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Three-dimensional assessment of transverse dentoskeletal mandibular dimensions after utilizing two designs of fixed mandibular expansion appliance: A prospective clinical investigation

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ABSTRACT

The aim of this clinical study was to evaluate and compare the dentoskeletal transverse mandibular arch dimensions following the use of two designs of fixed mandibular expanders using cone beam computed tomography (CBCT). Twenty orthodontic patients, 12 females and 8 males, with mean age of 13.4 ± 0.5 years were selected and randomly divided into two equivalent groups; group A consisted of 10 patients (4 boys, 6 girls) who were treated with modified Williams expander and group B consisted of 10 patients (4 boys, 6 girls) who were treated with a two-arm fixed expander. Consistent expansion instructions were given to all patients according to a standardized slow protocol of one quarter turn twice/week for both expanders. Routine orthodontic records as well as mandibular CBCTs were obtained before (T1) and immediately after expansion (T2) to estimate changes in dentoskeletal mandibular transverse dimensions. The data was statistically analyzed and the significance level was set at $p \leq 0.05$. Mandibular intercanine, inter-premolar, intermolar widths; and arch perimeter were significantly increased ($p \leq 0.05$) following expansion with both fixed expanders. However, the changes in inter-premolar width, intercanine width, and arch perimeter were significantly augmented in two-arm fixed expander group than modified Williams's group. In contrast, their effects on the skeletal mandibular body width were non-significant ($p > 0.05$). Both expanders yielded significant and equivalent dentoalveolar effects that were more evident with two-arm fixed expander than the William one. Both fixed designs enhanced mandibular transverse dental dimensions; however, they were unsuccessful to create any considerable skeletal effects.

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1. Introduction

A tooth size- arch length discrepancy is a common form of malocclusion in most orthodontic patients and the amount of such discrepancy; especially in mandibular arch is a vital factor for the extraction decision (Weinberg and Sadowsky, 1996; Motoyoshi

et al., 2005; Wendling et al., 2005). Given that treatment strategies have been changed lately to more conservative approaches, there is great awareness in non-extraction alternatives for space gaining, particularly in borderline cases. Among these are; interproximal reduction, distalization, and arch expansion. While the severity of crowding and the soft-tissue profile are the important determinants of the appropriate approach; stability, timing of treatment and different treatment approaches must also be considered (Williams, 1977; Busdrang et al., 2001; Housley et al., 2003; Wendling et al., 2005).

Relative to maxillary deficiency, transverse mandibular deficiency has received little awareness from researchers. Even though expansion can be done successfully in the maxillary arch, in mandibular arch, the expansion procedure has been thought to be less effective. This could be attributed to the anatomical limitations in the mandible, since, the maxilla has a midpalatal suture

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but the mandible has not. Therefore, the effect of mandibular expansion was believed to be localized to the alveolar process and mostly generate tipping of the buccal segment (Hamula, 1993; Burke et al., 1998; Busdrang et al., 2001; Maki et al., 2006; O'Grady et al., 2006; Tai et al., 2010, 2011).

Indeed, contradicting opinions exist regarding the effects and stability of mandibular expansion. Some reports have acknowledged that the mandibular expansion is theoretically not stable and the mandibular arch form cannot be altered by the appliance therapy, whereas further investigations have demonstrated that the mandibular arch width could be expanded permanently (Walter, 1953; Reidel, 1960; Shapiro, 1974; Little et al., 1990; Osborn et al., 1991; Weinberg and Sadowsky, 1996; Tai et al., 2010).

In fact, the effects of mandibular expansion have been exhaustively evaluated via dental model analysis and cephalometric radiography, in spite of its limitations which include projection errors, magnification, distortion, and the 2-dimensional representation of a three dimensional structure (Sandstrom et al., 1988; Housley et al., 2003; Clark, 2005; Motoyoshi et al., 2005; Wendling et al., 2005; Habersack et al., 2007; Sabuncuoglu et al., 2011; Sharada et al., 2011; Handelman, 2012; Kravitz, 2014). At present, these restrictions have been resolved to great extent by using Cone Beam Computed Tomography (CBCT) which provides 3-dimensional (3D) information, allowing for measurement of axial inclinations of the dentition and changes in the transverse dimensions free from distortion, magnification, and superimposition (Scarfe et al., 2006; Lagravere et al., 2008).

Although, a lot of 3D information has been published regarding maxillary expansion (William and Sim, 1993; Habersack et al., 2007; Garrett et al., 2008; Ballanti et al., 2009; Tai and Park, 2010; Baysal et al., 2011; Bazargani et al., 2013) very little have been reported about the mandibular arch expansion especially with the fixed approaches (William and Sim, 1993; Tai et al., 2010, 2011; Tai and Park, 2010). In view of the limited available literatures and 3D information, it is a matter of concern to explore the changes occurring in the mandibular arch concomitant to expansion using two different designs of fixed mandibular expanders via CBCT analysis.

2. Methodology

This randomized prospective study was carried out on a sample of 20 patients, 12 females and 8 males, ranged in age from 12 to 14 years with mean initial age was 13.4 ± 0.5 years old. They were randomly selected from the outpatient clinic, Department of Orthodontics, Faculty of Dental Medicine (Boys), Al-Azhar University, Cairo, Egypt. The study protocol was reviewed and approved by Institutional Review Board of Faculty of Dental Medicine (Boys), Al-Azhar University, Egypt. The research objectives were explained to all participants and/or their parents in details and an informed consent was signed by the parents before starting treatment. Another consent form explaining the treatment plans was also read and signed by the patient's guardian before commencing the treatment.

Sample size calculation was based on previous studies where a power statistical analysis via G*Power software (version 3.1.9.2; Universitat Dusseldorf, Dusseldorf, Germany) was undertaken (Maki et al., 2006; Tai and Park, 2010; Tai et al., 2011). Accordingly, a sample size of 20 patients, 10 in each group that had an 80% power to detect a difference between means of 5.77 with a significance level (alpha) of 0.05 (two-tailed) was observed. The sample included patients who fulfilled the following criteria:

1. Angle class I malocclusion with a moderate crowding in both arches, reduced maxillary and mandibular transverse dimensions that required non-extraction orthodontic approach.

2. Normal antero-posterior relationship and facial proportions with an average or low Frankfort mandibular plane angle as determined clinically and from cephalometric records.
3. Good oral hygiene.
4. No previous orthodontic treatment, history of trauma, and para-functions.
5. No systemic diseases or regular use of medication that could interfere with normal growth and/or orthodontic tooth movement.

Patients who had severe crowding, abnormal antero-posterior relationship and steep mandibular plane, poor oral hygiene or periodontal affection, and previous orthodontic treatment were excluded.

The sample was randomly divided into two equal groups, according to the type of the fixed mandibular expander used as follows: group A that consisted of 10 patients (4 boys, 6 girls) who were treated with modified design of William's expander and group B that consisted of 10 patients (4 boys, 6 girls) who were treated with two-arm fixed mandibular expander. The process of randomization and group allocation was undertaken with an allocation ratio of 1:1 and clinical assistants arbitrarily allocated patients into two experimental groups with 10 patients each, using a simple generated randomization plan through online software (<http://www.graphpad.com/quickcalcs/randomize2/>).

In both groups, the mandibular expansion as a first stage of a comprehensive orthodontic treatment was undertaken. The appliance was activated by centrally located jack-screw (Leone, Italy), at the middle of lingual region of the mandible and was held in position with the aid of two cemented bands (3 M Unitek Corporation, Monrovia, CA, USA) on the mandibular first permanent molars. A suitable size (8 mm) jack-screw was selected for all patients, and the expander was fabricated on the mandibular model.

In the first group, a mandibular fixed lateral expansion appliance was used that was a modified design of Williams' expander. The original design is a fixed appliance that was introduced by Williams and was designed to correct crowding in early mixed dentition (Fig. 1a). The appliance utilizes two long stainless tubes soldered to each of the lower primary second molar bands with extensions back to contact the lingual of first permanent molars. An expansion screw is secured to the molar bands by wire extensions extending to transverse the anterior portion of the mandible. An arc of 0.016 NiTi arch wire inserts into the forward ends of the stainless tubes and, as the expansion screw is activated the NiTi wire is moved forward to automatically decrowd the incisors (William and Sim, 1993). In the first group of the current study, a mandibular fixed expansion appliance was used that was similar to Williams expander but without the arc of 0.016 NiTi arch wire. The arms of expansion appliance were placed parallel to the occlusal line on the cervical third of the premolars teeth (Fig. 1b) (William and Sim, 1993).



Fig. 1. (a) Original design of Williams' mandibular expander; (b) Modified Williams' mandibular fixed expander used in the study (Group A).

On contrary, in group B, a 2-arm mandibular fixed lateral expansion appliance was used (Fig. 2). Similar to the first design, it utilizes 2 first molar bands and the expansion screw has two 0.060-inch extension arms (Leone, Italy). A 0.035-inch wire was soldered to these arms to add the required length so the wire can extend about 2 mm away from the alveolus, returning to the mid crown height of the first permanent molars to which it was soldered. This wire continues below the mid crown level of the second and first premolars. The alveolar and mid crown lengths of wire were joined in the first permanent molar region for rigidity of the appliance. The two arms of expander were adapted and relieved from the underlying tissue by about 1.5 mm to prevent tissue damage as much as possible. The arms of the expander together with the lingual wire were soldered to the middle of the lingual surfaces of the molar bands (Handelman, 2012).

Regarding the expansion protocol, the screw was activated one quarter turn twice/week, that amounting to approximately 0.25 mm and resulting in 0.5 mm expansion per week in all the patients from both the groups. Both appliances were activated up to the full capacity of the expansion screw and activation was continued until over correction was obtained for a period of 3 months. Following this, the screw of appliance was fixed with composite and the expander used as retainer (Housley et al., 2003; Tai et al., 2011).

At the same time, maxillary dental arch expansion was undertaken to correct arch constriction and to maintain the buccolingual relationship and occlusal contact of posterior teeth during mandibular expansion (Fig. 3a and b). The maxillary arch was treated with slow protocol using quad helix palatal expander (13 patients) or rapid protocol (7 patients) using Hyrax expander (Leone, Italy) (Tai et al., 2011).

Following achievement of the research objectives, regarding the stage of mandibular expansion, all patients continued their comprehensive treatment according to the proposed orthodontic treatment plans and all treatment procedures were performed by the same researcher (S.M.). Upper and lower preadjusted stainless steel brackets (3 M Unitek Corporation, Monrovia, CA, USA) 0.022 × 0.028 in. slot were bonded using light cure orthodontic adhesive (Transbond 3 M Unitek Corporation, Monrovia, CA, USA). A series of leveling NiTi arch wires (OrthoOrganizer Corporation, Monrovia, CA, USA) were used. The expander was left in situ as a passive retainer until reaching heavy rectangular 0.016 × 0.022 arch wire (Ortho organizer corporation, Monrovia, CA, USA) (See Figs 5–10).

Routine orthodontic records were obtained for each patient before treatment. Additionally, mandibular Cone Beam Computed Tomography (CBCT) images were taken before treatment (T1) and immediately following complete expansion approximately after 3 months (T2) for both groups. The CBCT images were



Fig. 2. Two-arm fixed mandibular expander (Group B) used in the study.



Fig. 3. (a) Quad helix maxillary expander used in the study; (b) Hyrax maxillary expander used in the study.

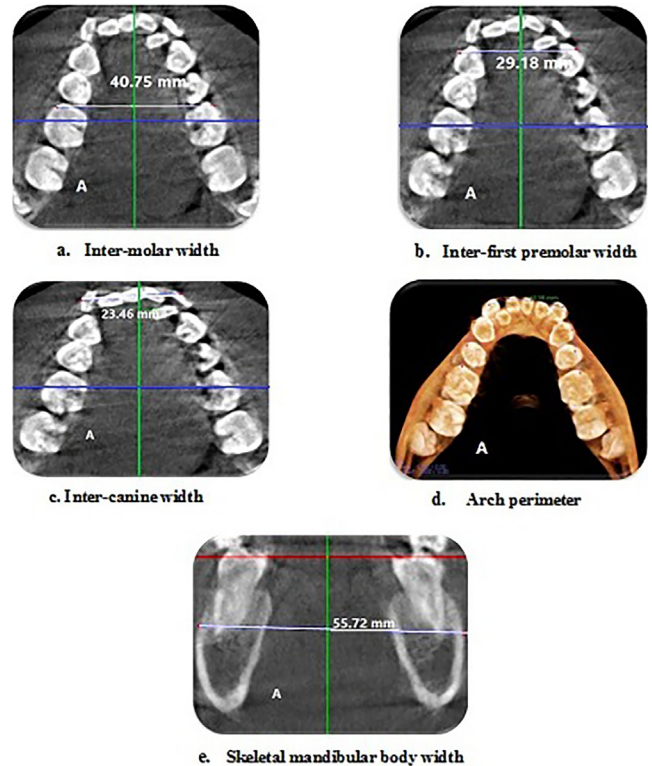


Fig. 4. Transverse dentoskeletal CBCT measurements used in the study.

acquired using a Planmeca Promax scanner (Planmeca, Helsinki, Finland). A scout view was obtained and adjustments were made to ensure that, all patients were correctly aligned in the scanner according to adjustment light beam before acquisition. The machine was supplied with cesium-iodide scintillator and amorphous silicon detector and the following exposure parameters were applied: 80 × 80 mm scan dimension, 12 × 9-cm field of view, 90 kV, 10 mA tube current, 18 s scan time, and 0.16 mm isotropic voxel size. The same subject's posture and the same settings were used for all the scans.

After acquisition, data were exported and transferred in Digital Imaging and Communications in Medicine (DICOM) format and imported into the software (Anatomage, San Jose, CA) to perform the required CBCT measurements. Serial of steps were followed to standardize the measurements in all scans. Superimposition; the set of DICOM data of the preoperative scan is loaded into the software, and then the set of the postoperative scan of the same patient was loaded over it. According to variation in positioning of both scans, a second adjustment was needed to ensure perfect superimposition, to guarantee linear and angular measurements at the exact level. Superimposition module was used to superimpose the postoperative scan over the preoperative one, where three



Fig. 5. Intra-oral photographs of a female patient planned for modified Williams' mandibular expander (Group A).



Fig. 6. Intra-oral mandibular photographs of a female patient treated with modified Williams' expander (Group A). (A) Immediately after cementation of expander. (B) After complete mandibular expansion. (C) Immediately after removal of expander for CBCT imaging.



Fig. 7. Intra-oral photographs of a female patient treated with modified Williams' mandibular expander (Group A) after complete active expansion stage and during fixed appliance therapy.

landmarks at different anatomical areas were chosen at each scan, menton, right and left gonions, and then registration of these landmarks was automatically performed by the software. Superimposition sequence was repeated for each patient individually. Orientation; after completion of superimposition, the T1 and T2 scans was one unit and moved in the same sequence. Orientation of the whole volume was made to ensure that the orthogonal reference lines (axial, coronal and sagittal) would intersect at the area of interest for each measurement (for both T1 and T2 scans), where adjustment of each measurement was made individually and repeated in the same manner in each scan. To set an identical reference plane in the T1 and T2 scans, the CBCT images were oriented along the mandibular plane. In order to construct

mandibular plane, three points were identified at the level of the lower border of mandible; menton anteriorly, right and left gonion posteriorly. At this orientation, the following views were obtained; axial, sagittal, and coronal views. After superimposition and orientation was completed, the two scans were viewed by the software either separately or superimposed, where the software allowed presentation either one set of data solely or both data at the same time, while reference lines remain at the same levels for both scans. All procedures and measurements (Table 1 and Fig. 4) were undertaken by one investigator (M.A.) who was blinded about the nature of the study groups and not directly involved in the study, and measurements accuracy and intraexaminer reliability were evaluated.



Fig. 8. Intra-oral photographs of a female patient planned for two-arm fixed mandibular expander (Group B).



Fig. 9. Intra-oral mandibular photographs of a female patient treated with two-arm fixed mandibular expander (Group B). A. Immediately after cementation of expander. B. After complete mandibular expansion. C. Immediately after removal of expander for CBCT imaging.



Fig. 10. Intra-oral photographs of a female patient treated with two-arm fixed mandibular expander (Group B) after complete active expansion stage and during fixed appliance therapy.

2.1. Statistical analysis

All statistical analyses were performed using Statistical Package for Social Science (SPSS, Version 23.0 Inc, IBM Corporation, NY, USA) for Windows. Descriptive statistics were calculated for all CBCT measurements in both groups. Data were presented as mean, standard deviation (SD) and, standard error (SE) for the mean values. Data were explored for normality testing by checking the distribution of data using Kolmogorov-Sminrov and Shapiro Wilk tests. Since the data were normally distributed, parametric statistical tests were used.

Comparisons of the effects of expansion within each group were performed via paired *t*-test to compare dentoskeletal variables between pre-expansion (T1) and post-expansion (T2) CBCT measurements within each group. Additionally, independent sample *t*-test was used to compare these variables between both groups. The significance level was set at $p \leq 0.05$.

3. Results

The present study was initially conducted on a sample of 20 orthodontic patients, 11 females and 9 males. They were randomly

Table 1
Definitions of linear dental and skeletal CBCT measurements used in the study (Reidel, 1960; Tai et al., 2010, 2011; Tai and Park, 2010).

Measurement	Definition
IMW	Intermolar width; the transverse distance between mesiobuccal cusp tip of mandibular right and left first molars in axial section (Fig. 4a).
IPW	Inter-premolar width; the transverse distance between buccal cusp tip of mandibular right and left first premolars in axial section (Fig. 4b).
ICW	Intercanine width; the transverse distance between cusp tip of mandibular right and left canines in axial section (Fig. 4c).
AP	Total arch perimeter measured from the mesio-occlusal line angle of the mandibular first permanent molar along the arch to the corresponding point on the other side in axial section (Fig. 4d).
OMBW	Outer mandibular body width; the transverse distance between outer surfaces of the mandibular body 13 mm below the alveolar crest in coronal section (Fig. 4e).

divided into two groups according to the type of mandibular expander; group A that was treated with modified Williams' mandibular expander and group B that utilized a two-arm fixed mandibular expander. Unfortunately, 4 patients (2 patients from each group) were dropped out during the observation period of the study because of failure of reasonable cooperation and compliance with the appliances during follow up visits. The remaining 16 patients have completed their treatment up to finishing the research objectives regarding the stage of mandibular expansion.

The CBCT images of four randomly selected subjects from each group were measured at least twice on 2 separate occasions, 3 weeks apart, by the same investigator. To determine the intra-examiner error of measurements, paired sample *t*-test was conducted for the mean difference between the first and the 2nd measurements. No statistically significant difference was found between 1st and 2nd measurements ($p > 0.05$). Additionally, no statistically significant difference was found for any measurement by using intraclass correlation coefficients. Moreover, there was no statistically significant difference ($p > 0.05$) between both groups in mandibular CBCT dentoalveolar measurements before expansion.

Table 2 shows descriptive statistics and comparison of mandibular CBCT dentoalveolar measurements in modified Williams mandibular expander group (group A) and two-arm fixed mandibular expander group (group B) using paired *t*-test before (T1) and immediately after expansion (T2). There were significant dentoalveolar changes from T1 to T2. In each group, there are

statistically significant increases in intermolar width ($p \leq 0.01$), inter-premolar width ($p \leq 0.01$), the mandibular intercanine width ($p \leq 0.01$), and arch perimeter and ($p \leq 0.001$, respectively). However, the skeletal mandibular body width (OMBW) measurement showed no significant changes after expansion ($p > 0.05$).

Table 3 shows comparison of the dentoalveolar changes (T1-T2) between both expansion groups using independent sample *t*-test. There are no statistically significant differences between both groups regarding the changes in intermolar width and skeletal mandibular body width ($p > 0.05$). However, the changes in inter-premolar, intercanine widths, and arch perimeter measurements showed statistically significant increase in two-arm fixed mandibular expander group than modified Williams expander one ($p < 0.05$).

4. Discussion

One of the goals of early treatment is to correct existing or developing dentoalveolar, skeletal, or muscular imbalances, thus improving the overall oral environment before permanent teeth have completely erupted. By initiating orthodontic and orthopedic therapy at a younger age, it is expected that many future abnormalities in the occlusion will be resolved with a simple second phase of full fixed appliances, thereby reducing the potential need for and severity of complex orthodontic treatment including permanent tooth extraction or orthognathic surgery later (Tai et al., 2011).

Mandibular arch crowding is a common orthodontic problem that represents a great challenge that the orthodontists face daily in practice. Either expansion or extraction may be employed to get a well leveled and aligned dental arch. However, loads of debate still exists regarding the efficiency of mandibular arch expansion. The dentoalveolar effects of mandibular expansion have been acknowledged in some literature; however these effects have not been documented (Walter, 1953; Reidel, 1960; Shapiro, 1974; Little et al., 1990; Osborn et al., 1991; Weinberg and Sadowsky, 1996; Housley et al., 2003; Tai et al., 2010).

The current prospective clinical study compared the dentoalveolar effects of two designs of mandibular expanders using CBCT. The selected fixed designs were proposed to require minimal patient compliance (William and Sim, 1993; Handelman, 2012) Moreover, the current patients ranged in age from 12 to 14 years with a mean age of 13.4 ± 0.5 years. This age range was selected because it was suggested that more favorable biological response is expected during adolescent time. A narrow age range was selected to reduce as possible the effect of age on the quality of

Table 2
Descriptive statistics and test of significance of the expansion effects in modified Williams' mandibular expander (group A) and two-arm fixed mandibular expander group (group B).

Variable	Before expansion			After expansion			Paired <i>t</i> -test			
	Mean	SD	SE	Mean	SD	SE	Difference Mean	<i>t</i> -value	<i>P</i> -value	Significance
Group A (n = 8)										
IMW	45.7	2.51	0.95	51.0	3.49	1.32	5.30	8.29	0.000	***
IPW	37.0	3.78	1.43	41.2	3.75	1.42	4.19	6.59	0.001	***
ICW	28.6	1.53	0.58	30.1	2.04	0.77	1.50	5.19	0.002	**
AP	72.8	2.81	1.06	77.4	4.29	1.62	4.57	7.37	0.000	***
OMBW	55.5	4.27	1.61	56.0	4.84	1.83	0.54	1.96	0.098	NS
Group B (n = 8)										
IMW	42.4	3.26	1.09	49.2	3.30	1.10	6.88	9.51	0.000	***
IPW	33.7	2.81	0.94	40.7	3.13	1.04	7.01	14.9	0.000	***
ICW	25.8	1.30	0.44	28.9	2.31	0.77	3.17	5.56	0.001	***
AP	69.7	3.17	1.06	77.9	4.43	1.47	8.27	7.67	0.000	***
OMBW	56.5	5.00	1.67	56.9	4.83	1.61	0.46	1.67	0.134	NS

n = number, SD = standard deviation, SE = standard error, *p* = probability level, ** = $p \leq 0.01$, *** = $p \leq 0.001$, NS = Non-Significant = $p > 0.05$, IMW = Intermolar width, IPW = Inter-premolar width, ICW = Intercanine width, AP = Arch perimeter, OMBW = Outer mandibular body width.

Table 3Comparison of changes in dentoskeletal measurements (T1-T2) between the two expansion groups using independent sample *t*-test.

Variable	T1- T2 difference in modified Williams expander group (n = 8)			T1- T2 difference in two-arm fixed mandibular expander group (n = 8)			Mean difference	<i>t</i> -value	<i>P</i> -value	Significance
	Mean	SD	SE	Mean	SD	SE				
IMW	5.30	1.69	0.64	6.88	2.17	0.72	1.58	1.59	0.134	NS
IPW	4.19	1.68	0.64	7.01	1.40	0.46	2.82	3.58	0.04	*
ICW	1.50	0.76	0.29	3.17	1.71	0.57	1.67	2.62	0.03	*
AP	4.57	1.64	0.62	8.27	3.23	1.07	3.71	2.97	0.01	*
OMBW	0.54	0.73	0.28	0.46	0.46	0.15	0.08	0.23	0.81	NS

T1 = before expansion, T2 = immediately after expansion, SD = standard deviation, SE = standard error, *p* = probability level, NS = Non-Significant at $p > 0.05$, * = significant at $p \leq 0.05$. IMW = Intermolar width, IPW = Inter-premolar width, ICW = Intercanine width, AP = Arch perimeter, OMBW = Outer mandibular body width.

expansion and to minimize the deleterious effects on periodontium. As well, the patients had a mild to moderate amount of crowding in both arches and both types of mandibular expanders have successfully relieved this crowding (Fig. 7 and 10).

Analogous evaluations have been attempted in previous studies. However, the majority of them were limited to using model analysis and/or the 2D radiographic evaluation with the overlaying soft tissue interferences (O'Grady et al., 2006; Sabuncuoglu et al., 2011; Sharada et al., 2011; Handelman, 2012; Kravitz, 2014). In the present research, measurements CBCT images have been used to overcome the limitations of conventional posteroanterior cephalometric radiograph in transverse width measurements, including the inability to reproduce the reference landmarks, intercanine, inter-premolar and intermolar widths due to superimposition of posterior segment. This method of assessment is suggested to provide better quantitative analysis and exactness of the measured parameters (Lagravere et al., 2008; Baysal et al., 2011).

4.1. Intermolar width

The intermolar width has been the most frequent measure of posterior arch dimension following expansion (Baysal et al., 2011). In the current study, comparison of T1 and T2 intermolar width measurements has indicated that both expanders produced significant changes. The intermolar width increased by an average of 5.30 mm in modified Williams mandibular expander group (group A) and 6.88 mm in two-arm fixed mandibular expander (group B) with a jack screw opening of 8 mm. However, this change was statistically non-significant between the two groups (Tables 2 and 3).

Regarding the amount of mandibular first molar expansion, the current results concur with the data of Tai et al., who assessed the CBCT changes of mandibular 1st molars in patients treated with removable Schwarz expander at different levels. They reported that, at the crown level, the mean width increase was 5.41 mm, the mean CEJ width increase was 4.39 mm and the mean root width increase was 2.40 mm (Hamada et al., 2002; Tai and Park, 2010; Tai et al., 2011). However, they found that the Schwarz expander produced significant tipping by about 8.5° for the right first molar and 8.9° for the left first molar.

Additionally, the present results are consistent with those of O'Grady et al. (2006) who reported a mean increase in intermolar width of 3.1 mm by using a removable mandibular Schwarz expander during early mixed dentition. Even though, these changes were somewhat smaller than the present one, their findings are still in agreement with the current results. The slight observed difference may be due to using a different type of expander and the younger age range of their sample.

In addition, the current findings are parallel to those of Housley et al. (2003) who investigated the effects of fixed mandibular lingual expander with coil spring after 3.5 ± 1.3 months using

cephalometric radiographs and study model analysis in a sample with a mean age of 12.5 ± 1.8 years. They observed significant den-toalveolar inclination and an increase in mandibular first molar width by 0.92 ± 1.64 mm. However, these results were much smaller than those of the current study that might be attributed to the 2D methods of evaluation and their different design of the mandibular expander. Likewise, Maki et al. (2006) reported an increased intermolar width of 5 mm and 5.89 ± 1.66 mm in patients with primary and mixed dentitions, respectively. In spite of dissimilar age range, type of expander, and treatment duration, these findings are in agreement with the present results.

A few number of studied evaluated particular designs of fixed mandibular expanders such as Transverse TransForce (Clark, 2005; Sharada et al., 2011) Arnold expanders (Kravitz, 2014) (include nickel titanium springs), and Trombone fixed expander (utilizes tube-sliding principle) (Sabuncuoglu et al., 2011). They used conventional 2D radiographs and dental model analysis and reported significant increase in intermolar width that was smaller than that reported in the present work. This might be attributed to the difference in sample size, since these studies were case reports, in addition to the difference in evaluation methods, pre-expansion criteria, expander design, activation protocol, and treatment duration.

4.2. Inter-premolar width

Regarding the changes in the inter-first premolar width, the current results demonstrated a significant increase with both expanders following mandibular expansion (Table 3). However, these changes were more considerable in the two-arm fixed mandibular expander group (7.01 mm) than in modified Williams one (4.19 mm). These findings are in harmony with those of Housley et al. (2003) and Handelman (2012) who reported a significant increase in inter-premolar width of 2.11 mm and 3.3 mm with a comparable fixed mandibular expander, respectively. However, these changes are smaller than those reported with the present expander design (group B). Once more, this could be due to differences in sample size, somewhat different design of expander, methods of assessment, and patient's age. In the report of Handelman (2012), among 47 patients treated with different appliances, the author used the mandibular expander for only 2 patients aged 33 and 50.8 years.

4.3. Intercanine width

The intercanine width in the present study was significantly increased in both groups. The mean increase observed in modified Williams' expander group was 1.5 mm whereas in two-arm fixed mandibular expander one it was 3.17 mm. These changes were more significant with the two-arm fixed mandibular expander than in modified Williams group (Table 3). These results are in

accordance with several studies although they utilized unlike designs of mandibular expansion, different activation protocols and assessment methodology (Hamula, 1993; Busdrang et al., 2001; Housley et al., 2003; Tai and Park, 2010; Sabuncuoglu et al., 2011). Their findings are comparable with the present study for Williams expander group; however it was smaller than those of the two-arm fixed mandibular expander group.

4.4. Arch perimeter

In the present investigation, the arch perimeter increased significantly in both mandibular expansion groups. Interestingly, the mean increase in arch perimeter was 4.57 mm in modified Williams expander group and 8.27 mm in two-arm fixed mandibular expander one, which might reflect the superiority of the this design (Table 3). Several studies have also reported an increase in the arch perimeter following mandibular expansion (Weinberg and Sadowsky, 1996; Housley et al., 2003; O'Grady et al., 2006; Tai et al., 2010, 2011; Sabuncuoglu et al., 2011). Nevertheless, such investigations have utilized different expander's design, methods of evaluation, patient's age range, and treatment duration. Housley et al. (2003) and O'Grady et al. (2006) found that mandibular dental arch perimeter was increased by 3.5 mm, and 3.7 mm, respectively. These findings displayed a lesser increase in arch perimeter than the present study that might be attributed to difference in the initial age range, sample distribution and size, design of expansion appliance and factors related to appliance construction and activation.

On the other hand, Sabuncuoglu et al. (2011) observed an increase in mandibular dental arch perimeter by 7.4 mm following treatment with Trombone expander that activated 1 mm per month. These findings concur with the present study regarding two-arm fixed mandibular expander group but showed greater mean changes in arch perimeter than the modified Williams expander one.

4.5. Skeletal effects of mandibular expanders

Concerning skeletal effects on mandibular bodies, the results of the current study showed nearly a comparable effect of both expanders. The outer mandibular body width (measured at 13 mm below alveolar crest) was increased by 0.54 mm and 0.46 mm in modified Williams and two-arm fixed mandibular expansion groups, respectively. However, these changes were not significant between both groups. Based on these results, it could be verified that the mandibular bodies were not affected by both appliances in spite of the observed dentoalveolar expansion.

The transverse dimension has been a focus of controversy among orthodontists. A key issue debated has been the possibility of altering the skeletal width of the maxilla or the mandible through either orthodontic or orthopedic treatment (Walter, 1953; Schiffman and Tuncay, 2001; Kusnoto et al., 2002). Although skeletal effects of expansion could be obtained in the maxillary arch, in mandibular arch, the expansion treatment has been thought to be less effective and less stable in the long term (Tai et al., 2010). Several mandibular lingual expansion appliances have been utilized to increase the transverse dimension of the mandibular arch; unfortunately, none of them succeeded in producing a skeletal outcome (Motoyoshi et al., 2005; Wendling et al., 2005; Tai et al., 2010, 2011; Tai and Park, 2010).

Through CBCT assessment of removable Schwarz expander, the results of Tai et al., were closer to the present study regarding skeletal effects of mandibular expansion appliances (Tai et al., 2010, 2011; Tai and Park, 2010). Although the mandibular arch expanded mainly by tooth inclination, the distance between the root tips were also increased. Others have reported dental changes in the mandible concurrent with maxillary expansion, which has been referred to as

spontaneous dental decompensation (Tai and Park, 2010). Still, no report has shown any change of the mandibular basal structures. Additionally, Hamada et al. (2002) reported that the alveolar process changed with mandibular expansion in an animal experiment. On the other hand, no effect was induced by the Schwarz appliance in the alveolar base and mandibular bodies.

In contrast, others reported that the mandibular transverse skeletal dimension significantly increased with lip bumper therapy. This disagreement with the present results could be due to different appliance used, different methods of 2-dimensional cephalometric evaluation, and different patient's age that may influence their results (Osborn et al., 1991; Vanarsdall et al., 2004).

It is important to note that during the period of present investigation, certain difficulties were encountered. The position of expander's screw, especially in the two-arm fixed mandibular expansion group resulted in many complications for the patients regarding different functions such as speech, eating and chewing in first days following expander's insertion. Moreover, all patients experienced pain in first two weeks and some of them suffered from a soft tissue swelling and inflammation around the appliance that was attributed to position of expander and difficulty in maintaining a good oral hygiene. The above-mentioned difficulties could explain the dropped out 4 patients from the study.

In the current study, the effects of two different designs of mandibular expansion appliances were evaluated in cases of Angle Class I malocclusion only, in an effort to standardize the pre-treatment characteristics of both groups as possible. However, assessment was focused for the immediate or short-term dentoalveolar changes. Future studies will include long-term data including post-expansion measurements. Moreover, it could be important to note that careful interpretation of the results should be considered, because the sample size in current study was relatively small. It is recommended to carry out further randomized clinical trials with a large sample size and different age range to investigate the dentoalveolar effects of both expanders with a more comfortable design and any possible gender difference.

Yet, inclusion of a control group in the present study with a similar skeletal pattern as the treated sample was not possible owing to ethical concerns. However, observation of untreated patients would be important to differentiate between changes added by the natural skeletal growth from those obtained by treatment. It is suggested to include a control group to exclude more or less growth change of the mandible.

5. Conclusion

Within the limitations of the present study, the following conclusions could be drawn:

1. Both fixed mandibular expanders produced equivalent dentoalveolar effects that were more evident with two-arm fixed mandibular expander than the modified Williams one regarding arch perimeter, inter-premolar, and intercanine widths.
2. Even though, both designs enhanced mandibular transverse dental dimensions, however, they were unsuccessful to create any considerable skeletal effects.
3. The current fixed mandibular expanders were effective for improvement of mandibular arch crowding and offered new possibilities for arch development in combination with fixed appliances Baysal et al., 2011.

Declaration of Competing of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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