasticity and low rigidity. However, there are some restrictions to NiTi wires as in patients with nickel sensitivity [9]. In these cases, an alternative arch wire was proposed such as nickel-free Gummetal arch wire that was suggested to applies light continuous forces [13]. In addition, multistrand (Supercable) NiTi arch wires were developed to provide greater spring back, increased resistance to deformation, and low force delivery, compared with the conventional singlestrand one [16].

The above mentioned arch wires were tested to some degree in several laboratory experiments [11,12].

Unfortunately, however, there is limited clinical data regarding the effect of these arch wires on the arch dimensions during the initial stage of orthodontic treatment particularly with the Gummetal one[13,16,18]. Consequently, this study aimed to investigate the effect of these arch wires on the arch dimensions during alleviating moderately crowded mandibular cases.

Patients of the current sample were selected with a narrow age range of 15 to 20 years to obtain, as much as possible, the same biological response. In addition, adolescent and young adults were included to negate the aging effects on the periodontium as possible [18]. In line with numerous studies; all groups were well matched for demographic characteristics and amount of initial crowding as possible [13,16,18].

In this study, all patients received the same bracket category that was 0.022 × 0.028-inch slot (3M, Unitek) Roth brackets. Moreover, all investigated arch wires had round configuration that conventionally utilized for alignment because tightly fitting resilient rectangular arch wires produce back-and forth movement of root apices as the teeth move into alignment [19]. As the first stage of the fixed appliance therapy is concerned with tooth alignment, effectiveness of this stage depends on several variables. In addition to the biological factors (periodontal health, cellular and connective tissue response), which are outside orthodontist's control, the choice of bracket system and arch wires has a direct influence on success of orthodontic tooth movement [18]. Since the present study aimed to compare different arch wires, it was important to standardize all other factors as possible that determine the alignment' rate, including bracket's type and the associated interbracket span.

The effect of the three arch wires on the transverse dimensions of crowded mandibular dental arch:

1. Mandibular inter-canine width:

In the present investigation, the inter-canine width was increased after 12 weeks observation period with both singlestrand and multistrand NiTi arch wires by an average 0.98 mm and 1.12 mm, respectively. However, there is no major increase with Gummetal arch wire (0.94 mm) compared with the pretreatment values. However, upon comparison of changes in the 3 arch wire groups, these changes were analogous in all patients. These results are compatible with the clinical study of Nordstrom et al [13] who found non-significant difference between singlestrand NiTi and Gummetal arch wires regarding the changes in inter-canine width.

Too, the present results are in harmony with several studies, although they utilized different materials and/ or assessment methods [2,3,6-8]. Walter[7] reported larger increase in the inter-canine width of 50 cases treated through non-extraction approach. There was 2 mm increase of inter-canine widths in 62% of cases and 1.4 mm increase in 38% of cases. Also, Herberger[8] found an average increase of 3.3mm, 2.9 mm and 1.9 mm, respectively in 3 longer observation intervals. As well, Aksu et al[2] had similar inclusion criteria and reported an average increase of 1.02mm ±1.64mm in mandibular inter-canine width with the conventional NiTi arch wires.

The results of the present research support those of Weinberg and Sadowsky [3] who found momentous an average increase in the inter-canine width of 0.9 mm following relief of mandibular arch crowding with conventional NiTi arch wires. Also, Glenn et al [6] found a mean increase in the mandibular inter-canine width of 0.5 mm with conventional NiTi arch wire.

In contrast, the present results oppose those of Maltagliati et al [4] and Pandis et al [5] who noted that the initial lower inter-canine distance showed little or no variation compared to the post-treatment value following conventional NiTi arch wire. This could be due to their different bracket types as they used self-ligating brackets.

2. Mandibular inter-1st premolar width*:*

In the current investigation, there was a pronounced increase in inter-1st premolar width after 12 weeks observation in patients treated with singlestrand NiTi arch wire by an average 1.86 mm (5.64%). However, there were non-significant increases in patients treated with Gummetal and multistrand NiTi arch wires by an average 0.88mm (2.61%) and 0.3 mm (0.93%), respectively. Nevertheless, when comparing these changes among the 3 arch wire groups, the increase in inter-1stpremolar width was more evident with singlestrand NiTi arch wire than Gummetal and multistrand NiTi arch wires.

These results are in harmony with some reports[1,3] that evaluated the effect of non-extraction therapy on the inter-1stpremolar width. Weinberg and Sadowsky [3] found significantly increased in mandibular inter-1stpremolar width after alignment with conventional NiTi arch wires by 1.6 mm ± 1.83mm. Moreover, Rasheed et al[1] also reported analogous results with the present investigation of significant differences regarding the inter-premolar widths.

3. Mandibular inter-molar width:

In the present study, there were insignificant changes in inter-molar widths by an average 0.03 mm, 0.2 mm, and 0.17 mm in patients treated with singlestrand, multistrand NiTi, and Gummetal arch wires, respectively. Moreover, when comparing these changes among the 3 arch wires, they were comparable in all patients of the study ($p>0.05$).

These observations concur with several previous studies that reported non-significant increase in the inter-molar width following non-extraction treatment [2,4,6]. Aksu et al [2] reported a non-significant increase of 0.59 mm in 30 non-extraction patients treated with conventional NiTi arch wires.

In addition, Glenn et al [6] also reported an increase in mandibular inter-molar width by 0.8 mm after alignment with conventional NiTi arch wires. Moreover, Maltagliati et al [4] noted that the initial lower inter-molar distance showed little or no variation in relation to the post-treatment value with conventional NiTi arch wires. However, their results were evaluated concerning self-ligating bracket.

On the other hand, the present results are not in accordance with those of Rasheed et al [1] and Walter [7] who reported a significant increase in the inter-molar width by average 1.86 mm and 1.8 mm, respectively. Indeed, the authors investigated different malocclusion forms and utilized different treatment modalities.

One limitation of this study could be the sample size that was adjusted to the minimum sufficient size based on previous study [17]. Perhaps; a larger sample size could be able to detect a significant difference among these aligning arch wires. Furthermore, inclusion of patients with severe crowding may reveal a difference in their clinical performance.

Unfortunately, there are no published studies that utilized Gummetal or multistrand NiTi arch wires in extraction cases. Additionally, limited information is available about the friction aspects. Future studies of these arch wires over a longer duration of evaluation with another bracket types could reveal clinical differences. Moreover, other wire sequences or configurations might demonstrate different clinical performance. It is recommended to carry out additional randomized clinical trial to further explore the clinical efficiency of Gummetal arch wire with on the incidence of root resorption and to confirm its advantage of being nickel free.

CONCLUSION

Based on the results of the present study, the following conclusions could be drawn:

1. Both singlestrand and multistrand NiTi arch wires resulted in greater mandibular arch expansion especially in the inter-canine region during leveling and alignment stage.
2. The Gummetal arch wire revealed insignificant changes in transverse mandibular arch dimensions subsequent to leveling and alignment.

REFERENCES

1. Rasheed T, Arif A, Ali A. Dental crowding and its relationship to tooth size and arch dimensions. J Nat Scie Res 2014;14.
2. Aksu M, Kocadereli L. Arch width changes in extraction and non-extraction treatment in class I patients. Angle Orthod 2005;75:948-52.
3. Weinberg M, Sadowsky G. Resolution of mandibular arch crowding in growing patients with class I malocclusion treated non-extraction. Am J Orthod Dentofac Orthop 1996;110:359-64.
4. Maltagliati L, Myiahira Y, Fattori L, Filho L, Cardoso M. Transversal changes in dental arches from non-extraction treatment with self-ligating brackets. Dental press J Orthod 2013;18:39-45.
5. Pandis N, Polychronopoulou, Makou M, Eliades T. Mandibular dental arch changes associated with treatment of crowding using self-ligating and conventional brackets. Eur J Orthod 2010;32:248-53.
6. Glenn G, Sinclair P, Alexander R. Non extraction orthodontic therapy: post-treatment dental and skeletal stability. Am J Orthod 1987;92:321-8.
7. Walter D. Comparative changes in mandibular canine and first molar widths. Angle Orthod 1962;32:232-40.
8. Herberger R. Stability of mandibular intercuspid width after long periods of retention. Angle Orthod 1981;51:78-83.
9. Riley M, Bearn D. A systematic review of clinical trials of aligning arch wires. Am J Orthod Dentofacial Orthop 2009;36:42-51.
10. Golz L, Papageorgiou S, Jager A. Nickel hypersensitivity and orthodontic treatment: a systematic review and meta-analysis. Contact Dermatitis 2015;73:1-14.
11. Dalstra M, Denes G, Melsen B. Titanium-niobium, a new finishing wire alloy. Clin Orthod Res 2000;3:6-14.
12. Suzuki A, Kanetaka H, Shimizu Y, Tomizuka R, Hosoda H, Miyazaki S, et al. Orthodontic buccal tooth movement by nickel-free titanium-based shape memory and superelastic alloy wire. Angle Orthod 2006;76:1041-46.
13. Nordstrom B, Shoji T, Anderson WC, Fields HW, Beck FM, Kim DG, et al. Comparison of changes in irregularity and transverse width with nickel-titanium and niobium-titanium-tantalum-zirconium archwires during initial orthodontic alignment in adolescents: A double-blind randomized clinical trial. Angle Orthod 2018;88:348-54.
14. Rucker B, Kusy R. Elastic flexural properties of multistranded stainless steel archwires. Angle Orthod 2002;72:302-9.
15. Ong E, Ho C, Miles P. Alignment efficiency and discomfort of three orthodontic arch wire sequences: a randomized clinical trial. Am J Orthod Dentofacial Orthop 2011;38:32-39.
16. Sebastian B. Alignment efficiency of superelastic coaxial nickel-titanium vs superelastic single-stranded nickel-titanium in relieving mandibular anterior crowding: a randomized controlled prospective study. Angle Orthod 2012;82:703-8.
17. Gravina M, Brunharo I, Fraga M, Artese F, Campos M. Clinical evaluation of dental alignment and leveling with three different types of orthodontic wires. Dental Press J Orthod 2013;18:31-37.
18. Abdelrahman R, Al-Nimri K, Al Maaitah E. A clinical comparison of three aligning arch wires in terms of alignment efficiency: A prospective clinical trial. Angle Orthod 2015;85:434-39.
19. Proffit W, Fields H, Sarver D. Contemporary Orthodontics. 4th ed. St Louis, Mo: Mosby;2007:551-52.