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TRABALHOS MAIS RELEVANTES

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Comparison of condylar displacement between three biotypological facial groups by using mounted models and a mandibular position indicator

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Objective: Facial-type—associated variations in diagnostic features have several implications in orthodontics. For example, in hyperdivergent craniofacial types, growth imbalances are compensated by displacement of the condyle. When diagnosis and treatment planning involves centric relation (CR), detailed knowledge of the condylar position is desirable. The present study aimed to measure condylar displacement (CD) between CR and maximum intercuspation in three facial types of an asymptomatic orthodontic population. **Methods:** The study was conducted in 108 patients classified into three groups of 36 individuals each (27 women and 9 men; mean age, 20.5 years), based on the following facial patterns: hyperdivergent, hypodivergent, and intermediate. To quantify CD along the horizontal and vertical axes, the condylar position was analyzed using mounted casts on a semi-adjustable articulator and a mandibular position indicator. The Student *t*-test was used to compare CD between the groups. **Results:** Vertical displacement was found to be significantly different between the hyperdivergent and hypodivergent groups ($p < 0.0002$) and between the hyperdivergent and intermediate groups ($p < 0.0006$). The differences in horizontal displacement were not significant between the groups. In each group, vertical CD was more evident than horizontal displacement was. **Conclusions:** All facial types, especially the hyperdivergent type, carried a significantly high risk of CD. Therefore, the possibility of CD should be carefully evaluated and considered in the assessment of all orthodontic cases in order to accurately assess jaw relationships and avoid possible misdiagnosis.
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Key words: Cephalometrics, Centric relation, Condylar displacement, Growth evaluation, Maximum intercuspation

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INTRODUCTION

Adaptive condylar displacement (CD) refers to the shift from a seated condylar position or centric relation (CR) to a condylar position corresponding to maximum intercuspation (MI). Consequently, CD may have diagnostic and clinical implications.[1-4] Orthodontists who follow the functional occlusion principles published by Roth[1] accept that when the normal proportional relation of 0.75 between the posterior cranial base (sella-articulare) and ramus height (articulare-gonion) increases to a value of 1.0, the risk of an adapted intra-articular condyle shift increases, making the assessment of the mandibular position clinically pertinent.

This is, however, a controversial subject.[5] Despite the consensus regarding dual bites as an alternative to surgical treatment in adults, for diagnostic and treatment purposes, evaluation of the orthopedic position of CR is the most physiologically appropriate[6]; in fact, it is recommended as the morphofunctional aim of any orthodontic occlusal treatment.[1,7] Since CR is the most consistent and reproducible positional reference,[8] accurate studies of dental and maxillomandibular relationships are dependent on CR assessment. Splint therapy allows stabilization of the condyle in CR for therapeutic or diagnostic purposes, prior to orthodontic treatment.[9]

In patients with a hyperdivergent facial type, CD represents a mechanism of compensation to posterior-anterior facial imbalance. Since the mandible articulates with the cranial base, vertical growth of the anterior face should ideally match posterior facial growth.[10] However, if this does not occur, the condyle can rotate in the temporomandibular joint or slide vertically or anteroposteriorly in order to adjust to the imbalance.[1-3,8,11,12] An increased joint space could lead to articular instability since the articular disc can lose its tight apposition between the condyle and cranial base and easily dysfunction.[1] Previous studies have shown that posterior mandibular displacement leads to temporomandibular disorders (TMD)[6] and morphological changes.[13] Additionally, studies focusing on the relation between facial configuration and TMD indicate an association of hyperdivergency with TMD.[14,15]

The assessment of the normal condyle-fossa relationship is also debatable. In normal samples, tomographic imaging reveals a wide variability in condylar position,[16,17] and intra-articular joint damage has been detected in asymptomatic patients.[18] More recently, a study analyzing clinical data from magnetic resonance imaging and limited cone-beam computed tomography reported that the variability in CD is limited in normal individuals, and quantitative standards for the clinical evaluation of the condylar position were suggested.[19]

Since the condylar axis can be widely influenced by occlusion,[2,4] it is of paramount importance to determine its displacement in three-dimensional space.[20] Conventional radiological examinations do not provide accurate and valuable information in this regard;[16,17] consequently, a mandibular position indicator (MPI) and other similar tools have been introduced to allow quantification of the three-dimensional displacement of the condylar axis.[3,21,22]

The significance and clinical relevance of identifying and integrating CD in orthodontic diagnosis and treatment planning, when it surpasses a threshold of 2 mm in the horizontal or vertical axis has been established.[2,4,7] In addition, CD of significant magnitude occurs frequently in the asymptomatic population[4,23] and represents an attempt to compensate for disproportions. Accurate diagnosis requires the assessment of occlusal interferences and skeletal relationships, without the influence of the neuromuscular system. Despite reasonable evidence of facial configurations being more prone to articular instability, data related to the subject is scarce and conflicting. Girardot[12] reported a more significant CD in hyperdivergent facial morphologies, whereas Burke et al.[24] found diminished upper articular joint spaces in the same facial type. In contrast, Hidaka et al.[11] found no relationship between facial type and condylar position.

Therefore, the aim of this observational study was to clarify the above-mentioned conflicting findings and throw more light on the relationship between facial type and condylar position. Therefore, CD was measured in the hyperdivergent facial type and compared with those of the hypodivergent and intermediate types. The hypothesis of this study was that CD was greater and more frequent in the hyperdivergent facial type.

MATERIALS AND METHODS

The research protocol was reviewed and approved by the Ethical Committee of the Faculty of Dental Medicine of University of Porto (#20071210). The study sample comprised 108 Caucasian asymptomatic individuals, 81 women and 27 men, aged between 12 and 46.2 years, with a mean age of 20.5 years. Data used for the study included information from anamnesis and clinical examinations, lateral cephalograms in MI, study casts and clinical records for CR mounting on a SAM® 2P semi-adjustable articulator (Figure 1), and complete MPI registrations (SAM®; Präzisionstechnik GmbH, München, Germany) (Figures 2 and 3).

The subjects were selected based on the clinical records of 742 consecutive first presentations at an orthodontic private practice. Based on the study criteria, we included individuals, who, during the preceding

Figure 1. Study casts mounted in centric relation on an SAM® 2P semi-adjustable articulator.

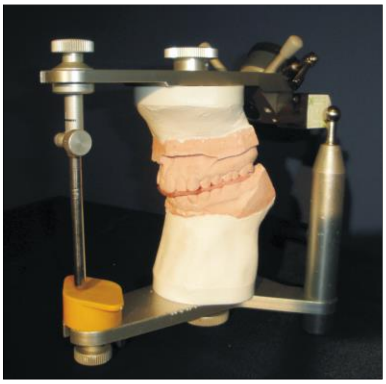

Figure 2. A mandibular position indicator attached to a cast of the upper arch, and maximum intercuspation wax registration interposed between the two casts in order to register the corresponding condylar position.

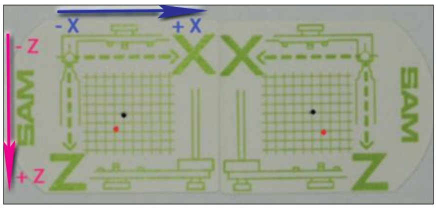

Figure 3. A mandibular position indicator registration: black and red dots represent right and left condylar positions corresponding to centric relation and maximum intercuspation, respectively. Axial displacements are as follows: for the right condyle, −0.9 mm in XX' and +1.8 mm in ZZ'; and for the left condyle, −1.3 mm in XX' and +2.2 mm in ZZ'.

5 years, had neither suffered facial trauma nor been subjected to orthodontic treatment. For the selection of asymptomatic individuals, the Helkimo Index[25] was used, and only patients with codes Di0 or Di1 were chosen. To avoid the effect of distortions related to growth on condylar position registration,[26] patients in stages 4, 5, or 6 of skeletal maturation according to the cervical vertebral maturation method[27] were considered for this study. Subjects with a negative vertical CD ($\Delta Z < 0$) on the MPI reading were excluded.[8] To classify the subjects into groups based on distinct facial patterns, two matched factors of Jarabak's cephalometric analysis were used.[28] Subjects with the posterior facial height (PFH; sella-gonion)/anterior facial height (AFH; nasion-menton) ratio ≤ 59% and the lower gonial angle (LGA; nasion-gonion-menton) ≥ 76° were grouped into the hyperdivergent group. The hypodivergent group comprised subjects with the PFH/AFH ≥ 65% and LGA ≤ 69°. In the third intermediate group, the PFH/AFH was 59−65% and LGA was 69°−76°. Thus, based on the skeletal facial features, 3 matched groups containing 36 individuals each, 27 women and 9 men, were generated. A single operator with 5 years' experience was involved in all the clinical and laboratory experiments. A single arbitrary face bow and SAM® 2P articulator were used for mounting the stone casts (Velmix; Kerr® Manufacturing Co., Romulus, MI, USA) with the CR wax records (DeLar Bite Registration Wax; DeLar® Corporation, Lake Oswego, OR, USA). Horizontal and vertical CD were evaluated using a single MPI and MI wax records (Moyco® Industries Inc., Philadelphia, PA, USA).

The MI records were obtained before CR registration, by asking the patient to bite firmly with the teeth in MI. After being chilled in ice water, record accuracy was checked in the mouth. For CR registration, Roth's power centric technique[8] was performed immediately after neuromuscular deprogramming with the patient relaxed and reclined at 45°. Two cotton rolls were interposed between the dental arches for a minimum of 10 minutes. CR bite registration was performed in two stages. With the softened wax, the anterior section was obtained by guiding the mandible during closure in order to avoid protrusion. The cusps responsible for premature inter-arch contact were maintained 2-mm apart. Next, the anterior wax was hardened in ice water and then interposed between the arches simultaneously

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with the posterior softened wax section in order to accomplish the registration. The mandible was guided during closure, and when the anterior teeth fit into the corresponding anterior wax indentations, the patient was asked to bite firmly. With this technique, as the posterior wax section was softened, muscular strength helped to adjust the vertical intra-articular condylar position.[29]

For wax registration of MI, the corresponding position of the condyle was registered with the MPI, and its accuracy was checked after every 5 registrations. A micrometre (Nr.H 114834; Carl Zeiss® AG, Oberkochen, Germany) was used to measure the horizontal (XX') and vertical (ZZ') CD components, and each measurement was repeated three times. The average of two close values was considered the final value.

The methodology applied in this study had been checked at the beginning of data collection, and the Lauritzen technique was used to assess the accuracy of CR records and laboratory procedures.[28]

To evaluate intra-operator error, the reproducibility of CR records, mounting procedures, accomplishment and measurement of MPI registrations, and cephalometric measurements were performed by the same operator during two different sessions that were one-week apart. For these procedures, 5 patients were randomly selected, and the clinical measurements were obtained twice during each session, resulting in the need for two articulator-mounting sets for each subject. During the second session, two new CR records were used to remount the mandibular cast to each previously articulator mounting. The procedure was repeated twice for each mounting set. The new MI records allowed comparisons of the MPI registrations. The results were systematized into tables for analysis.

Statistical analysis

For direct measurements, errors were analyzed using the analysis of variance test. According to the following equation, the standard error (SE) was obtained depending on the sample variance (SV):

$$SE = \pm\sqrt{SV} = \pm\sqrt{\frac{1}{N-1}\sum_{i=1}^{N}(X_i-\bar{X})^2};$$

where N refers to the sample size; X_i, dimension observed for measurement I; and $\bar{x}$, mean value of observations.

For indirect measurements, the following equation of error propagation was applied:

$$\sigma = \pm\sqrt{\left(\frac{\partial F}{\partial X_1}\right)^2 \cdot SE_1^2 + \left(\frac{\partial F}{\partial X_2}\right)^2 \cdot SE_2^2 + \cdots + \left(\frac{\partial F}{\partial X_M}\right)^2 \cdot SE_M^2};$$

where X_j refers to the dimension measured (j = 1,..., M); SE_j, standard error associated with X_j; and $X = F(X_1, X_2, \ldots X_M)$, dimension based on dimensions of X_j.

To determine the direction and magnitude of any condylar shift, an initial descriptive study of data was performed, which was followed by a comparative study. A Student *t*-test, with 0.05 level of confidence, was used to analyze the differences in CD along the vertical and horizontal planes among the three groups.

RESULTS

Analysis of the measurement errors of the different assessments showed an error margin < 4.5%, which is considered acceptable.[28]

No negative vertical CD ($\Delta Z < 0$) on the MPI readings was registered. In the total sample (n = 216 condyles, Table 1), horizontal displacement CD-XX' ≥ 2 mm and CD-XX' ≤ −2 mm occurred in 14/216 condyles (6.49%), whereas vertical displacement CD-ZZ' ≥ 2 mm occurred in 60/216 condyles (27.77%). Therefore, CD-XX' ≤ −2 mm occurred in hyperdivergent and intermediate groups in 2.78% and 4.17% of cases, respectively, whereas CD-XX' ≥ 2 mm was more frequent in the hypodivergent group (8.33%). The most frequent displacements were observed in a posterior direction in the hyperdivergent and intermediate groups. Along the ZZ' axis, the frequency of CD-ZZ' ≥ 2 mm was high in all the groups, with registered values of 34.72%, 23.61%, and 25.0%, respectively, in the hyperdivergent, hypodivergent, and intermediate groups.

The values of horizontal displacement ranged from −3.5 mm to 4 mm, whereas vertical displacement ranged from 0 to 4.1 mm (Table 2).

To assess the effective magnitude of CD, the displacements along the XX' axis were summed, and the absolute values were considered (Table 3). A comparison of the magnitude of CD among the three groups showed more extensive CD in the hyperdivergent group (118.7 mm) along the ZZ' axis and in the hypodivergent group (67.53 mm) along the XX' axis. The magnitude of horizontal displacement was approximately similar in all the groups, varying from 53.5 mm in the intermediate to 67.53 mm in the hypodivergent group. Results of the *t*-test showed that vertical displacement was statistically different between hyperdivergent and hypodivergent groups ($p < 0.0002$) and hyperdivergent and intermediate groups ($p < 0.0005$). No significant difference in horizontal displacement was noted between the groups ($p < 0.071$).

DISCUSSION

Taking into account the obvious differences between the facial groups, the anatomo-physiological features

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Table 1. Number and percentage of condyles (72 condyles per group) displaced along the horizontal (XX') and vertical (ZZ') axes

CD (mm)	Hyperdivergent (n = 72)		Hypodivergent (n = 72)		Intermediate (n = 72)	
	XX'	ZZ'	XX'	ZZ'	XX'	ZZ'
CD ≤ −2	2 (2.78)	-	0	-	3 (4.17)	-
−2 < CD < 0	39 (54.17)	-	20 (27.78)	-	30 (41.67)	-
CD = 0	4 (5.56)	7 (9.72)	13 (18.06)	25 (34.72)	17 (23.61)	15 (20.83)
0 < CD < 2	26 (36.11)	40 (55.56)	33 (45.83)	30 (41.67)	20 (27.78)	39 (54.17)
CD ≥ 2	1 (1.39)	25 (34.72)	6 (8.33)	17 (23.61)	2 (2.78)	18 (25)

Values are presented as number (%).
CD, Condylar displacement.

Table 2. Mean values (SD) and minimum and maximum (mm) horizontal (XX') and vertical (ZZ') displacements in the three groups

Type	Mean (SD)			Minimum (mm)		Maximum (mm)	
	XX' (SD)	ǀXX'ǀ (SD)*	ZZ' (SD)	XX'	ZZ'	XX'	ZZ'
Hyperdivergent	−0.09 (1.03)	0.84 (0.60)	1.65 (0.83)	−2.15	0	4	3.3
Hypodivergent	0.44 (1.14)	0.94 (0.78)	1.05 (1.10)	−1.95	0	3.65	4.1
Intermediate	−0.07 (1.09)	0.74 (0.80)	1.16 (0.91)	−3.5	0	3.45	3.1

SD, Standard deviation.
*ǀXX'ǀ (SD) means considering absolute values.

Table 3. Summation of displacements along the horizontal (XX') and vertical (ZZ') axes (mm), and the corresponding mean values in the three groups

x (mm)	XX'			ZZ'		
	Hyperdivergent	Hypodivergent	Intermediate	Hyperdivergent	Hypodivergent	Intermediate
≤ −2	−4.2	0	−8.55	-	-	-
−2 < x < 0	−29.4	−17.95	−20.65	-	-	-
x = 0	0	0	0	0	0	0
0 < x < 2	22.94	32.53	18.25	55.3	28.55	40.9
≥ 2	4	17.05	6.05	63.4	46.9	42.55
Sum (absolute values)	60.54	67.53	53.5	118.7	75.45	83.45
Mean	0.84	0.94	0.74	1.64	1.05	1.16
Standard deviation	0.60	0.78	0.80	0.83	1.10	0.91
t-test (*p*-value)						
Hyperdivergent - Hypodivergent			0.20279			0.00017*
Hyperdivergent - Intermediate			0.20460			0.00053*
Hypodivergent - Intermediate			0.07090			0.25624

x, Horizontal condyle displacement.
*$p \le 0.05$.

of hyperdivergent facial types may be the reason that condyle function is prone to articular instability. This study aimed to test the hypothesis that CD was greater and more frequent in the hyperdivergent facial type.

The three groups examined in this study represented individuals with clear hyperdivergent (dolicofacial) features, hypodivergent (brachifacial) features, and with intermediate qualities. The intermediate group included mesofacial subjects and individuals with dolicofacial or brachifacial tendencies.

The clinically significant CD threshold of 2 mm has diagnostic importance,[2,4,7] leading to clinical implications.[3] In fact, it is recommended to use this information to convert cephalometric tracings when displacements of ≥ 2 mm are found along at least one of the axes. A smaller magnitude of CD yields none or no significant changes in traditional cephalometric measurements.[2] In the 216 condyles analyzed in this study, CD ≥ 2 mm was found in approximately 30% of the cases (CD-ZZ' ≥ 2 mm in 27.77, CD-XX' ≥ 2 mm, and CD-XX' ≤ −2 in 6.49; Table 1). In general, these results are in agreement with those of previous studies, although some discrepancies in frequencies were found.[2,4,11,12,23,26] These differences may be related to the criteria used for sample selection, neuromuscular deprogramming methodology, or CR recording techniques. The use of hard anterior stops for CR bite registration can duplicate the frequency of CD ≥ 2 mm.[4,23]

It was suggested that a more efficient deprogramming technique could result in a higher frequency of CD in the three groups. Ideally, complete deprogramming should be performed before CR registration; however, it is not practical in daily orthodontic practice, and the method of interposition of cotton rolls for 10 minutes was used in this study. Therefore, the registrations obtained represent the most superior and anterior positions of the condyles in the joint the clinician was able to take during the moment of clinical procedure in the asymptomatic patients. However, differences in the effective CR position can be noted in some cases.

Posterior displacement was slightly more frequent (43.52%) than anterior displacement (40.74%). The higher frequency of posterior condylar shift is consistent with previous studies and is related to posterior occlusal prematurity guiding the mandible in this direction.[2,3,11,12,23]

The analysis of CD and its comparison between the three groups showed that CD was more frequent in the hyperdivergent group, corroborating the initial hypothesis. This group, considering the number of condyles with CD ≥ 2 mm, presented a frequency of vertical displacement of 34.72%, which is higher than the 28.8% reported by Girardot.[12] With respect to the absolute values of horizontal displacement, the hyperdivergent group registered 4.17% in contrast to 24.2% reported by Girardot. The great majority of XX' displacements were between −2 and 2 mm. Therefore, in the hyperdivergent group, 54.17% of displacements occurred in the posterior direction with magnitudes between −2 and 0 mm. In contrast, Hidaka et al.[11] found vertical and horizontal CD ≥ 2 mm of 14% and 2%, respectively. However, their study sample was inherently different from that of our study.

In the hyperdivergent and intermediate groups, high frequencies were recorded in the posterior direction (56.95 and 45.84%, respectively); in contrast, in the hypodivergent group, the higher frequency was in anterior direction (54.16%). The frequencies of posterior, anterior, and vertical displacements in the intermediate group were midway between the other two groups. These findings may be related to the differences in facial configurations, i.e., the distinct patterns of muscle activity and behavior facing fulcrums. In fact, in the hypodivergent biotype, the elevator muscles are stronger and aligned vertically across the first molars, being positioned more anteriorly than those in the hyperdivergent group. This leads to the exertion of more force in the anterior direction.

The magnitude of means (absolute values) along XX' was 0.84 mm, 0.94 mm, and 0.74 mm; along ZZ', it was 1.65 mm, 1.05 mm, and 1.61 mm, respectively, in the hyperdivergent, hypodivergent, and intermediate groups (Table 2). Girardot[12] found mean values of 1.21 mm for hyperdivergent and 0.66 mm for hypodivergent along XX' and 1.7 mm for hyperdivergent and 1.2 mm for hypodivergent along ZZ'. The mean values that closely matched those of our study were those related to the vertical plane and may be related to the method used to record CR. The hard anterior stop used in Roth's power centric technique supports the generation of a more seated condylar position, as it is the internal strength of the masticatory muscles that positions and vertically seats the condyles in the fossae.[3,8,29] Therefore, the registration of the vertical axis shift is less dependent on individual operator technique. Previous studies,[4,23] with deprogrammed subjects, found greater vertical displacements and established that more efficient deprogramming procedures can allow assessment of greater CD mean values, particularly along the vertical axis.[26] However, other studies contradicted these results. Burke et al.[24] studied the association of condyle features of Class II preadolescent patients with facial configurations and found correlations between diminished superior joint spaces and vertical patterns. These differences may be related to intrinsic variations in the samples and to a lack of functional examination of the subjects. In fact, the neuromuscular system can display two kinds of responses to occlusal fulcrums. One displaces the condyle in the joint to achieve maximal occlusal contact, whereas the other is the appearance of an anterior open bite, characterized by only posterior teeth contacts, with the CD being reduced in this situation. Moreover, Hidaka et al.[11] did not find any relation between facial patterns and CD. Their evaluation was performed using the mandibular plane

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angle and disregarded the individual's skeletal maturity and functional examination, which are factors that can strongly compromise condylar shifts.

In this study, greater vertical displacement was observed in the hyperdivergent group: CD was found to be 1.57 and 1.42 times greater than that in the hypodivergent and intermediate groups (Table 3). Horizontal displacements were closer and varied from 53.5 mm to 75.45 mm. In all the groups, the magnitude of vertical shifts was always higher than that of the horizontal shifts, which is in agreement with the findings of previous studies.[2,4,11,12,23,26] This finding shows that, although CD is frequent in all three facial groups, a higher risk of shift is observed in the hyperdivergent group, which is in agreement with Girardot's results.[12] It is important to note that both studies reported significant differences in CD along the ZZ' axis (present study: hyperdivergent-hypodivergent groups, $p < 0.0002$ and hyperdivergent-intermediate groups, $p < 0.0005$; Girardot study: hyperdivergent-hypodivergent groups, $p < 0.008$), but for horizontal displacements only Girardot, reported this finding (hyperdivergent-hypodivergent groups, $p < 0.0001$). In the present study, for XX' axis displacements, no significant differences were observed, but a trend could be suggested between the hyperdivergent and intermediate groups ($p < 0.071$).

Although referring to asymptomatic samples, both studies indicate that the physical features of the hyperdivergent group predispose it to a higher risk of developing TMD.[14,15] However, it is important to note that the transverse shift was not considered, despite being recognized as an etiologic factor of TMD.[30] Therefore, this potential relationship needs to be investigated further.

The results of this study suggest that orthodontic treatment planning related to the CR must involve assessment of the condyle shift. However, it is not possible to quantify displacement clinically, directly in the mouth[4,8,23] or by using MI hand-assembled casts. When detected, occlusal discrepancy provides no information regarding the nature of CD.[4,17] This study especially emphasizes on the vertical component of CD, which is even more difficult to detect. The MPI instrumentation procedure permits easy and accurate[3,8,21,22] quantification of CD and allows taking this data into account when planning treatment, introducing diagnostic clinical implications, and reducing misdiagnosis.[2,4]

In contrast with MI hand-assembled casts, articulator-mounted cast analysis can display cases with different features and with a distinctly difficult level of treatment. The discrepancy can be altered not only in the sagittal plane, with differences in overjet and molar relationship, but also in the transverse and vertical planes.[2,4] The analysis of the initial occlusal contacts can support differential diagnosis of skeletal and dentoalveolar openbite or crossbite. When approaching transversal problem the consideration of interocclusal type of contacts, the cuspid to cuspid or cuspid to inclined slope contact, can help to discard the skeletal nature of malocclusion. Additionally, simulation of a true hinge axis (vertical mandibular autorotation) can provide information regarding features of the Class II malocclusion. In case of a vertical Class II malocclusion, overjet can be corrected when posterior occlusal interferences are eliminated; however, in case of a sagittal Class II malocclusion, overjet remains, and a different treatment plan is required. The method described in this study can reveal important information with regard to vertical malocclusion, which is not provided by other diagnostic techniques, causing frequent failure in occluso-functional orthodontic treatment.

Overall, since a significant magnitude of CD occurs in all the three asymptomatic groups and since it is not possible to predict the condylar position, it is crucial to mount models in CR as a routine diagnostic procedure.[2,4] Our study clearly shows that in patients with a hyperdivergent facial pattern, the risk of misdiagnosing an orthodontic case is approximately 30%, when condylar position in not assessed.

CONCLUSION

The findings of this study show that the hyperdivergent group has a significantly greater CD along the vertical axis than do the two other groups. No differences were found in horizontal displacement between the groups. Therefore, if CD is not considered during the assessment of orthodontic cases, the risk of misdiagnosis is high for all facial types, being significantly higher in patients with the hyperdivergent facial type.

REFERENCES

1. Roth RH. Functional occlusion for the orthodontist. J Clin Orthod 1981;15:32-40, 44-51 contd.
2. Shildkraut M, Wood DP, Hunter WS. The CR-CO discrepancy and its effect on cephalometric measurements. Angle Orthod 1994;64:333-42.
3. Crawford SD. Condylar axis position, as determined by the occlusion and measured by the CPI instrument, and signs and symptoms of temporomandibular dysfunction. Angle Orthod 1999; 69:103-15.
4. Cordray FE. Three-dimensional analysis of models articulated in the seated condylar position from a deprogrammed asymptomatic population: a pro-

spective study. Part 1. Am J Orthod Dentofacial Orthop 2006;129:619-30.
5. Rinchuse DJ, Kandasamy S. Myths of orthodontic gnathology. Am J Orthod Dentofacial Orthop 2009;136:322-30.
6. Isberg AM, Isacsson G. Tissue reactions of the temporomandibular joint following retrusive guidance of the mandible. Cranio 1986;4:143-8.
7. Slavicek R. Clinical and instrumental functional analysis and treatment planning. Part 4. Instrumental analysis of mandibular casts using the mandibular position indicator. J Clin Orthod 1988; 22:566-75.
8. Wood DP, Elliott RW. Reproducibility of the centric relation bite registration technique. Angle Orthod 1994;64:211-20.
9. Beard CC, Clayton JA. Effects of occlusal splint therapy on TMJ dysfunction. J Prosthet Dent 1980; 44:324-35.
10. Isaacson JR, Isaacson RJ, Speidel TM, Worms FW. Extreme variation in vertical facial growth and associated variation in skeletal and dental relations. Angle Orthod 1971;41:219-29.
11. Hidaka O, Adachi S, Takada K. The difference in condylar position between centric relation and centric occlusion in pretreatment Japanese orthodontic patients. Angle Orthod 2002;72:295-301.
12. Girardot RA Jr. Comparison of condylar position in hyperdivergent and hypodivergent facial skeletal types. Angle Orthod 2001;71:240-6.
13. Desai S, Johnson DL, Howes RI, Rohrer MD. Changes in the rabbit temporomandibular joint associated with posterior displacement of the mandible. Int J Prosthodont 1996;9:46-57.
14. Ahn SJ, Baek SH, Kim TW, Nahm DS. Discrimination of internal derangement of temporomandibular joint by lateral cephalometric analysis. Am J Orthod Dentofacial Orthop 2006;130:331-9.
15. Hwang CJ, Sung SJ, Kim SJ. Lateral cephalometric characteristics of malocclusion patients with temporomandibular joint disorder symptoms. Am J Orthod Dentofacial Orthop 2006;129:497-503.
16. Pullinger AG, Hollender L, Solberg WK, Petersson A. A tomographic study of mandibular condyle position in an asymptomatic population. J Prosthet Dent 1985;53:706-13.
17. Hatcher DC, Blom RJ, Baker CG. Temporomandibular joint spatial relationships: osseous and soft tissues. J Prosthet Dent 1986;56:344-53.
18. Ribeiro RF, Tallents RH, Katzberg RW, Murphy WC, Moss ME, Magalhaes AC, et al. The prevalence of disc displacement in symptomatic and asymptomatic volunteers aged 6 to 25 years. J Orofac Pain 1997; 11:37-47.
19. Ikeda K, Kawamura A. Assessment of optimal condylar position with limited cone-beam computed tomography. Am J Orthod Dentofacial Orthop 2009; 135:495-501.
20. Cordray FE. The importance of the seated condylar position in orthodontic correction. Quintessence Int 2002;33:284-93.
21. Alexander SR, Moore RN, DuBois LM. Mandibular condyle position: comparison of articulator mountings and magnetic resonance imaging. Am J Orthod Dentofacial Orthop 1993;104:230-9.
22. Levine D, Gosink BB. Ultrasound shows changes in postmenopausal pelvis. Diagn Imaging (San Franc) 1992;14:96-101.
23. Karl PJ, Foley TF. The use of a deprogramming appliance to obtain centric relation records. Angle Orthod 1999;69:117-24.
24. Burke G, Major P, Glover K, Prasad N. Correlations between condylar characteristics and facial morphology in Class II preadolescent patients. Am J Orthod Dentofacial Orthop 1998;114:328-36.
25. Helkimo M. Epidemiological surveys of dysfunction of the masticatory system. Oral Sci Rev 1976;7:54-69.
26. Fantini SM, Paiva JB, Rino Neto J, Dominguez GC, Abrão J, Vigoritto JW. Increase of condylar displacement between centric relation and maximal habitual intercuspation after occlusal splint therapy. Braz Oral Res 2005;19:176-82.
27. Baccetti T, Franchi L, McNamara JA Jr. The Cervical Vertebra Maturation (CVM) method for the assessment of the optimal treatment timing in dentofacial orthopedics. Semin Orthod 2005;11:119-29.
28. Ramalhão MJ. Deslocamento condilar nos tipos faciais hiperdivergentes [Thesis]. Porto: University of Porto; 2009.
29. Wood DP, Floreani KJ, Galil KA, Teteruck WR. The effect of incisal bite force on condylar seating. Angle Orthod 1994;64:53-61.
30. McNamara JA Jr, Seligman DA, Okeson JP. Occlusion, Orthodontic treatment, and temporomandibular disorders: a review. J Orofac Pain 1995;9:73-90.

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REVIEW ARTICLE

Orthodontic wires and its corrosion—The specific case of stainless steel and beta-titanium

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Abstract Efficient orthodontic treatments rely on the perfect design and condition of orthodontic wires. Different wires made from different metals and alloys are available in the market. Although no wire is the best for the entire treatment, they must obey certain properties such as biocompatibility, formability, weldability, low coefficient of friction, resilience, shape memory, low stiffness, and high elastic limit. Even with the buildup of protective layers, wires exposed to the oral environment can suffer corrosion. This gradual destruction of materials resulting from chemical reactions can have several adverse effects such as the release of elements from metals, roughening of the wire surface, and weakening of appliances, which can lead to mechanical failure or even fracture of the orthodontic materials. Corrosion of orthodontic wires is strongly related with the acidic environment of the buccal cavity and the presence of fluoride ions, prophylactic agents, and mouthwash solutions. In this review, a brief description of the different commercially available wires is given. Moreover, the desirable features and properties to be considered in the search for the ideal wire are addressed. Finally, the role of pH and fluoride ions on the corrosion of wires is discussed. Results from different experiences over the years are likewise provided. Special attention is given to stainless steel and beta-titanium wires, because these two alloys are frequently used in the treatment phases in which the wires are exposed to the oral environment for lengthy periods.

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Introduction

Orthodontic treatment is vital for improving and maintaining good oral and dental health, as well as creating an attractive smile that contributes to the development of self-esteem.

The mechanical foundation of orthodontic therapy is based on the principle that stored elastic energy can be converted into mechanical work by tooth movement, and that the ideal control of tooth movement requires the application of a system of distinctive forces properly supported by accessories such as orthodontic wires.[1]

Model wires should be designed to move teeth with continuous forces and should remain elastic.[2] Different wire alloys are available for orthodontic treatment. However, no wire is optimal for orthodontic applications during all the different stages of treatment.[2] The properties required for orthodontic wires depend on their application, but commonly desirable mechanical characteristics include high springback, low stiffness, good formability, and low friction.[3] Nevertheless, several features and properties must be considered in the search for the ideal wire.

Mechanical properties of orthodontic wires

In the past decades, a variety of wire alloys was introduced into orthodontics, leading to improvement of treatments. The appropriate use of the different existing wires may reduce the duration of the treatment and enhance patient comfort. Several characteristics of orthodontic wires are considered desirable for optimum performance during treatment. A brief description of each of these desirable wire characteristics is provided.

Modulus of elasticity (stiffness)

Modulus of elasticity (stiffness) can be defined as the resistance to permanent deformation. It is proportional to the stiffness of the material[4] and can be determined by the binding forces between atoms. As these forces are constant for each metal structure, stiffness is a constant property of each metal. In orthodontics, it represents the force required to deflect or bend a wire.[1] Low stiffness wires are preferable because they provide the ability to apply lighter and more constant forces during arch deactivation.[4]

Elastic limit

Elastic limit relates to the maximum amount of workload that can be applied to a wire before it undergoes permanent plastic deformation and can no longer return to its original shape. A high elastic limit, with low stiffness, is desirable.[1]

Resilience

Resilience is inversely proportional to the elastic limit and represents the amount of stored energy available in the wire to move teeth,[4] corresponding to the stored energy in the wire, when deformed elastically and released when unloaded. High levels of resilience are preferable.[1]

Shape memory effect

Many materials will show a permanent deformation if their elastic limit is exceeded. However, after an apparent deformation, certain metals will return to their original shape when heated. This effect is called "shape memory effect". When materials return to their original form after reaching the point of deformation, the accumulated forces in the wire are dispersed in a consistent manner for a lengthy period, which is essential to assure teeth movement.[1]

Formability, weldability, and friction

While weldability is the wire's ability to be fused to other materials, the formability of the wire is its ability to be bent into desirable shapes (such as loops and bends).[1,2,4] Friction refers to the resistance of a material when sliding over another and, in orthodontics, it corresponds to the quality of sliding between the wire and orthodontic accessories.[4]

Biocompatibility

Because orthodontic wires are positioned close to the oral mucosa for lengthy periods, they should be resistant to corrosion and prevent the release of ions in the oral cavity, and should not cause allergic reactions. In other words, orthodontic wires must be biocompatible with oral tissues.[1]

Different metals and alloys used in orthodontics

Stainless steel (FeCrNi; SS) alloys

Until the 1930s, the available orthodontic wires were made of gold. Austenitic SS was introduced as an orthodontic wire in 1929, and because of its superior strength, higher modulus of elasticity, good resistance to corrosion, and moderate costs, SS promptly gained acceptance and preference over gold.[4] The alloy of SS most frequently used for orthodontic materials is the American Iron and Steel Institute type 304, containing 18—20% of chromium and 8—10% of nickel.[3,5] SS wires have good biocompatibility, good corrosion resistance, excellent formability, high yield strength, and high modulus of elasticity.[4,6]

Cobalt—chromium (CoCr) alloys

Consisting of cobalt (40%), chromium (20%), silver (16%) and nickel (15%), this alloy was first developed in the 1940s for the manufacture of watch springs and found its place in orthodontics in the 1960s. Regardless of their greater resistance to fatigue and distortion, the mechanical properties of CoCr wires are very similar to those of SS.

Nickel—titanium alloys

Nickel—titanium (NiTi) alloys were introduced into clinical use in 1972. It was produced under the trade name Nitinol, with a composition of 55% nickel and 45% of titanium. Several other brands of NiTi wires were launched in the market in 1976. However, none of these wires showed thermal activation, shape memory effect, or superelasticity. In 1985, a new superelastic NiTi alloy, developed especially for application in orthodontics, was reported.[1] NiTi alloys have good springback and flexibility that allow large elastic deflections.[7] Heat treatment of these alloys changes their crystallographic arrangement, producing the so-called "shape memory". This phenomenon results from a crystalline phase change known as "thermoelastic martensitic transformation" and describes the effect of restoring the original shape of a deformed wire by heating it through its transitional temperature range.[8,9] This transformation from the distorted to the original shape involves a transformation of nitinol from the martensitic to the austenitic phase. However, these alloys present poor formability, which is a disadvantage. Moreover, the bending of these wires has a harmful effect on their springback property.[4]

Copper—nickel—titanium alloys

Copper—nickel—titanium (CuNiTi) alloys consist of nickel, titanium, copper, and some chromium. These wires became available on the market in the mid-1990s. The addition of copper to the alloy enhances the thermal-reactive properties of the wire and makes it highly resistant to permanent deformation.[1]

Beta-titanium alloys

In 1979, Goldberg and Burstone[6] introduced for the first time a beta-titanium (β-Ti) alloy into orthodontic applications. β-Ti alloy is commercially available as "TMA" (titanium—molybdenum alloy) and, although one company owned its manufacturing rights for many years,[10] the alloy is currently marketed by a wide diversity of commercial brands.[1] β-Ti wires possess an excellent balance of properties suitable for many orthodontic applications such as good corrosion resistance, low potential for hypersensitivity, low stiffness, high springback, excellent formability, and good weldability, even compared with SS and cobalt—chromium—nickel orthodontic wires.[3,6,10—12] The modulus of elasticity of β-Ti is about twice that of nitinol and less than one-half that of SS, making it ideal for applications where less force than the one from steel is required, but where a lower modulus material such as nitinol would be insufficient to produce the desired force magnitude.[4] These properties allow a simplified appliance design that can deliver superior force without requiring the addition of loops and helices. In the beginning, β-Ti wires were used for specific applications in a segmented arch technique for the making of retraction loops. Nowadays, β-Ti are used in many applications such as intrusion arches, uprighting molar spring, and cantilevers for intrusion or extrusion of teeth.[11]

Corrosion of orthodontic wires

Within orthodontics, nickel is one of the most commonly used metals in wires, as it is included in NiTi, SS, and other alloys. However, nickel is the most common metal to cause contact dermatitis and to induce more cases of allergic reactions. Reports have suggested that a concentration of approximately 30 mg/L of nickel may be sufficient to prompt a cytotoxic response.[13] Moreover, some complexes of nickel have been considered carcinogenic, allergenic, and mutagenic.[14] NiTi alloys can have >50% of nickel content and, consequently, release sufficient nickel ions to cause allergic reactions.[15] Additionally, there have been reports of nickel-nonsensitive patients who have become nickel-sensitive after using NiTi wires.[16] SS has a nickel content of 8%,[15] but its crystal lattice binds the nickel ions, making them unavailable to react.[13] Hence, these low nickel content alloys are unlikely to cause nickel hypersensitivity, being tolerated by nickel-sensitive patients. Besides nickel, the suspected genotoxic chromium metal is also known to cause adverse biologic effects such as hypersensitivity, dermatitis, and asthma.[17]

Because of its ionic, thermal, microbiological, and enzymatic properties, the oral environment is favorable to the biodegradation of metal wires and their alloys, with consequent release of metal ions in the oral cavity.[18] The major process of degradation of metals is corrosion. Oral conditions such as the temperature, the quantity and acidity of saliva, the presence of certain enzymes, and the physical and chemical properties of solid and liquid food may influence corrosion processes.

Along with the release of elements from metals or alloys, corrosion of orthodontic wires can lead to roughening of the surface and weakening of the appliances and can severely affect the ultimate strength of the material, leading to mechanical failure or even fracture of the orthodontic materials.

To resist corrosion, SS, CoCr, and titanium alloys depend on the formation of a passive surface oxide film. However, even though these protective oxide films are present on the metal surface, metal ions can still be released.[16] Not only is the protective oxide layer susceptible to both mechanical and chemical disruption, but the oxide film can also slowly dissolve as the metal is exposed to oxygen from the surrounding medium. Acidic conditions and fluoride-containing products can contribute to these processes.[19] As a matter of fact, the corrosion and deterioration of certain metals and alloys have been related with the acidic environment of the buccal cavity and with the presence of fluoride ions in several toothpastes and mouthwash solutions.[20—29]

Effect of pH in orthodontic wire corrosion

Metal corrosion is an electrochemical process in which a metal surface exposed to a conducting aqueous electrolyte usually becomes the site for two simultaneous chemical reactions: oxidation and reduction (redox). Taking iron in a weak acid solution as an example, the oxidation (or anodic reaction) results in the production of ferrous ions (Equation (1)), whereas reduction (or cathodic reaction) results in the consumption of electrons produced by the anodic reaction, with the production of hydroxide ions, water, or hydrogen gas (Equations (2)—(4)).

$$Fe_{(aq)} \rightarrow Fe^{2+}_{(aq)} + 2e^{-}_{(aq)} \quad (1)$$

$$O_{2(aq)} + 2H_2O_{(l)} + 4e^-_{(aq)} \rightarrow 4OH^- \quad (2)$$

$$O_{2(aq)} + 4H^+_{(aq)} + 4e^-_{(aq)} \rightarrow 2H_2O_{(l)} \quad (3)$$

$$2H^+_{(aq)} + 2e^-_{(aq)} \rightarrow H_{2(g)} \quad (4)$$

Although the cathodic reaction represented by Equation (2) should be considered for corrosion processes under natural environments, under acidic (or even low acidic) environments Equation (3) and, particularly, Equation (4) are the most relevant, being the ones that should be taken into account regarding the corrosion of wires in the oral cavity.

The extension of corrosion will depend on the nature of the solvent in which the metal is immersed and, unless the metal can form a protective surface layer (passivation), the corrosion process endures until total consumption of the metal or the cathodic reactant occurs.

Metals in oral appliances are constantly challenged by acidic foods and liquids, such as soft drinks, which will supposedly promote the cathodic reaction of corrosion and, consequently, the anodic reaction (dissolution of the metal) as well.

The pH effect on orthodontic wires corrosion has been widely studied. In 2003, Huang et al.[16] measured the amount of ions released from NiTi wires immersed in artificial saliva with different pH values as a function of time. They concluded that the amount of released metal ions increased with immersion time in all conditions and that the amount was greater when more acidic solutions were involved. They also observed that the average amount of nickel ions released per day was higher in the first days, probably owing to the formation of a TiO_2 protective layer on the wire surface. This protective layer was confirmed through X-ray photoelectron spectroscopy (XPS) in 2004 by Huang,[30] who—resorting to cyclic potentiodynamic polarization curves and scanning electron microscopy (SEM)—also observed that the corrosion potential and corrosion rate increased with the decrease in pH value. Polarization curves can be very useful in the assessment of corrosion susceptibility, because they provide information on passivity, pitting susceptibility, and corrosion rate. Among others, Figueira et al.[31] used this technique to evaluate the susceptibility of NiTi commercial samples to corrosion resistance and the effect of pH on the corrosion behavior in solutions with different pH values. Although the increase in the pH value led to a decrease in the corrosion potential, no significant differences were detected in the passive behavior for the studied pH range, leading to the conclusion that NiTi has a good corrosion resistance. Moreover, in accordance with other studies,[16,30] their XPS studies reveal that, although the surface layer of NiTi after immersion in the different solutions has some $Ni(OH)_2$ content, TiO_2 is the main constituent.

Effect of fluorinated and other prophylactic agents

Mouth rinsing with fluoride-containing products is an effective method for prevention of caries because of the complicated morphologies of orthodontic appliances. Regular use of products containing fluoride during the course of orthodontic treatment is essential because fluoride ion can promote the formation of calcium fluoride globules that stimulate remineralization.[32–34]

Clinically available fluoride-containing products have a variety of fluoride concentrations (250–10,000 mg/L) and pH values (3.5–7).[35,36] Prophylactic fluoride gels with a low pH were found to be more effective in the increase of calcium fluoride (CaF_2) formation.[32]

Reduction of corrosion resistance of pure titanium and titanium alloys in fluoride-containing environments has also been reported,[37] with the use of fluoride-containing rinses or gels being harmful to titanium in acidic environments. Titanium corrodes not only in the presence of sodium fluoride (NaF) in acidic solution but also at high pH values if the NaF concentration is considerably high.[35] The fluoride ions degrade the protective titanium oxide film formed on titanium and titanium alloys. The contact of electrolyte with the metal is possible through the pores of the oxide layer that can contain several oxides of different stoichiometries such as TiO, Ti_2O_3, or TiO_2, although TiO_2 is the most frequently observed.[38]

Once titanium-based orthodontic wires become exposed to acidulated topical NaF products, hydrofluoric acid (HF) can be produced according to Equation (5), and HF will then rapidly dissolve titanium, in accordance with Equations (6) and (7), and/or 8, leading to corrosion of the metal alloy[37,39]:

$$H_3PO_4 + 3NaF \rightarrow Na_3PO_4 + 3HF \quad (5)$$

$$Ti_2O_3 + 6HF \rightarrow 2TiF_4 + 3H_2O \quad (6)$$

$$TiO_2 + 4HF \rightarrow TiF_4 + 2H_2O \quad (7)$$

$$TiO_2 + 2HF \rightarrow TiF_2 + H_2O \quad (8)$$

In 2002, Schiff et al.[36] compared the electrochemical properties of different titanium alloys ($TiAl_6V_4$, NiTi, and NiTiCo, and pure titanium) according to the pH and fluoride content of the saliva. The polarization curve assays showed that for pure titanium and $TiAl_6V_4$, the corrosion rate increased as the medium became more acidic, then fluoridated and finally fluoridated–acidified. Although NiTi and NiTiCo were less affected by the fluoridated–acidified medium, fluoride had a negative effect on all materials. In agreement, surface analysis by SEM showed surface degradation on the tested alloys that had been exposed to fluoridated–acidified saliva. Later, in 2004, Schiff et al.[34] also assessed the corrosion influence of three commercial fluoride mouthwashes on four titanium alloys orthodontic wires (TMA, TiNb, NiTi, and CuNiTi). Corrosion potential was measured over time, and corrosion resistance of titanium alloys was determined. From the results obtained, it was possible to divide the alloys into two groups: one composed by nickel–titanium-based alloys (NiTi and CuNiTi), which were strongly corroded in the presence of monofluorophosphate found in one of the tested mouthwash solutions, and the other composed by TMA and TiNb, which were less resistant to corrosion in the presence of stannous and amine fluoride. These results were confirmed by SEM analysis of the alloys' surface, emphasizing the need to recommend the proper mouthwash depending on the alloy used. In 2010, Lee et al.[40] evaluated the effect of fluoride prophylactic agents in four different brands of commercial NiTi archwires. The tests were made in acidic artificial saliva with different NaF concentrations (0.01%, 0.1%, 0.25%, and 0.5%), mimicking commercial fluoride-containing toothpastes. The polarization resistance of the different wires was calculated on the polarization curves experiments. Significant differences were found among the tested wires regardless of the NaF concentration in artificial saliva, although XPS analysis revealed a similar chemical composition of the passive film on the surface of all tested NiTi archwires. This apparent discrepancy could be due to different surface textures, roughness, and defects produced in the wires during the manufacturing process, which was observed by SEM and atomic force microscopy experiments. Nevertheless, all tested NiTi archwires revealed a decrease in corrosion resistance as the NaF concentration increased. This effect was more accentuated in high (0.5%) NaF-containing solution, which corresponds to a fluoride ion concentration of 2250 mg/L. These results are indicative of severe damage of the TiO_2-based protective film and are in accordance with other previously reported studies showing that a fluoride ion concentration of 250—500 mg/L is enough to promote NiTi wire corrosion.[33,34]

Corrosion of the TMA and NiTi alloys in fluorinated mouthwash solutions can also occur via hydrogen embrittlement.[41,42] This phenomenon can also be responsible for the degradation of the mechanical properties of titanium-based alloys. In 2005, Walker et al.[39] evaluated the effects of different fluoride prophylactic agents on the mechanical properties of two nickel—titanium based NiTi orthodontic archwires (NiTi and CuNiTi) after being immersed in an acidulated fluoride agent and a neutral fluoride agent for 90 minutes at 37°C. Both unloading elastic modulus (*E*) and unloading yield strength (YS) had significantly decreased after fluoride exposure. However, the CuNiTi wire mechanical properties were not affected by fluoride agents. The variation in NiTi mechanical properties resulted from fluoride-related hydrogen embrittlement that affected the NiTi wire unloading-related phase shift. Regarding CuNiTi, the addition of copper appeared to have inhibited fluoride-related degradation of the wire mechanical properties. Nevertheless, SEM assays for characterization of fluoride treatment effects on wires revealed that NiTi and CuNiTi wires suffered corrosive changes on surface topography.

SS and beta-titanium

Usually, there are three phases in orthodontic treatments: 1 = leveling and aligning, 2 = space closure and anterior/posterior correction, and 3 = detailing and finishing. β-Ti and SS wires are the most frequently used in Phases 2 and 3, which leaves them exposed to the oral environment for longer periods.[43] Thus, it is vital to understand their corrosion behavior. Both wires show high formability, which allows them to be bent into different configurations such as specialized loops.[4,6] Unlike titanium alloys, the passive layer of SS wires is composed of Cr_2O_3/Fe_2O_3.[44,45] Nevertheless, this corrosion resistance barrier can also be damaged. To determine the possible differences in the corrosive potential of SS and TMA wires, Kim and Johnson[46] subjected these wires to anodic polarization in a physiologic solution (0.9% NaCl) with neutral pH. Results showed that TMA wires exhibited the lower corrosive potential. In addition, SEM photographs revealed that SS wires were readily susceptible to corrosion. Similar results were observed by Huang,[44] who—after conducting cyclic potentiodynamic and SEM analysis of SS wires in acid artificial saliva at 37°C—detected that the pH had a significant influence on the corrosion parameters of the stressed SS wires. In 2006, Lin et al.[45] performed SEM, atomic force microscopy, and linear polarization analysis and showed that SS wires from different brands and types, with different surface roughness and defects, presented significant differences in their corrosion resistance. Although only pH seems to be harmful to SS wires,[47] both pH and fluoride concentration have negative effects on β-Ti wires, with hydrogen embrittlement in fluoride solutions being one of the reasons for β-Ti alloy fracture during clinical treatment.[10] Nevertheless, β-Ti corrosion resistance behavior is higher than that in other wires.[48] In 2003, Watanabe and Watanabe[49] assessed surface roughness and colors after immersion of TMA wires in fluoride prophylactic agents with different pH values and observed that the TMA immersed in acidic fluoride solution changed color and surface morphology within 1 hour, exhibiting a high surface roughness after 24 hours. This is in accordance with other studies[50—52] showing that degradation of mechanical properties in β-Ti orthodontic wires increases with longer immersion periods. In 2007, Walker at al[43] evaluated the effect of fluoride prophylactic agents on the loading and unloading elastic modulus and yield strength of β-Ti and SS wires. After the wires were immersed for 90 minutes in different fluoride solutions at 37°C, the functional unloading mechanical properties of both wires decreased in acidulated and neutral fluoride agents. Moreover, SEM experiments showed corrosive changes on the surface topography of both wires after exposure to both solutions.

Concluding remarks

Over the years, there have been great concerns about the impact of orthodontic wire corrosion. The literature suggests that metal ions are released during orthodontic treatment, but the level is far lower than that ingested in a routine daily diet. The effects of pH and fluoride concentration on β-Ti and SS wires might be negative in prolonged orthodontic treatment time. It is a proven fact that corrosion of orthodontic devices occurs, but the impact of corrosion on orthodontic treatment and on patient's health is still not fully understood. Future work in more clinically relevant conditions is vital for better comprehension. It would be interesting to conduct additional assays and test the effect of other properties on corrosion, such as fatigue resistance when subjected to force applied to the wires.

Conflicts of interest

The authors have no conflicts of interest relevant to this article.

References

1. Quintão CCA, Brunharo IHVP. Orthodontic wires: knowledge ensures clinical optimization. *Dental Press J Orthod* 2009;14: 144–57.
2. Kusy RP. A review of contemporary archwires: their properties and characteristics. *Angle Orthod* 1997;67:197–207.
3. Verstrynge A, Van Humbeeck J, Willems G. In-vitro evaluation of the material characteristics of stainless steel and beta-titanium orthodontic wires. *Am J Orthod Dentofacial Orthop* 2006;130:460–70.
4. Kapila S, Sachdeva R. Mechanical properties and clinical applications of orthodontic wires. *Am J Orthod Dentofacial Orthop* 1989;96:100–9.
5. Oh K-T, Choo S-U, Kim K-M, Kim K-N. A stainless steel bracket for orthodontic application. *Eur J Orthod* 2005;27:237–44.
6. Burstone CJ, Goldberg AJ. Beta titanium: a new orthodontic alloy. *Am J Orthod* 1980;77(2):121–32.
7. Ferreira MdA, Luersen MA, Borges PC. Nickel–titanium alloys: a systematic review. *Dental Press J Orthod* 2012;17:71–82.
8. Santoro M, Nicolay OF, Cangialosi TJ. Pseudoelasticity and thermoelasticity of nickel–titanium alloys: a clinically oriented review: part I temperature transitional ranges. *Am J Orthod Dentofacial Orthop* 2001;119:587–93.
9. Santoro M, Nicolay OF, Cangialosi TJ. Pseudoelasticity and thermoelasticity of nickel-titanium alloys: a clinically oriented review: part II. Deactivation forces. *Am J Orthod Dentofacial Orthop* 2001;119:594–603.
10. Kaneko K, Yokoyama K, Moriyama K, Asaoka K, Sakai J, Nagumo M. Delayed fracture of beta titanium orthodontic wire in fluoride aqueous solutions. *Biomaterials* 2003;24: 2113–20.
11. Gurgel JA, Pinzan-Vercelino CR, Powers JM. Mechanical properties of beta-titanium wires. *Angle Orthod* 2011;81:478–83.
12. Juvvadi SR, Kailasam V, Padmanabhan S, Chitharanjan AB. Physical, mechanical, and flexural properties of 3 orthodontic wires: an in-vitro study. *Am J Orthod Dentofacial Orthop* 2010;138:623–30.
13. Rahilly G, Price N. Current products and practice: nickel allergy and orthodontics. *J Orthod* 2003;30:171–4.
14. Petoumeno E, Kislyuk M, Hoederath H, Keilig L, Bourauel C, Jäger A. Corrosion susceptibility and nickel release of nickel titanium wires during clinical application. *J Orofac Orthop* 2008;69:411–23.
15. Agarwal P, Upadhyay U, Tandon R, Kumar S. Nickel allergy and orthodontics. *Asian J Oral Health Allied Sci* 2011;1:61–3.
16. Huang HH, Chiu YH, Lee TH, et al. Ion release from NiTi orthodontic wires in artificial saliva with various acidities. *Biomaterials* 2003;24:3585–92.
17. Sfondrini MF, Cacciafesta V, Maffia E, et al. Nickel release from new conventional stainless steel, recycled, and nickel-free orthodontic brackets: an in vitro study. *Am J Orthod Dentofacial Orthop* 2010;137:809–15.
18. Kao C-T, Ding S-J, He H, Chou MY, Huang T-H. Cytotoxicity of orthodontic wire corroded in fluoride solution in vitro. *Angle Orthod* 2007;77:349–54.
19. House K, Sernetz F, Dymock D, Sandy JR, Ireland AJ. Corrosion of orthodontic appliances—should we care? *Am J Orthod Dentofacial Orthop* 2008;133:584–92.
20. Matono Y, Nakagawa M, Matsuya S, Ishikawa K, Terada Y. Corrosion behavior of pure titanium and titanium alloys in various concentrations of acidulated phosphate fluoride (APF) solutions. *Dent Mater J* 2006;25:104–12.
21. Kocijan A, Merl DK, Jenko M. The corrosion behaviour of austenitic and duplex stainless steels in artificial saliva with the addition of fluoride. *Corros Sci* 2011;53:776–83.
22. Barcelos AM, Luna AS, Ferreira NDA, Braga AVC, Lago DCBD, Senna LFD. Corrosion evaluation of orthodontic wires in artificial saliva solutions by using response surface methodology. *Mater Res* 2013;16:50–64.
23. Kang EH, Park SB, Hyung-Il KIM, Kwon YH. Corrosion-related changes on Ti-based orthodontic brackets in acetic NaF solutions: surface morphology, microhardness, and element release. *Dent Mater J* 2008;27:555–60.
24. Katič V, Čurkovič L, Ujevič Bošnjak M, Špalj S. Determination of corrosion rate of orthodontic wires based on nickel–titanium alloy in artificial saliva. *Materwiss Werksttech* 2014;45: 99–105.
25. Ünal HI. Effect of fluoride added artificial saliva solution on orthodontic wires. *Prot Met* 2012;48(3):367–70.
26. Ahn HS, Kim MJ, Seol HJ, Lee JH, Kim HI, Kwon YH. Effect of pH and temperature on orthodontic NiTi wires immersed in acidic fluoride solution. *J Biomed Mater Res Part B* 2006;79: 7–15.
27. Nakagawa M, Matsuya S, Udoh K. Effects of fluoride and dissolved oxygen concentrations on the corrosion behavior of pure titanium and titanium alloys. *Dent Mater J* 2002;21: 83–92.
28. Kuhta M, Pavlin D, Slaj M, Varga S, Lapter-Varga M, Slaj M. Type of archwire and level of acidity: effects on the release of metal ions from orthodontic appliances. *Angle Orthod* 2009; 79:102–10.
29. Fais LMG, Fernandes-Filho RB, Pereira-da-Silva MA, Vaz LG, Adabo GL. Titanium surface topography after brushing with fluoride and fluoride-free toothpaste simulating 10 years of use. *J Dent* 2012;40:265–75.
30. Huang HH. Surface characterizations and corrosion resistance of nickel–titanium orthodontic archwires in artificial saliva of various degrees of acidity. *J Biomed Mater Res A* 2005;74: 629–39.
31. Figueira N, Silva TM, Carmezim MJ, Fernandes JCS. Corrosion behaviour of NiTi alloy. *Electrochim Acta* 2009;54:921–6.
32. Lussi A, Hellwig E, Klimek J. Fluorides — mode of action and recommendations for use. *Schweiz Monatsschr Zahnmed* 2012;122:1030–6.
33. Schiff N, Boinet M, Morgon L, Lissac M, Dalard F, Grosgogeat B. Galvanic corrosion between orthodontic wires and brackets in fluoride mouthwashes. *Eur J Orthod* 2006;28:298–304.
34. Schiff N, Grosgogeat B, Lissac M, Dalard F. Influence of fluoridated mouthwashes on corrosion resistance of orthodontics wires. *Biomaterials* 2004;25:4535–42.
35. Muguruma T, Iijima M, Brantley WA, Yuasa T, Kyung H-M, Mizoguchi I. Effects of sodium fluoride mouth rinses on the torsional properties of miniscrew implants. *Am J Orthod Dentofacial Orthop* 2011;139:588–93.
36. Schiff N, Grosgogeat B, Lissac M, Dalard F. Influence of fluoride content and pH on the corrosion resistance of titanium and its alloys. *Biomaterials* 2002;23:1995–2002.
37. Boere G. Influence of fluoride on titanium in an acidic environment measured by polarization resistance technique. *J Appl Biomater* 1995;6:283–8.
38. Toumelin-Chemla F, Rouelle F, Burdairon G. Corrosive properties of fluoride-containing odontologic gels against titanium. *J Dent* 1996;24:109–15.
39. Walker MP, White RJ, Kula KS. Effect of fluoride prophylactic agents on the mechanical properties of nickel–titanium-based orthodontic wires. *Am J Orthod Dentofacial Orthop* 2005;127:662–9.
40. Lee T-H, Huang T-K, Lin S-Y, Chen L-K, Chou M-Y, Huang H-H. Corrosion resistance of different nickel–titanium archwires in acidic fluoride-containing artificial saliva. *Angle Orthod* 2010; 80:547–53.

41. Tal-Gutelmacher E, Eliezer D. Embrittlement of secondary Hydrogen-containing phases in Titanium-based alloys. *Glass Phys Chem* 2005;31:96—101.
42. Tal-Gutelmacher E, Eliezer D. The hydrogen embrittlement of titanium-based alloys. *JOM* 2005;57:46—9.
43. Walker MP, Ries D, Kula K, Ellis M, Fricke B. Mechanical properties and surface characterization of beta titanium and stainless steel orthodontic wire following topical fluoride treatment. *Angle Orthod* 2007;77:342—8.
44. Huang H-H. Corrosion resistance of stressed NiTi and stainless steel orthodontic wires in acid artificial saliva. *J Biomed Mater Res A* 2003;66A:829—39.
45. Lin M-C, Lin S-C, Lee T-H, Huang H-H. Surface analysis and corrosion resistance of different stainless steel orthodontic brackets in artificial saliva. *Angle Orthod* 2006;76:322—9.
46. Kim H, Johnson JW. Corrosion of stainless steel, nickel—titanium, coated nickel—titanium, and titanium orthodontic wires. *Angle Orthod* 1999;69:39—44.
47. Mirjalili M, Momeni M, Ebrahimi N, Moayed MH. Comparative study on corrosion behaviour of Nitinol and stainless steel orthodontic wires in simulated saliva solution in presence of fluoride ions. *Mater Sci Eng C* 2013;33:2084—93.
48. Kassab EJ, Gomes JP. Assessment of nickel titanium and beta titanium corrosion resistance behavior in fluoride and chloride environments. *Angle Orthod* 2013;83:864—9.
49. Watanabe I, Watanabe E. Surface changes induced by fluoride prophylactic agents on titanium-based orthodontic wires. *Am J Orthod Dentofacial Orthop* 2003;123:653—6.
50. Kaneko K, Yokoyama Ki, Moriyama K, Asaoka K, Sakai Ji. Degradation in performance of orthodontic wires caused by hydrogen absorption during short-term immersion in 2.0% acidulated phosphate fluoride solution. *Angle Orthod* 2004; 74:487—95.
51. Kwon YH, Seol H-J, Kim H-I, Hwang K-J, Lee S-G, Kim K-H. Effect of acidic fluoride solution on β titanium alloy wire. *J Biomed Mater B Appl BiomaterRes* 2005;73B:285—90.
52. Ogawa T, Yokoyama Ki, Asaoka K, Sakai Ji. Hydrogen absorption behavior of beta titanium alloy in acid fluoride solutions. *Biomaterials* 2004;25:2419—25.

3. **Eugénio Martins, Joana Cristina Silva, Carlos A. Pires, Maria João Feio Ponces Ramalhão, Jorge Dias Lopes. Coronal joint spaces of the Temporomandibular joint: Systematic review and meta-analysis. J Clin Exp Dent. 2015;7(3):435-40**

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Coronal joint spaces of the Temporomandibular joint: Systematic review and meta-analysis

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Abstract

Introduction: The joint space measurements of the temporomandibular joint have been used to determine the condyle position variation. Therefore, the aim of this study is to perform a systematic review and meta-analysis on the coronal joint spaces measurements of the temporomandibular joint.

Material and Methods: An electronic database search was performed with the terms "condylar position"; "joint space"AND"TMJ". Inclusionary criteria included: tomographic 3D imaging of the TMJ, presentation of at least two joint space measurements on the coronal plane. Exclusionary criteria were: mandibular fractures, animal studies, surgery, presence of genetic or chronic diseases, case reports, opinion or debate articles or unpublished material. The risk of bias of each study was judged as high, moderate or low according to the "Cochrane risk of bias tool". The values used in the meta-analysis were the medial, superior and lateral joint space measurements and their differences between the right and left joint.

Results: From the initial search 2706 articles were retrieved. After excluding the duplicates and all the studies that did not match the eligibility criteria 4 articles classified for final review. All the retrieved articles were judged as low level of evidence. All of the reviewed studies were included in the meta-analysis concluding that the mean coronal joint space values were: medial joint space 2.94 mm, superior 2.55 mm and lateral 2.16 mm.

Conclusions: the analysis also showed high levels of heterogeneity. Right and left comparison did not show statistically significant differences.

Key words: *Temporomandibular joint, systematic review, meta-analysis.*

Introduction

One of the main components of the TMJ is the mandibular condyle as it connects the mandible, the only bone of the craniomandibular complex that moves, to the temporal bone by the TMJ. Therefore, the mandibular condyle position has been advocated by several authors to be a main factor of equilibrium of the masticatory system and its ideal position has been a very controversial issue during the past years.

Several hypotheses have been proposed from the most retruded position of the condyle in the glenoid fossa to the most superior, to the current most anterosuperior position with the disk in between (1-3). In the meantime, the relationship between changes in condylar position and the presence of temporomandibular disorders (TMD) is also very controversial within the scientific community (4-7).

As there is some evidence suggesting the influence of dental occlusion on the mandibular condyle position, it is easily understood the importance of determining the condyle position to perform complex rehabilitations and orthodontic treatments (6). According to Hidaka *et al.* (8) 38,7% of orthodontic patients suffer of a degree of condylar displacement that may jeopardize the treatment plan (8). Therefore, it becomes very clear the importance of including the determination of condyle position during orthodontic diagnostic procedures.

There are several methods described in the literature to determine condylar position, including radiographic techniques (9-12). Although, only with the introduction of the evaluation of the TMJ in Laminographies suggested by Robert Ricketts, it became possible to radiographically quantify the joint space measurements and determine the condyle position (9).

Since then, the evolution of radiology has allowed to perform three-dimensional analysis of the structures and accurately determine several measurements, including TMJ spaces on computed tomography (CT), cone-beam computed tomography (CBCT) and magnetic resonance imaging (MRI) (13-18). Many studies have been performed to determine condyle position, both on the sagittal and coronal plane, using mainly CT and CBCT as these exams are more common in dental practice.

The aim of this study is to perform a systematic review of the literature and meta-analysis concerning the coronal joint spaces to define the ideal coronal joint spaces.

Material and Methods

-Information sources and search strategy

A comprehensive electronic database search to identify relevant publications was conducted, and the reference lists in relevant articles were searched manually for additional literature. No language restrictions were set although no attempt to explore the informally published literature was made. The following databases were searched: Medline (Pubmed), Lilacs, Scopus, Ebsco (Host by University of Porto), Cochrane Central Register of Controlled Clinical Trials.

A search was performed with the terms "condylar position"; "joint space"AND"TMJ" with no year of publication restriction in order to include the highest number of articles (to 22 April 2014). No restriction to study design was applied.

Faculty of Dental Medicine of University of Porto and Portuguese Society of Dentofacial Orthopedics' libraries were also consulted for printed articles not available online.

-Selection criteria

At the first stage, two reviewers independently screened the titles of the retrieved records, and only the titles related to temporomandibular joint spaces were included. Next, the abstracts of the retrieved publications were read by the two reviewers and categorised according to the method used to determine condylar position. An article had only to be justified by one reviewer to be included in the second selection phase. Eligibility of the retrieved articles was determined by applying the following inclusion criteria: (1) tomographic examination of the TMJ (2) determination of coronal joint space measurements at least on two different points.

The main reasons for exclusion were: mandible fractures, studies not performed in living humans, surgical interventions, studies with patients with syndromes or chronic diseases (including degenerative pathology of the TMJ), examination of the condylar position only with clinical methods, 2D radiographs or magnetic resonance imaging, orthodontic or splint therapy, samples containing only patients in the primary or mixed/ early permanent dentition, case reports, discussion or debate articles. All not published studies were also excluded.

The analysis was based on primary materials. When an abstract was considered by at least one author to be relevant, it was read in full text. At the second stage, the full texts were retrieved and critically examined. Reference lists from the articles selected on the second stage were screened and articles related to condylar position assessment by joint space measurements were hand-searched. Book chapters and reviews were excluded since the aim of this systematic review was to evaluate primary studies.

-Data treatment

The following data were extracted from the selected articles: year of publication, study type, study method, sample description, joint space measurements on the coronal plane, error analysis method, statistical analysis and author's conclusion. One reviewer author then extracted the mentioned data from the included articles and the second author checked. Any disagreement was resolved with discussion between the two authors until a consensus was reached. The risk of bias was assessed according to the "Cochrane risk of bias tool" (19) as suggested by the "PRISMA statement for reporting systematic reviews and meta-analyses of studies that evaluate health care interventions: explanation and elaboration" (20).

-Meta-analysis

The values studied in this meta-analysis were the coronal joint space measurements (medial, superior and lateral joint space) and the differences between the right and left joints. As not all the included articles presented the values for all the spaces from the right and left joints, the analysis were performed including all the data presented in each selected study. For the comparative analysis between the right and left joints, mean and standard deviation values from the samples of each article were used. For global joint space assessment, mean and standard deviation of the total sample (including both the values from the right and left joints) were used. d

The restricted maximum-likelihood (REML) method was used to estimate de variability between the studies. Inverse variance method was used to assess the weight of each study (21).

Heterogeneity was determined using the Q Cochran Test and the I² statistics by Higgins and Thompson (21).

Statistical analysis was performed using "R", version 2.15.2 from "The R Project for Statistical Computing", available from http://www.r-project.org.

Results

-Search results

From the initial search strategy 916 articles were retrieved from Medline (Pubmed), 1114 from Scopus, 158 from EBSCOhost, 19 from Lilacs and none from the Cochrane Central Register of Controlled Clinical Trials. The number of articles reviewed in each phase of this systematic review is presented in the PRISMA. After excluding 978 duplicates, 1230 articles remained for review. In the first phase selection, the observers screened the articles by reading titles and abstracts. Articles that were not eligible because of irrelevant aims and were not directly related to this systematic review were excluded, thus 61 articles remained for further reading. 28 articles were assessed for eligibility. After screening all the articles full text according to the inclusion/ exclusion criteria, 4 (10,22-24) articles classified for final review.

-Type of study and method used to determine joint space measurements

No randomized clinical trials (RCTs) have been performed on coronal joint spaces of the TMJ. A prospective study (23) and two retrospective studies (22,24) have been found meeting the eligibility criteria. A prospective and retrospective study was also found (10). Three of the retrieved articles (22-24) performed cone-beam computed tomography (CBCT) to obtain the 3D images of the TMJ, while Christiansen *et al.* (10) used CT images.

Dalili *et al.* (22) measured the distance from the most prominent medial and lateral poles of each condyle to the intersection point of two tangent lines from the deepest point of the glenoid fossa to the respective medial and lateral slopes. In the meantime, Ikeda *et al.* (24) divided the mediolateral width of the condyle in sextants in the coronal view and projected the midpoint perpendicularly to the true horizontal line (THL) to its surface to find the central coronal point. The medial and lateral coronal points derived from lines perpendicular to the THL extending from the junction of the medial or laterals first and second sextants, respectively. The shortest distances from the medial, central and lateral points to the fossa were then measured. At last, Henriques *et al.* (23) identified the most medial and lateral points of the condyle and draw a line and its midpoint was considered to trace another line at 90 degrees and two other at 45 degrees laterally and medially respectively. The intersection point of these lines with the condyle surface and the glenoid fossa were determined and the distance in between measured.

Christiansen *et al.* (10) measured the closest distance between the most centred and superior point of the condyle (CJS) and the most medial point of the condyle (MJS) to the glenoid fossa.

-Quality assessment

The summary of the quality assessment of the reviewed articles is on table 1.

Globally, the statistical analysis performed on each case were adequate to the goals of the research. However, only one article (22) presents normality tests in order to determine the statistical tests to apply. On the other three studies (10,23,24) it is not possible to evaluate the validity of the statistical tests applied (T Student and ANOVA) as they were used in small samples with no information about the normality of the data. One of the selected articles (23) does not present the correlation coefficient used. None of the studies reports estimation of the sample size and method error analysis was only performed on one study (22). In summary, all of the retrieved articles were classified as low level of evidence according to the "Cochrane risk of bias tool".

-Meta-analysis

The four articles included on the review were used in this meta-analysis. For the medial joint space, the four studies presented the mean values, although the same was not true for the lateral joint space, as Christiansen *et al.* (10) did not measure this space. Similarly, Dalili *et al.* (22) did not consider the superior joint space.

The mean medial, lateral and superior joint space values assessed with this meta-analysis were 2.94 mm, 2.16 mm and 2.55 mm respectively (Figs. 1-3). High heterogeneity was found among the four articles: ($Q(3) = 60.37$; $P<0.001$; $I2 = 95.73\%$) for the MJS; ($Q(2) = 31.55$; $P<0.001$; $I2 = 92.20\%$) for the LJS; ($Q(2) = 7.16$; $P=0.028$; $I2 = 72.53\%$) for the SJS.

Table 1. Summary of the quality assessment of the four retrieved articles.

	Estimate of sample size	Sample description	Error analysis	Normality tests	Adequate statistics provided	Randomization	Statistical analysis	Level of evidence
1[22]	No/ Not known	Yes	No	Yes	Yes	No	Adequate	Low
2[24]	No/ Not known	Yes	Yes	No information	Yes	No	Adequate	Low
3[23]	No/ Not known	Yes	No	No information	Yes	No	Adequate	Low
4[10]	No/ Not known	Yes	No	No information	Incomplete*	No	Adequate	Low

*level of significance unclear.

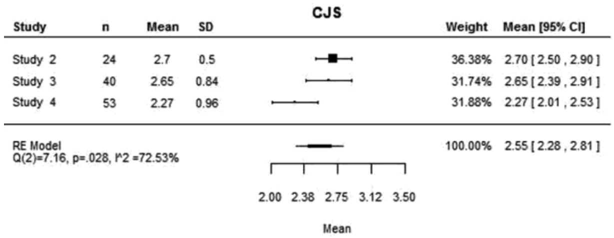

Fig. 1. Mean medial joint space value and for each study and mean difference between medial joint space between right and left joint and for each study.

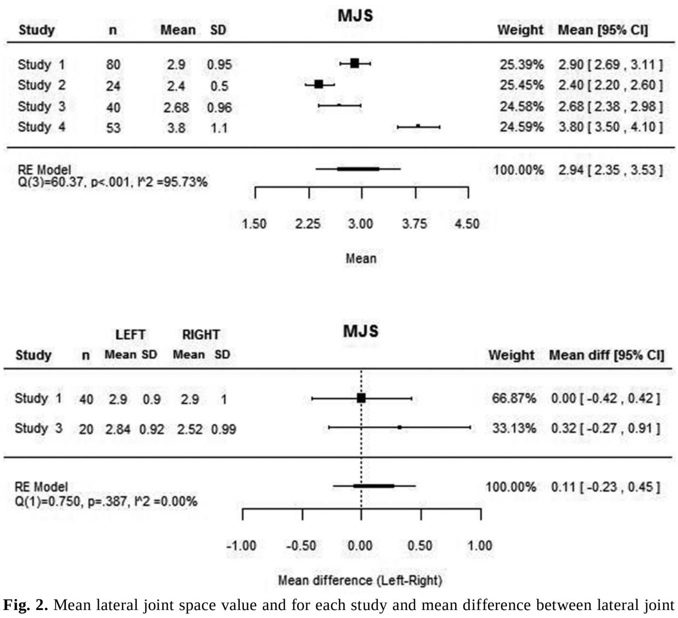

Fig. 2. Mean lateral joint space value and for each study and mean difference between lateral joint space between right and left joint and for each study.

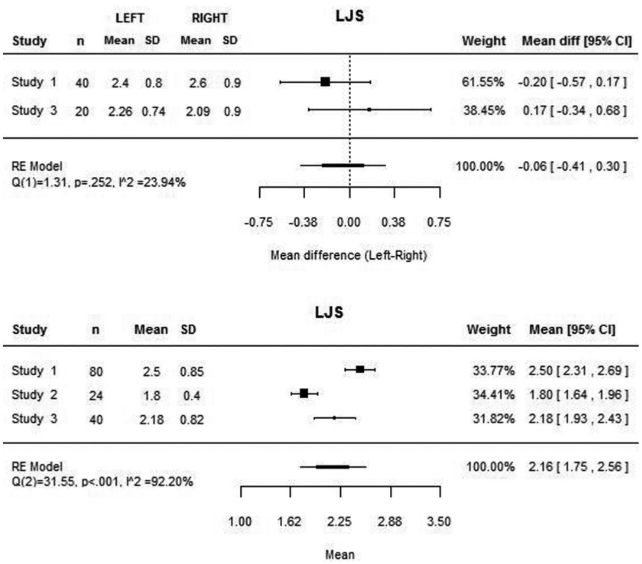

Fig. 3. Mean superior joint space value and for each study.

The mean differences between the right and left joints are close to zero both to the medial and lateral joint space (Figs. 1,2). However, these values are based only on two studies (22,23) as the remaining do not present the values for each joint separately. Concerning the superior joint space, the values of each joint separately is present only on the study of Henriques *et al.* (23), being the mean difference of 0.35 mm (95% CI: -0.17, 0.87). The heterogeneity analysis shows that the difference values are homogeneous both to the medial and lateral joint space.

Discussion

Joint space measurements have been used to assess the mandibular condyle position radiographically since Ricketts used this method in laminographies (9). Since then, the technology has evolved so much that it is now possible to assess the joint space in 3D radiographic imaging with CT, CBCT and MRI. Therefore, a systematic review to assess the relevance of these methods and their scientific evidence is necessary. In the present study, all the articles about joint space assessment on 2D radiographic examination of the TMJ were excluded as these methods have proven lower accuracy both in the image acquisition process and in measurements, than 3D radiographic methods (18). MRI was also excluded because this exam is not indicated to assess hard structures and, as both the mandibular condyle and the glenoid fossa that limit the joint space are mainly bone and cartilage, this is not the best exam for accurately determine joint space measurements (25). Furthermore, all the articles including extensive treatment that could significantly influence the joint space, like orthodontic treatment and splint therapy, have been excluded. Finally, studies with samples exclusively on the mixed and early permanent dentition were excluded as the mandibular condyle is not completely formed before the end of the growth, usually between 15 to 16 years old. The exclusion of studies that only assessed the joint space in less than two separate points of the TMJ was due to the definition of the position of an object in space depending on three coordinates. According to this, the analysis of the joint space only on one point does not provide enough information to determine the position of the mandibular condyle in the glenoid fossa.

The review enhanced the lack of studies about coronal TMJ space analysis with tomographic imaging as only four articles matched the eligibility criteria. Furthermore, the retrieved studies present small samples which determine that its results should be read with caution.

As all the studies were classifie as low level of evidence according to the “Cochrane risk of bias tool” the authors suggest the need to perform more studies with structured methodology that lead to more solid conclusions.

A meta-analysis of the results of the four retrieved articles was performed. However, the authors are aware that its results should be carefully interpreted as it is based on few studies with low level of evidence.

According to the attained values, the mean MJS, LJS and CJS were 2.94 mm, 2.16 mm and 2.55 mm respectively. However, the analysis also showed high heterogeneity that reduces significantly the power of these values. Therefore, more research is needed in order to achieve more homogeneous values that allow direct comparison of results and solid conclusions.

On the contrary, homogeneity was found among the difference between right and left joint, which suggests the absence of statistically significant differences between both sides. However, this analysis was only based on two studies and should not be considered a strong conclusion.

Conclusions

The conclusions of this systematic review and meta-analysis concerning the coronal joint space measurements are:

- Lack of scientific evidence, as all the retrieved articles were of low level of evidence;
- The meta-analysis suggest the following mean values for the coronal joint spaces: 2.94 mm MJS, 2.16 mm LJS and 2.55 mm CJS;
- High heterogeneity among the studies;
- Suggestion of the absence of statistically significant differences between the coronal joint space of the right and left joints.

References

1. Posselt U. Studies in the mobility of the human mandible. Acta Odontol Scand. 1952;10(superscriptpl):19-27.
2. Van Blarcom C, Campbell S, Can A. The glossary of prosthodontic terms. 7 ed. St Louis: Mosby; 1999.
3. Dawson PE. New defintion for relating occlusion to varying conditions of the temporomandibular joint. J Prosthet Dent. 1995;74:619-27.
4. Farrar WB, McCarthy WL, Jr. Conventional radiography compared with arthrography in internal derangements of the temporomandibular joint. J Prosthet Dent. 1983;50:585-6.
5. Weinberg LA. Correlation of temporomandibular dysfunction with radiographic findings. J Prosthet Dent. 1972;28:519-39.
6. Crawford SD. Condylar axis position, as determined by the occlusion and measured by the CPI instrument, and signs and symptoms of temporomandibular dysfunction. Angle Orthod. 1999;69:103-15; discussion 15-6.
7. Roth RH. Temporomandibular pain-dysfunction and occlusal relationships. Angle Orthod. 1973;43:136-53.
8. Hidaka O, Adachi S, Takada K. The difference in condylar position between centric relation and centric occlusion in pretreatment Japanese orthodontic patients. Angle Orthod. 2002;72:295-301.
9. Rickets RM. Present status of laminagraphy as related to dentistry. J Am Dent Assoc. 1962;65:56-64.
10. Christiansen EL, Chan TT, Thompson JR, Hasso AN, Hinshaw DB, Jr., Kopp S. Computed tomography of the normal temporomandibular joint. Scand J Dent Res. 1987;95:499-509.
11. Kandasamy S, Boeddinghaus R, Kruger E. Condylar position assessed by magnetic resonance imaging after various bite position registrations. Am J Orthod Dentofacial Orthop. 2013;144:512-7.
12. Ikeda K, Kawamura A. Assessment of optimal condylar position with limited cone-beam computed tomography. Am J Orthod Dentofacial Orthop. 2009;135:495-501.
13. Moshiri M, Scarfe WC, Hilgers ML, Scheetz JP, Silveira AM, Farman AG. Accuracy of linear measurements from imaging plate and lateral cephalometric images derived from cone-beam computed tomography. Am J Orthod Dentofacial Orthop. 2007;132:550-60.
14. Honey OB, Scarfe WC, Hilgers MJ, Klueber K, Silveira AM, Haskell BS, et al. Accuracy of cone-beam computed tomography imaging of the temporomandibular joint: comparisons with panoramic radiology and linear tomography. Am J Orthod Dentofacial Orthop. 2007;132:429-38.
15. Hilgers ML, Scarfe WC, Scheetz JP, Farman AG. Accuracy of linear temporomandibular joint measurements with cone beam computed tomography and digital cephalometric radiography. Am J Orthod Dentofacial Orthop. 2005;128:803-11.
16. Ludlow JB, Laster WS, See M, Bailey LJ, Hershey HG. Accuracy of measurements of mandibular anatomy in cone beam computed tomography images. Oral Surg Oral Med Oral Pathol Oral Radiol Endod. 2007;103:534-42.
17. Lascala CA, Panella J, Marques MM. Analysis of the accuracy of linear measurements obtained by cone beam computed tomography (CBCT-NewTom). Dentomaxillofac Radiol. 2004;33:291-4.
18. Quintero JC, Trosien A, Hatcher D, Kapila S. Craniofacial imaging in orthodontics: historical perspective, current status, and future developments. Angle Orthod. 1999;69:491-506.
19. Collaboration TC. Cochrane reviewers' handbook 2004. Available from: http://www.cochrane.org/resources/handbook.
20. Liberati A, Altman DG, Tetzlaff J, Mulrow C, Gotzsche PC, Ioannidis JP, et al. The PRISMA statement for reporting systematic reviews and meta-analyses of studies that evaluate health care interventions: explanation and elaboration. PLoS Med. 2009;6:e1000100.
21. Higgins JP, Thompson SG, Deeks JJ, Altman DG. Measuring inconsistency in meta-analyses. BMJ. 2003 Sep 6;327(7414):557-60.
22. Dalili Z, Khaki N, Kia SJ, Salamat F. Assessing joint space and condylar position in the people with normal function of temporomandibular joint with cone-beam computed tomography. Dent Res J (Isfahan). 2012;9:607-12.
23. Henriques JC, Fernandes Neto AJ, Almeida Gde A, Machado NA, Lelis ER. Cone-beam tomography assessment of condylar position discrepancy between centric relation and maximal intercuspation. Braz Oral Res. 2012;26:29-35. c
24. Ikeda K, Kawamura A, Ikeda R. Assessment of optimal condylar position in the coronal and axial planes with limited cone-beam computed tomography. J Prosthodont. 2011;20:432-8.
25. Commission E. Radiation protection nº 172. CONE BEAM CT FOR DENTAL AND MAXILLOFACIAL RADIOLOGY: Evidence-based guidelines. In: Protection D-GfEDDNEUDR, editor. Luxemburgo 2012c

Conflict of Interest

The authors declare no conflict of interests in this investigation.

4. **Jorge M, Vaz M, Lopes J, Ustrell-Torrent JM, Farahani B, Ponces MJ. Biomechanical effects of Teuscher activator in hyperdivergent Class II malocclusion treatment: A finite element analysis. J Clin Exp Dent. 2021;13(11):1124-1130.**

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Biomechanical effects of Teuscher activator in hyperdivergent Class II malocclusion treatment: A finite element analysis

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Abstract

Background: In orthodontic treatment, the combination of an activator with a headgear is commonly used in treatment of the hyperdivergent Class II malocclusion. However, the distribution of stresses transmitted to the maxilla by these appliances has been little studied. This study aimed to compare the biomechanical effects of stresses transmitted to the maxilla and teeth by a Teuscher activator (TA) for different lines of action of extraoral force, using finite element analysis.

Material and Methods: A tridimensional finite element model of the maxilla and teeth was created based on the true geometry of a human skull. The (TA) and the face bow were designed in 3D computer-aided design and fixed in the maxilla model. To study the effects of mechanical stress transmitted to the maxilla in the treatment of hyperdivergent Class II malocclusion with (TA) combined with extraoral forces, five different finite element models were used, considering the centers of resistance of the maxilla and dentition.

Results: The results showed that stresses increased progressively when the force line of action moved in posteroanterior direction. Von Mises equivalent stress was lower in Model 1 (0°) than in Model 5 (60°). In Models 1 (0°) and 2 (15°), molars suffered greater distal displacement and incisors showed extrusion. In Model 3 (30°), the force line of action promoted a distal displacement of molars and incisors. In Models 4 (45°) and 5 (60°), the whole maxillary anterior sector showed counterclockwise displacement.

Conclusions: Different force lines of action influence the intensity and distribution of orthodontic and orthopedic forces in the maxilla. The extraoral force's line of action used in Model 3 (30°) is the most compatible with the objectives of the hyperdivergent Class II malocclusion treatment in growing patients.

Key words: *Class II, Headgear, Early treatment, FEA.*

Introduction

Class II malocclusion may be caused by dental or skeletal maxillary protrusion or both. Patients with Class II malocclusion and the hyperdivergent phenotype usually suffer a variable combination of skeletal and dentoalveolar changes in the three spatial planes. They also have retrognathic mandibles, long posterior and anterior dentoalveolar facial heights, increased gonial angles and mandibular planes, among other changes (1,2).

The most common and least invasive approach in the early treatment of this condition has been using high pull extraoral force when maxillary displacement restriction, distalization, and maxillary molar intrusion are important goals for sagittal and vertical correction and faciale profil improvement (3-11).

Nevertheless, several studies have reported unwanted effects of using functional appliances combined with extraoral forces for vertical control, namely, the partial restriction of the maxilla's anterior displacement, increased anteroinferior facial height, and posterior rotation of the mandible however, those studies are not consensual (8,12-14).

In hyperdivergent Class II malocclusion treatment, understanding the tridimensional (3D) effects of biomechanical stress transmitted to the maxilla, namely to teeth and mid-facial skeletal structures, is crucial to identify the best force line of action for better vertical control at the maxillary level.

Few studies focused on explaining the effects of the dissipation of biomechanical stress transmitted to the maxilla by functional appliances combined with extraoral forces used in hyperdivergent Class II malocclusion treatment (15,16).

The use of finte element analysis FEA has been a useful tool in the evaluation of biomechanical effects, such as displacements, strains and stresses induced in living structures by external forces and is considered an asset in predicting the effects of orthodontic treatment (17-20).

Therefore, this study aimed to use finte element analysis FEA to compare, in these patients, the biomechanical effects of stresses transmitted to the maxilla by a Teuscher activator (TA) with different directions of the extraoral force.

Material and Methods

-Model Configrations: Maxilla and Teeth

A 10-year-old female patient with Class II, division 1 malocclusion and a hyperdivergent Class II skeletal pattern was selected for this study. She had not been subjected to any previous orthodontic treatment. A dentulous human maxilla obtained from the Grab CAD database was used as a reference.

A 3D computer-aided design (CAD) model of the patient's maxilla, including teeth, was created based on images of the patient obtained from DICOM (digital imaging and communication in medicine) data in computed tomography (CT) format. The use of these images to create the model was approved by the Ethics Committee of the Faculty of Dental Medicine of the Porto on May 5, 2018, under registration number 527. The model had to be adjusted to the patient's dimensions for agreement between the numerical model and the clinical case. Measurements were made on the physical model using a dial-caliper (Absolute Digimatic, Mitutoyo).

The model was then processed using the CAD software SolidWorks® (Dassault Systems SolidWorks Corp., Concord, MA, EUA), and all CAD data were adapted to the patient's anatomy. This study focused on the maxillary region, limited superiorly by the orbital flor and posteriorly by the pterygomaxillary suture. The final model was composed of the maxilla, the skull base (zygomatic, nasal, and sphenoid), the incisors, and the maxillary firt molars. Due to the patient's age, the permanent premolars were absent at treatment onset.

-Model Configurations: Teuscher Activator and Face Bow

A (TA) combined with a face bow was incorporated in the maxillae and teeth' anatomical model to represent clinical conditions. A 3D model of the (TA) and face bow was developed using the SolidWorks® software, based on images of the physical model and measurements obtained with the dial-caliper.

The (TA) consists of an acrylic monobloc that surrounds the whole occlusal and palatal aspects of teeth up to the distal level of the maxillary firt molar and about 2 mm of their buccal aspect. Superiorly, at the palate level, it has a Coffin spring made of steel wire (diameter: 0.09 mm). Its anterior maxillary portion has four springs made of steel wire (diameter: 0.08 mm) to offer torque to the maxillary incisors and some retention to the (TA) when inserted in the dental arch. Laterally, at the level of the primary second molar, two metallic tubes attached to the TA's acrylic accommodate the face bow's inner bow.

The face bow consists of a stainless-steel arch (diameter: 1.1 mm) with two bows: the inner bow and the outer bow. The inner bow enters a metallic tube laterally attached to the TA's acrylic at the level of the primary second molar.

In our model, the outer bow assumed different angulations, taking into account the center of resistance of the maxilla (CResM) and dentition (CResD), and five different lines of action of extraoral force were applied.

The (TA) was modeled as a simple acrylic bloc, and each incisal edge and cusp of the teeth was well inserted into the acrylic. The outer bow's geometry, where force is applied (hooks), was modeled. However, to simplify the numerical simulation, hooks were not considered.

Numerical studies were conducted using FEA simulated in Abaqus® in the static time step regime to assess stress distribution. The maxilla's anatomical model and the (TA) with the face bow were imported to the FEA model and five (finite element) models were created to simulate the application of five different force lines of action (Fig. 1).

and modeled as a single unit. Rigid bodies are particularly effective for modeling relatively rigid parts of a model in Abaqus®, especially when the tissues' mechanical properties are significantly inferior to those of the materials that compose them.

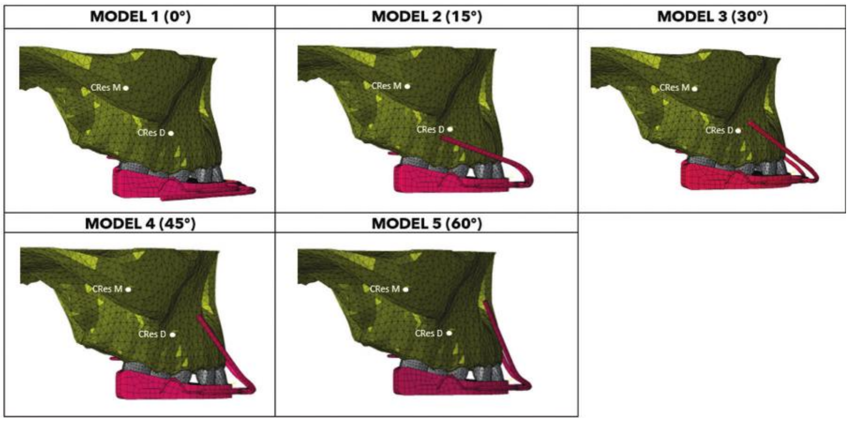

Fig. 1: Finite element model where the force lines of action used for each of the five models are indicated (M1 (0°), M2 (15°), M3 (30°), M4 (45°) and M5 (60°).

The finite element mesh included a total number of 37.326 and 150.781 nodes and elements, respectively. In which 145.313 linear tetrahedral elements of type C3D4, 4018 linear quadrilateral elements of type S4R and 1.290 linear triangular elements of type S3 built the mesh.

-Materials' Boundary Conditions and Properties

The mechanical properties of each part of the model were defined using young's modulus and Poisson's coefficient. Every material was assumed as homogeneous, isotropic, and linearly elastic. The boundaries of the bone's cortical and cancellous layers, enamel, and dentin were not considered in this study to facilitate the creation of the finite element mesh and simplify the model. Thus, a single value was used to represent both properties. The mechanical properties used for the teeth, bone, and (TA) have been reported in the literature (21) and are summarized in Table 1.

The (TA) and the face bow were considered a rigid body

Table 1: Mechanical properties of the materials: Young´s modulus and Poisson´s coefficient.

Material	Young's Modulus (GPa)	Poisson's Ratio
Bone	10	0.3
Teeth	20	0.3
Teuscher Appliance	200	0.33

The force's magnitude was selected based on clinical situations, according to the literature (16). A 4.4N (450 g) load was applied on each side of the geometric model, creating five models to simulate five different force lines of action (Model 1 (0°), Model 2 (15°), Model 3 (30°), Model 4 (45°), and Model 5 (60°) (Fig. 1).

The model's boundary conditions were set according to the junction between the maxilla and the cranial bone structures. Accordingly, the geometric model was fixed on the maxillary (skull base) and posterior (pterygoid pillar) surfaces, hence preventing displacement or rotation in any direction. Tight contact was assumed in the interfaces between the different parts of the model. Stress distribution in the five models studied was estimated by linear static analysis. A mesh convergence study was conducted based on the von Mises stresses (23). Von Mises stress results, estimated at an approximate midpoint of the maxilla and in a uniform-stress region, converged as the mesh density increased. Considering the geometric complexity, the mesh convergence study allows evaluating the quality of the approximation obtained (Fig. 2).

Results

The objective of creating a maxillary biomechanical model to simulate Class II malocclusion treatment using a (TA) combined with a face bow was achieved. Von Mises equivalent stress was selected as the parameter for outcome evaluation (23).

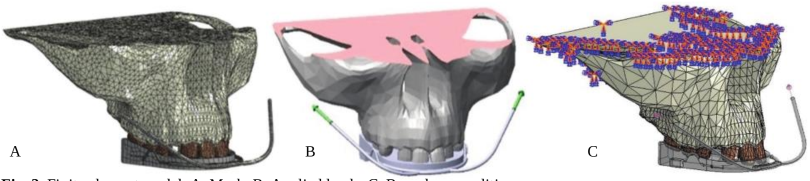

Fig. 2: Finite element model: A. Mesh. B. Applied loads. C. Boundary conditions.

A color scale was used, where red colors indicate areas subjected to a high-stress peak, while blue colors reflet stress levels close to zero. The main focus of the results was the concentration of stress transmitted to the maxilla by the (TA) with fiv different force lines of action (Fig. 1).

The results showed that different force lines of action interfered with stress distribution in the bone structures (Table 2). In every model tested, the highest stress concentration was found in the frontal region. The maxilla's anterior region, near the incisor foramen, showed slight stress dissipation through the palate in the anteroposterior direction. This stress distribution pattern was found in every model, but the maximum stress intensity varied (Fig. 3, Table 2).

Model 5 (60°) induced the highest stress concentration,

Table 2: Maximum von Mises stress values.

Maximum von Mises stress values (MPa)		
	Teeth	**Maxilla**
Model 1 (0°)	0.18310	0.22400
Model 2 (15°)	0.14285	0.43779
Model 3 (30°)	0.13956	0.59886
Model 4 (45°)	0.14307	0.72114
Model 5 (60°)	0.16438	0.80412

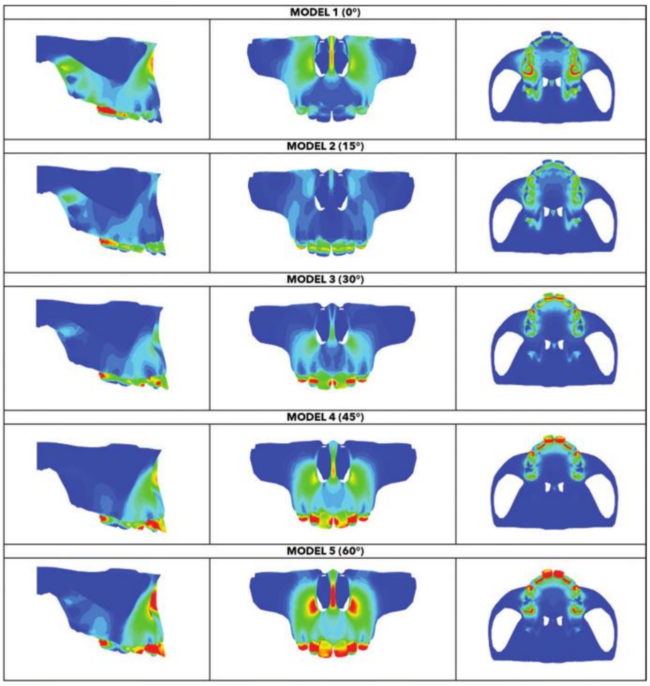

Fig. 3: Von Mises stress distributions obtained from different models by FEM, values are in MPa.

as observed in (Fig. 3). Conversely, stress concentration was lowest in Model 1 (0°). Stress increased progressively when the force line of action moved in a posteroanterior direction. Model 1 (0°) showed that stress concentration was highest at the molars, the nasal bone (nasal septum and pyriform aperture limits), and the pterygoid fossa. Despite showing the lowest stress concentration, this model showed increased stress distribution in an anteroposterior direction. In Model 2 (15°), the highest stress concentration occurred at the molars, and stress at the incisors was higher than in Model 1 (0°). However, stress concentration at the nasal septum was lower. In Model 3, stress concentration was highest at the molars. Stress at the incisors was higher than in the previous models and was distributed in the frontal region. Models 4 (45°) and 5 (60°) had similar stress distribution areas, but Model 5 (60°) showed the greatest distribution area and the highest stress levels compared to the other models. Due to force application, stress distribution was more similar between Models 1 (0°) and 2 (15°) and between Models 4 (45°) and 5 (60°), (Fig. 3).

Regarding individual dentoalveolar tooth behavior, results show higher stress at the incisors and molars than at the support region.

Although the applied force's magnitude was similar in every model, in Models 1 (0°) and 2 (15°), molars suffered greater distal displacement and incisors showed extrusion. In Model 3 (30°), the force line of action promoted distal displacement of molars and incisors. In Models 4 (45°) and 5 (60°), the whole maxillary anterior sector showed counterclockwise displacement (Fig. 4).

Discussion

FEA is based on a mathematical model whose geometry and boundary conditions are similar to the structure's ones and considers the mechanical properties of each component of the model. It is basically a numerical calculation tool that divides continuous bodies into discrete eleiments – finte elements, with mechanical properties close to those of the tissues they represent. The results' approximation depends inversely on the size and number of elements, which is why the convergence analysis was conducted von Mises. FEA may be useful to optimize oral structures and predict orthodontic treatments since *in-vivo* studiess are difficl t, time-consuming, and expensive. Moreover, numerical simulation has been reported as an effective tool for assessing the effects of different orthodontic appliances (17,18,20).

Force application in the maxilla creates differential stresses that emay influnce maxillary growth, thus being considered a valid approach for growing hyperdivergent patients with Class II malocclusion and associated maxillary protrusion (11,13,24). The effects of stress transmitted to the maxilla in this type of hyperdivergent Class II malocclusion treatment are extremely important but have been little studied. Thus, this study implemented FEA to assess the distribution of stress transmitted to the maxilla (teeth and maxillofacial complex) by a (TA) combined witha fiv different lines of action of extraoral force.

Some parameters, including the force's magnitude, point of application, and line of action, must be considered for obtaining excellent results when using extraoral forces (25,26-28).

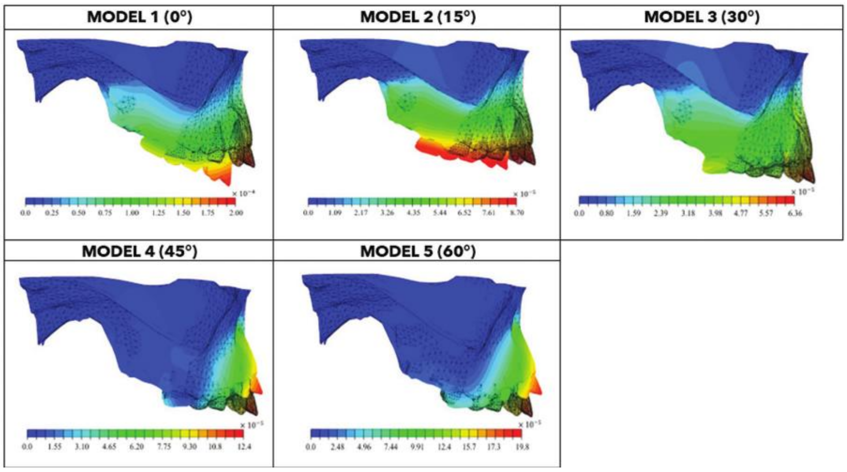

Fig. 4: Displacement magnitude profiles captured on deformed and undeformed shape for different models extracted from FEM, values are in mm.

Bowden *et al*., (25) in 1978, confirmed the importance of knowing the point of force application to better understand changes in palatal plane inclination. If the force vector passes through the maxilla's center of resistance, no momentum is created, and the maxilla should not rotate. However, if the force vector does not coincide with the maxilla's center of resistance, the maxilla is expected to rotate. In that case, the direction and the momentum created will depend on the shortest perpendicular distance between the force vector and the corresponding center of resistance.

In 1986, Teuscher showed that, when a high - pull force whose line of action coincides with the maxilla's center of resistance (CResM) and the maxillary dentition's center of resistance (CResD) is used, no rotations are expected, either by the maxilla or the maxillary dentition. However, if that force line of action passes between the CResM and the CResD, the maxilla rotates clockwise, and the maxillary dentition rotates counterclockwise. On the other hand, if the force line of action passes below the CResM and the CResD, both the maxilla and the maxillary dentition rotate clockwise (27).

In our study, a 4.4-N (450 g) force was applied on each side of the model with five different lines of action to identify the one that better suited the maxillary vertical and sagittal control in hyperdivergent Class II malocclusion treatment of a growing patient (26,27,29).

Using the extraoral force combined with the (TA) is particularly important because the forces are dissipated not only to the teeth but to every structure covered by the TA's acrylic, contrary to what happens when the extraoral force is applied directly on the bands placed on maxillary molars.

In our study, despite all the maxillary dentitions being covered by the TA's acrylic, the highest stress concentration was found at the level of the incisors and first molars. Some previous studies using FEA focused only on the application of high - pull extraoral forces directly on the maxillary first molars and showed some areas of stress on the root surface of the maxillary first molar (15, 16, 30).

A study conducted by Maruo *et al*., (16) modeled the maxilla, the maxillary teeth, and the headgear but did not consider the activator. They detected the highest displacement of the maxillary first molars with the low (cervical) pull, followed by the horizontal pull and the high pull. They also obtained greater intrusion of the maxillary first molar with the high pull, contrary to what was observed in our study (16). However, in our study, the (TA) was also modeled, besides the bone and every tooth, at treatment onset. Overall, the dynamics of the structures represented in that study do not intimately coincide with those presented in our models.

The materials' properties considered in our study represent mean values that do not take into account the patient's individual differentiation, age, gender, and diet. Moreover, the periodontal ligament was not considered to avoid any inconsistency and imprecision associated with modeling due to the differences between the periodontal ligament and the bone's mechanical properties. Despite these limitations, the results obtained in this study are extremely useful due to providing pertinent information for orthodontists and allowing the optimization of clinical procedures. In fact, the impact the different force lines of action have on the clinical effect highlights the importance of this precise control to reach the results set in the treatment planning.

In our study, Model 3 (30°) was the most consistent with the clinical objectives of hyperdivergent Class II malocclusion treatment in a growing patient due to the posterior displacement of the teeth and the nasomaxillary complex. Thus, anterior and inferior displacements were limited due to normal growth, contributing to the correction of the skeletal discrepancy because of promoting maxillomandibular differential growth.

In Models 1 (0°), and 2 (15°), the force application resulted in a clockwise displacement of the whole maxillary complex, which is not desirable in hyperdivergent Class II malocclusion treatment since it results in undesirable increased anteroinferior facial height. In Models 4 (45°) and 5 (60°) the maxillary complex rotated counterclockwise with a posterior dental extrusion effect, which is not desirable in hyperdivergent Class II malocclusion treatment, as it promotes a posterior rotation of the mandible or, conversely, a need for condylar distraction inside the joint to allow for adaptative dental intercuspidation.

We hope that the present study promotes further studies that assess the effects of extraoral forces' biomechanical stresses on both the maxilla and the mandible.

Conclusions

In this study, a finite element model was built to simulate the TA's effects on hyperdivergent Class II malocclusion treatment. The model was created based on a real anatomical geometry obtained by CT and the tissues' mechanical properties reported in the literature. The tissues were considered homogeneous and isotropic, and the analysis was conducted exclusively based on a linear elastic behavior. Considering the model's limitations, the FEA allowed obtaining results consistent with the clinical practice ones. The same model was used to simulate five situations of extraoral force application, and the comparative analysis of the results allows some important conclusions:

• Different lines of action of extraoral force combined with the Teuscher activator influence stress intensity and orthodontic and orthopedic force distribution in the maxilla.

• Stresses increased progressively when the force line of action moved in a posteroanterior direction.

• The extraoral force's line of action used in Model 3 (30°) is the most compatible with the objectives of the hyperdivergent Class II malocclusion treatment in growing patients because it promotes displacement of the teeth and maxillary complex, promoting vertical control.

References

1. McNamara JA Jr. Components of class II malocclusion in children 8-10 years of age. Angle Orthod. 1981;51:177-02.
2. Buschang PH, Sankey W, English J. Early treatment of hyperdivergent open-bite malocclusions. Semin Orthod. 2002;8:130-40.
3. Teuscher U. A growth-related concept for skeletal class II treatment. Am J Orthod. 1978;74:258-75.
4. Wheeler TT, McGorray SP, Dolce C, Taylor MG, King GJ. Effectiveness of early treatment of class II malocclusion. Am J Orthod Dentofacial Orthop. 2002;121:9-17.
5. Singh GD, Thind BS. Effects of the headgear-activator Teuscher appliance in the treatment of class II Division 1 malocclusion: a geometric morphometric study. Orthod Craniofac Res. 2003;6:88-5.
6. Marsan G. Effects of activator and high-pull headgear combination therapy: skeletal, dentoalveolar, and soft tissue profile changes. Eur J Orthod. 2007;29:140-8.
7. Martins RP, da Rosa Martins JC, Martins LP, Buschang PH. Skeletal and dental components of class II correction with the bionator and removable headgear splint appliances. Am J Orthod Dentofacial Orthop. 2008;134:732-41.
8. Franchi L, Pavoni C, Faltin K Jr., McNamara JA Jr., Cozza P. Long-term skeletal and dental effects and treatment timing for functional appliances in class II malocclusion. Angle Orthod. 2013;83:334-40.
9. Silvestrini BF, Lazzarotti L, Bini S, Migliorati M, Ugolini A. Maxillary "en masse" high-pull traction in class II division 1 subjects: which kind of skeletal outcomes does it produce? Eur J Paediatr Dent. 2020;21:271-6.
10. Kang JM, Park JH, Bayome M, Oh M, Park CO, Kook YA, et al. A three-dimensional finite element analysis of molar distalization with a palatal plate, pendulum, and headgear according to molar eruption stage. Korean J Orthod. 2016;46:290-300.
11. Jacob HB, Buschang PH, dos Santos-Pinto A. class II malocclusion treatment using high-pull headgear with a splint: a systematic review. Dental Press J Orthod. 2013;18:21-7.
12. Zervas ED, Galang-Boquiren MT, Obrez A, Costa Viana MG, Oppermann N, Sanchez F, et al. Change in the vertical dimension of class II division 1 patients after use of cervical or high-pull headgear. Am J Orthod Dentofacial Orthop. 2016;150:771-81.
13. Nucera R, Militi A, Lo Giudice A, Longo V, Fastuca R, Caprioglio A, et al. Skeletal and dental effectiveness of treatment of class II malocclusion with headgear: a systematic review and meta-analysis. J Evid Based Dent Pract. 2018;18:41-58.
14. Oh E, Ahn SJ, Sonnesen L. Evaluation of growth changes induced by functional appliances in children with class II malocclusion: superimposition of lateral cephalograms on stable structures. Korean J Orthod. 2020;50:170-80.
15. Gautam P, Valiathan A, Adhikari R. Craniofacial displacement in response to varying headgear forces evaluated biomechanically with finite element analysis. Am J Orthod Dentofacial Orthop. 2009;135:507-15.
16. Maruo IT, Maruo H, Saga AY, de Oliveira DD, Argenta MA, Tanaka OM. Tridimensional finite element analysis of teeth movement induced by different headgear forces. Prog Orthod. 2016;17:18.
17. Huiskes R, Chao EY. A survey of finite element analysis in orthopedic biomechanics: the first decade. J Biomech. 1983;16:385-09.
18. Knop L, Gandini LG Jr, Shintcovsk RL, Gandini MR. Scientific use of the finite element method in orthodontics. Dental Press J Orthod. 2015;20:119-25.
19. Tanne K, Hiraga J, Kakiuchi K, Yamagata Y, Sakuda M. Biomechanical effect of anteriorly directed extraoral forces on the craniofacial complex: a study using the finite element method. Am J Orthod Dentofacial Orthop. 1989;95:200-7.
20. Tanne K, Matsubara S, Sakuda M. Stress distributions in the maxillary complex from orthopedic headgear forces. Angle Orthod. 1993;63:111-8.
21. Chaves-Fernandes L, Farinazzo-Vitral RW, Yoshito-Noritomi P, Abrantes-Schmitberger C, da Silva Campos MJ. Influence of the hyrax expander screw position on stress distribution in the maxilla: A study with finite elements. Am J Orthod Dentofacial Orthop. 2019;155:80-7.
22. Freitas MR, Lima DV, Freitas KM, Janson G, Henriques JF. Cephalometric evaluation of class II malocclusion treatment with cervical headgear and mandibular fixed appliances. Eur J Orthod. 2008;30:477-82.
23. Mises Rv. Mechanik der festen körper im plastisch-deformablen zustand. Nachrichten von der Gesellschaft der Wissenschaften zu Göttingen. Mathematisch-Physikalische Klasse. 1913;4:582-92.
24. Türkkahraman H, Sayin MO. Effects of activator and activator headgear treatment: comparison with untreated Class II subjects. Eur J Orthod. 2006;28:27-34.
25. Bowden DE. Theoretical considerations of headgear therapy: a literature review. 2. Clinical response and usage. Br J Orthod. 1978;5:173-81.
26. Pfeiffer JP, Grobéty D. A philosophy of combined orthopedic-orthodontic treatment. Am J Orthod. 1982;81:185-01.
27. Teuscher U. An appraisal of growth and reaction to extraoral anchorage. Simulation of orthodontic-orthopedic results. Am J Orthod. 1986;89:113-21.
28. Jeong GM, Sung SJ, Chun YS, Mo SS. Finite-element investigation of the center of resistance of the maxillary dentition. Korean J Orthod. 2009;39:83-94.
29. Feizbakhsh M, Kadkhodaei M, Zandian D, Hosseinpour Z. Stress distribution in maxillary first molar periodontium using straight pull headgear with vertical and horizontal tubes: a finite element analysis. J Dent Res. 2017;14:117-24.
30. Alosman HS, Bayome M, Vahdettin L. A 3D finite element analysis of maxillary molar distalization using unilateral zygoma gear and asymmetric headgear. Orthod Craniofac Res. 2021;24:261-7.

Ethics

The use of these images to create the model was approved by the Ethics Committee of the Faculty of Dental Medicine of the Porto on May 5, 2018, under registration number 527.

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Authors' contributions

M.J. - conceptualization, investigation; M.V. - methodology and supervision; J.D.L. - writing the original draft; J.M.T.U.- methodology and for¬mal analysis; B.F. - data curation and investigation; M.J.P. - writing, re¬viewing, editing and visualization.

All authors have read and agreed to the published version of the manuscript.

Conflict of interest

The authors declare that they have no conflict of interest.

5. Nobre R, de Castro SM, Ponces MJ, Lopes JD, Ferreira AP. The relation between mandibular symphysis and the Angle class in orthodontic treatment. Med Pharm Rep. 2022;95:446-454.

The relation between mandibular symphysis and the Angle class in orthodontic treatment

DENTAL MEDICINE

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Abstract

Objectives. Facial perception depends on the different components of the face. The chin is a striking anatomical structure in the individual's identity and mandibular symphysis (MS) shape influences the adjacent soft tissue, determining facial harmony. In lateral cephalometry, the MS corresponds to the image of the mandibular body in its anterior curvature. It shape, inclination and thickness provide valuable information for orthodontic diagnosis and prognosis. Since facial features are associated with malocclusions, the present investigation aims to relate the height, thickness and inclination of the MS using Angle's Class.

Methods. 495 lateral incidence cephalograms of an orthodontic population were analyzed using a previously developed and tested software. The sample was randomly selected and the height, thickness and inclination of the MS were measured. The values were statistically analyzed ($p \leq 0.05$).

Results. The distribution according to Angle's Class was 48.9% for Class I, 34.7% for Class II Division 1, 7.4% for Class II Division 2 and 8.9% for Class III. The MS height did not´t show significant differences between the three dental classes. The MS thickness was significantly increased in Class II Division 2 and Class I subjects (p = 0,037). The MS inclination was significantly less in Class III subjects when compared to Class I and Class II Division 1 ($p \leq 0.001$).

Conclusions. The MS presented variations, which may be associated with a natural compensation against malocclusion, influencing the position of the teeth and their relationship with the other dento-craniofacial structures and with consequences on the facial harmony.

Keywords: mandibular symphysis, chin, angle class, orthodontic treatment, facial aesthetics

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Background and aims

The perception of the face is based on the recognition of the different subcomponents of the face [1,2]. Among the most relevant anatomical areas for addressing orthodontic problems, the mandible stands out due to the importance that this skeletal structure plays in the composition of facial balance and also the aesthetic perspective [3-5].

The term symphysis is reserved to define a certain type of suture or bone joint with special characteristics, such as immobility, which distinguish it from other joints in the body. Anatomically, it is the structure that establishes the union between the two halves of the mandibular bone in the anterior region, coinciding with the sagittal plane [6,7]. It is present in the lower 1/3 of the face and, therefore, it is relevant in terms of aesthetics and facial harmony [1,4,8]. In harmonious faces, the lower third is equivalent in size to the middle third and the upper third [9-11]. Symphysis, mentum, chin, mentonian symphysis, mental symphysis and chin bone are some of the various designations used in the literature for this structure.

Lateral teleradiography and the respective cephalometry are one of the oldest and most important elements of study in orthodontics [12,13]. Cephalometric analysis allows us to assess the relationship between the different craniofacial structures, fundamentally with regard to their shape, dimension and position. In lateral cephalometry, the mandibular symphysis (MS) corresponds to the anterior region of the mandibular bone, which serves as the base for the incisor teeth. It presents itself in an image well delineated by the cortical bone that demarcates it with a very characteristic "drop" shape. This structure corresponds to the image of the mandibular body in its anterior curvature.

When analyzing the MS, we must take into account its shape, dimension and inclination, as these provide important information for the orthodontic diagnosis and prognosis of the treatment plan. In this context, the main objective of the study was to relate the height, thickness and inclination of the mandibular symphysis using the Class of Angle. As secondary objectives, this study intends to evaluate factors that influence mandibular symphysis morphology, as well as to establish the importance of incorporating symphysis analysis in orthodontic treatment.

Methods

The present study is observational, cross-sectional, exploratory and descriptive.

Three thousand randomly selected individuals from a population of orthodontic cases from an orthodontic clinic in Northern Portugal were analyzed. From these, we obtained a final sample of 495 individuals who met the inclusion criteria.

Inclusion criteria: patients with initial records that: have not been subjected to any type of orthodontic treatment; protocol photographs; panoramic radiography and lateral teleradiography of the face; orthodontic exam. The lateral cephalograms had to have the mandibular symphysis clearly visible.

Exclusion Criteria: poor definition and quality of teleradiography; no cephalometric tracing; major oral rehabilitations; edentulous patients; absence of upper and/or lower central incisors.

The DOLPHIN IMAGING® program was used for observation and calibration of teleradiographies and execution of the cephalometric tracing (according to Ricketts) and the MB RULER® program for measuring angles (in degrees - º) and distances (in millimeters - mm). These values were properly filed in an Excel® document for further statistical analysis.

The symphysis variables analyzed were:

- Height: vertical distance between point Is and the horizontal line that passes through Mentum Point (Me).

- Width: distance between points Pogonion (Pog) and the most posterior point of the symphysis (L-Pog).

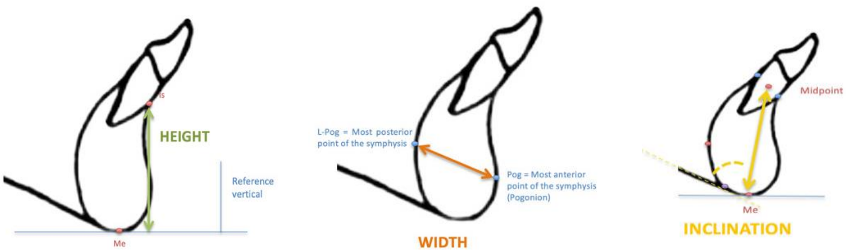
- Inclination: Angle that the line [Midpoint-Mentum Point] makes with the mandibular plane.

Figures 1, 2 and 3 show how the symphysis variables were measured.

Statistical analysis was performed using IBM® SPSS® version 25.0. The ANOVA methodology was used to compare the measures, and when significant differences were detected, Tukey's multiple comparison tests were used. The decision rule used consisted of detecting significant statistical evidence for probability values less than 0.05.

Ethical considerations: to carry out this study, facial cephalograms already existing in a clinical file were used, so the present study does not present any risk, since nothing was carried out in patients. During the research, all the ethical rules described in the current legislation were considered, namely regarding the treatment and storage of data, where the confidentiality of all information was guaranteed, and the data used are not identifiable to the patient.

Taking these facts into account, approval was requested from the Ethics Committee, from which a positive response was obtained.



Figures 1, 2 and 3. Symphysis variables (1-Height, 2-Width, 3- Inclination).

Results

Statistical analysis of measurement error: to verify the degree of systematic difference between the measurements of the pair by the same examiner at two times, preceded by verification of the normal distribution, the t-student test for paired samples was used in 10% of a sample randomly selected from the set of 495 valid cases. The results are shown in table I. According to the results of the t-student test for paired samples,[a] there are no significant differences in the mean values of the measurements at the two times.

Table I. Student t-test results for measurement error evaluation.[a]

	t	gl	p value	Result
MS height	1.934	59	0.058	Not significant
MS width	-0.143	59	0.887	Not significant
MS inclination[a]	-0.300	59	0.201	Not significant

The total sample consists of 495 cases, of which 140 are male (28.3%) and 355 are female (71.7%), aged between 7.06 and 68.02 years.

Individuals from all Angle Classes were present in the sample: 224 Class I subjects (45.3%), 159 Class II Division (Div.) 1 subjects (32.2%), 34 Class II Div.2 (6.9%), 42 Class III individuals (8.5%) and 36 undefined individuals (it was not possible to define their dental class).

Table II presents the sample characterization data in relation to the symphysis measures variables according to the Angle Class.

To compare symphysis measurements according to Angle Class, the ANOVA methodology was used to compare mean values between groups, and when significant differences were detected, Tukey's multiple comparison tests were used. The results are summarized in table III.

Table III. ANOVA results according to Angle Class.

	gl	F	p value	Result
MS height[a]	(4.488)	2.821	0.025	Significant
MS width[a]	(4.488)	2.691	0.031	Significant
MS inclination	(4.488)	10.452	<0.0001	Significant

Tukey's multiple comparison tests for significant results are shown in table IV.

From the results shown in table IV, significant differences were detected in the mean values in the pairs marked with (*). The profile graphs in figures 4, 5 and 6 illustrate these results.

The height of the symphysis did not show significant differences between the three dental classes.

The symphysis width was significantly greater in Class II Div.2 subjects.

The symphysis inclination was significantly lower in Class III subjects when compared to Class I subjects, and Class II Div.1 individuals had the highest MS inclination value.

Table II. Summary statistics for measures according to Angle Class.

	Angle Class	N	Mean	Standard Dev.	Min.	Max.
MS height	Class I	226	31.49	3.59	21.46	43.13
	Class II Div.1	159	31.31	3.74	22.68	38.69
	Class II Div.2	34	31.81	2.97	23.48	38.82
	Class III	41	31.91	4.32	24.64	40.86
	Undefined	35	33.55	3.96	25.25	42.07
	Total	495	31.64	3.72	21.46	43.13
MS width	Class I	226	14.05	1.85	8.82	23.56
	Class II Div.1	159	14.18	1.95	9.72	19.78
	Class II Div.2	34	15.05	1.64	11.12	18.56
	Class III	41	14.26	2.20	10.22	23.36
	Undefined	35	13.65	1.92	10.64	18.86
	Total	495	14.15	1.92	8.82	23.56
MS inclination	Class I	226	76.00	5.46	62.44	89.13
	Class II Div.1	159	77.61	6.82	26.96	89.03
	Class II Div.2	34	73.95	5.24	66.08	87.57
	Class III	41	71.57	5.33	62.00	82.80
	Undefined	35	74.05	6.08	56.85	84.39
	Total	495	75.87	6.18	26.96	89.13

Table IV – Multiple comparisons according to the Angle Class.

	(I) Angle Class	(J) Angle Class	mean difference (I-J)	p value
MS height (mm)	Class I	Class II Div.1	0.17119	0.992
		Class II Div.2	-0.32445	0.989
		Class III	-0.42806	0.960
		Undefind	-2.06558*	0.019
	Class II Div.1	Class II Div.2	-0.49564	0.954
		Class III	-0.59926	0.887
		Undefind	-2.23677*	0.011
	Class II Div.2	Class III	-0.10361	1.000
		Undefind	-1.74113	0.289
	Class III	Undefind	-1.63753	0,305
MS width (mm)	Class I	Class II Div.1	-0.12469	0.970
		Class II Div.2	-0.99735*	0.037
		Class III	-0.20609	0.969
		Undefind	0.40519	0.769
	Class II Div.1	Class II Div.2	-0.87266	0.111
		Class III	-0.08140	0.999
		Undefind	0.52988	0.570
	Class II Div.2	Class III	0.79126e	0.381
		Undefind	1.40254*	0.020
	Class III	Undefind	0.61128	0.632
MS inclination (º)	Class I	Class II Div.1	-1.60818	0.071
		Class II Div.2	2,.04689	0.336
		Class III	4,.42607*	0.000
		Undefind	1.95096	0.373
	Class II Div.1	Class II Div.2	3.65507*	0.011
		Class III	6.03425*	0.000
		Undefind	3.55914*	0.013
	Class II Div.2	Class III	2.37918e	0.421
		Undefind	-0.09593	1.000
	Class III	Undefind	-2.47511	0.371

a e *significnt d ffernces for a 5%s igni ficane l evel .

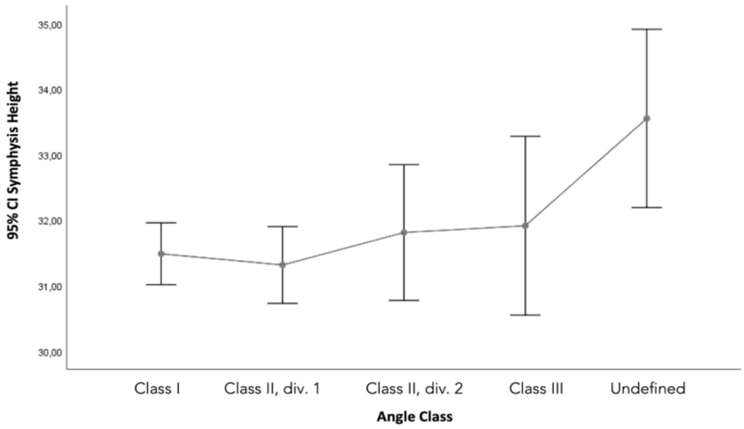


Figure 4. Mean values of symphysis height and respective 95% CI according to Angle's Class.

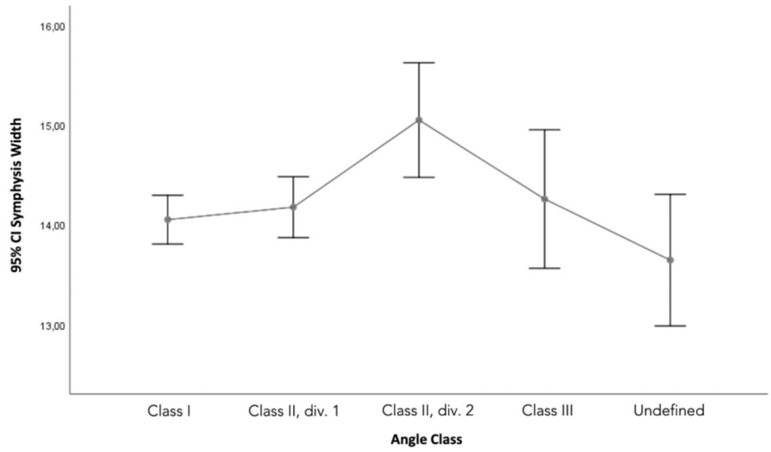


Figure 5. Mean values of symphysis width and respective 95% CI according to Angle's Class.

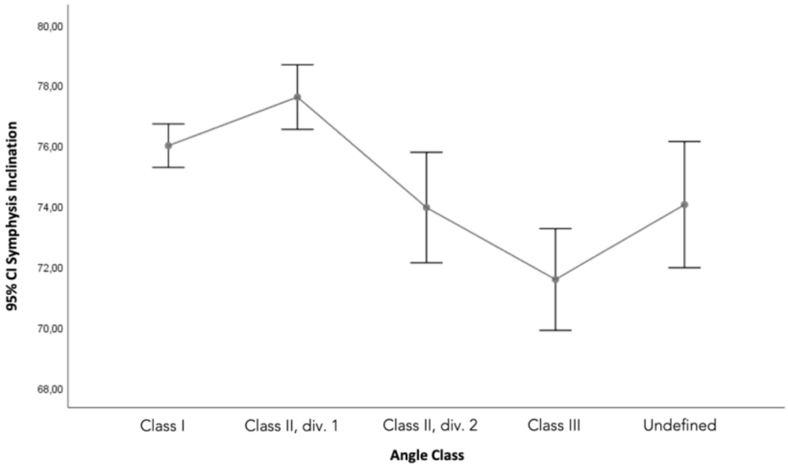


Figure 6. Mean values of symphysis inclination and respective 95% CI according to Angle's Class.

Table V presents the sample characterization data regarding the variables of the symphysis measurements, by sex (male and female) and in totality.

To assess whether thererare diffeences in the mean measurements of male and female individuals, a t-student test was performed for the independent samples. The results of these tests are summarized in table VI.

According to these results, in terms of mean values, a men have a significnt ly higher mean value than women in terms of symphysis thickness.

Table V. Summary measurements of the symphysis measurements.

		Male	Female	Total
MS height	Mean	32,22	31,43	31,65
	Median	32,74	31,49	31,73
	Standard Deviation	4,51	3,37	3,74
	Minimum	22,84	21,46	21,46
	Maximum	43,13	42,43	43,13
MS width	Mean	14,66	13,95	14,15
	Median	14,57	13,82	14,08
	Standard Deviation	2,08	1,81	1,92
	Minimum	8,82	9,68	8,82
	Maximum	23,36	23,56	23,56
MS inclination	Mean	76,42	75,63	75,85
	Median	76,63	75,69	76,00
	Standard Deviation	5,94	6,28	6,19
	Minimum	56,85	26,96	26,96
	Maximum	88,57	89,13	89,13

Table VI. Results ofathe t-student test for symphysis measurements according to sex.

	t	gl	p value	Result
MS height	1,871	203,358	0,063	Not significnt
MS widtha	3,756	492	<0,0001	Significnt
MS inclinaation	1,279	492	0,201	Not significnt

Discussion

When analyzing the MS, its shape, dimension and inclination should be taken into account. Within the limits of variation, these are influenced by various factors, such as genetic factors, ethnicity, lower incisor inclination, and facial type [14-20].

The total sample consisted of 495 cases, with 71.1% females and 28.3% males. Regarding sexual dimorphism in the mandibular symphysis, men had a higher mean value for symphysis width than women (Table V), which is in agreement with the results obtained in other studies in which this parameter was analyzed [6,15,18,21-30]. In this research, men had an average width of 14.66 mm against 13.95 mm for females.

In the research by Yaser Khan et al. [11] the reported values were 13.00 mm for men and 11.81 mm for women, corroborating the existence of sexual dimorphism in terms of width. According to Formby [31], in general, females showed lesser growth changes than males, and the latter have more changes in the total depth of the skeleton in the pogonion area, thus justifying the higher values of symphysis thickness. Lesrel et al. [32] justify the differences in width in relation to gender by a compensatory bone phenomenon (remodeling) [25]. On the other hand, Iuliano-Burns [33] justifie the bone dimorphism in MS by the later growth in males and claims that the differences in bone width are partially established before puberty [34].

Regarding to height, although the diffeence was not statistically significnt, there was also a diffeence among values, which was bigger in men than in women (Table V). In the present study, we obtained mean values of 32.22 mm for men and 31.43 mm for women. Compared with a study by Yaser Hamed Khan et al. [11] that evaluated the dimensions of the chin, and where the same method to analyze the height of the symphysis was used, the results they obtained were 28.95 mm for men and 28.31 mm for women. Both studies found a higher height symphysis in males compared to females.

Between the three dental classes, the height of the symphysis did not show significant differences, even though class III individuals were the ones with higher values. These results are in agreement with the results of other studies, which report that these individuals present greater vertical growth and that it is associated with an increase in cortical bone thickness [35,36].

Regarding the Angle Class, the height of the mandibular symphysis did not show significnt diffeences between the three dental classes (Table IV, Figure 4). The symphysis width was significntly larger in Class II Div.2 individuals (Table IV, Figure 5). The inclination of the symphysis was significntly lower in individuals with dental Class III when compared to individuals with Class I. Individuals with Class II Div.1 had a bigger inclination of the mandibular symphysis when compared to individuals with Class II Div.2 and Class III, although this difference is not statistically significant compared to Class I (Table IV, Figure 6).

The symphysis showed variations, which may be associated with a natural compensation for malocclusion, influencing the position of the teeth and their relationship with other dento-craniofacial structures [8,19,36-38].

It is currently agreed that the position of the mandibular incisors is directly related to the inclination of the MS, regardless of the type of occlusion [3,6,39]. Thus, the position of the mandibular incisors in relation to the supporting bone is an important factor in planning, in the evaluation of progress, as well as in determining the outcome of orthodontic treatment [40,41].

The shape of the symphysis is also associated with the amount of alveolar bone, with a narrow MS being associated with a thin alveolar bone and a wide MS with a thick alveolar bone [35,42]. A careful analysis of the bone condition of each individual should be performed before developing an orthodontic treatment plan, especially when considering a large amount of movement [14,15,43,44]. In patients with a thicker/wider symphysis, the protrusion of the incisors is aesthetically acceptable and, therefore, treatment without extractions is feasible [28,45]. On the other hand, a greater height of the symphysis and a small chin would be candidates for a treatment plan with extractions to compensate for discrepancies in the length of the dental arch [31]. The height and projeetion of the MS influnce the adjacent soft tissue. It is also important to understand and consider the mandibular growth in the treatment plan to have more predictable results, thus determining the harmony and facial aesthetics [11,35,46,47].

The most appreciated structures for facial recognition and for the perception of empathy among others are contained within what has been defind as the "inner triangle" (a triangle whose base surrounds the eyebrows and one of the vertices is located in the chin) [1,2,47-49]. The chin is one of the most visible structures of the face, not only in frontal view, but also in profil view, and its prominence is one of the facial features that society tends to associate with an individual's personality. Thus, the treatment plan must take into account the morphology of the symphysis (height, width and inclination), the position of the lower incisors and the amount of bone available [28,29,35,36,50]. The treatment must consider both the hard tissues and the soft and the search for symmetry and proportionality of the face should prevail for a facial balance.

Conclusions

The width of mandibular symphysis had the highest values in Class II Division 2 individuals and the inclination had the lower values in Class III individuals.

The shape of mandibular symphysis is influnced by several factors and due to dental malocclusion, symphysis varies.

This highlights the importance of incorporating mandibular symphysis analysis when planning orthodontic treatment.

References

1. Prokopakis EP, Vlastos IM, Picavet VA, Nolst Trenite G, Thomas R, Cingi C, et al. The golden ratio in facial symmetry. Rhinology. 2013;51:18-21.
2. Hashim PW, Nia JK, Taliercio M, Goldenberg G. Ideals of facial beauty. Cutis. 2017;100:222-224.
3. Grehs RA. Morphological, dimensional and positional characteristics of the human mandibular symphysis, under a radiocephalometric approach. Thesis - Campinas State University; 1979.
4. Sella Tunis T, Hershkovitz I, May H, Vardimon AD, Sarig R, Shpack N. Variation in Chin and Mandibular Symphysis Size and Shape in Males and Females: A CT-Based Study. Int J Environ Res Public Health. 2020;17:4249.
5. Sella Tunis T, May H, Sarig R, Vardimon AD, Hershkovitz I, Shpack N. Are chin and symphysis morphology facial type-dependent? A computed tomography-based study. Am J Orthod Dentofacial Orthop. 2021;160:84-93.
6. Al-Khateeb SN, Al Maaitah EF, Abu Alhaija ES, Badran SA. Mandibular symphysis morphology and dimensions in different anteroposterior jaw relationships. Angle Orthod. 2014;84:304-309.
7. Breeland G, Aktar A, Patel BC. Anatomy, Head and Neck, Mandible. In: StatPearls. Treasure Island (FL): StatPearls Publishing; 2022 Jan.
8. Torgut AG, Akan S. Mandibular symphysis morphology in diffeent skeletal malocclusions and its correlation with uvulo-glossopharyngeal structures. Cranio. 2021;39:533-540.
9. Turk T, Cakmak F, Sumer M. Advancement of mandibular symphysis with distraction osteogenesis. Am J Orthod Dentofacial Orthop. 2009;135:232-240.
10. Câmara P. Aesthetics in orthodontics: dental (DRED) and facial (DREF) aesthetic reference diagrams. Dental Press Magazine of Orthodontics and Facial Orthopedics. 2006;11:130-156.
11. Beckmann SH, Kuitert RB, Prahl-Andersen B, Segner D, The RP, Tuinzing DB. Alveolar and skeletal dimensions associated with lower face height. Am J Orthod Dentofacial Orthop. 1998;113:498-506.
12. Molina-Berlanga N, Llopis-Perez J, Flores-Mir C, Puigdollers A. Lower incisor dentoalveolar compensation and symphysis dimensions among Class I and III malocclusion patients with diffeent facial vertical skeletal patterns. Angle Orthod. 2013;83:948-955.
13. Ricketts RM. Cephalometric synthesis: An exercise in stating objectives and planning treatment with tracings of the head roentgenogram. American Journal of Orthodontics.

1960;46:647-673.

14. Guerino P, Marquezan M, Mezomo MB, Antunes KT, Grehs RA, Ferrazzo VA. Tomographic Evaluation of the Lower Incisor's Bone Limits in Mandibular Symphysis of Orthodontically Untreated Adults. Biomed Res Int. 2017;2017:9103749.
15. Gracco A, Luca L, Bongiorno MC, Siciliani G. Computed tomography evaluation of mandibular incisor bony support in untreated patients. Am J Orthod Dentofacial Orthop. 2010;138:179-187.
16. Meredith HV. Change in the profile of the osseous chin during childhood. Am J Phys Anthropol. 1957;15:247-252.
17. Horowitz SL. Osborne RH, DeGeorge FV. A cephalometric study of craniofacial variation in adult twins. Angle Orthod. 1960;30:1-5.
18. E BC. A longitudinal cephalometric study of growth of the human mandibular symphysis. Northwestern University Bollet. 1968;68(11):6-14.
19. Garn SM, Lewis AB, Vicinus JH. The inheritance of symphyseal size during growth. Angle Orthod. 1963;33:222-231.
20. Schudy FF. Vertical growth versus anteroposterior growth as related to function and treatment. Angle Orthodontist. 2009;34:75-93.
21. Khan YA, Kishore SV, Bukhari A, Rachala MR, Sashidhar NR. Alveolar and Skeletal Chin Dimensions Associated with Lower Facial Height Among Different Divergent Patterns. J Clin Diagn Res. 2016;10:ZC75-ZC80.
22. Swasty D, Lee J, Huang JC, Maki K, Gansky SA, Hatcher D, et al. Cross-sectional human mandibular morphology as assessed in vivo by cone-beam computed tomography in patients with different vertical facial dimensions. Am J Orthod Dentofacial Orthop. 2011;139(4 Suppl):e377-e389.
23. Merrot O, Vacher C, Merrot S, Godlewski G, Frigard B, Goudot P. Changes in the edentate mandible in the elderly. Surg Radiol Anat. 2005;27:265-270.
24. Burstone CJ. The integumental profile. Am J Orthod. 1958;44:1-25.
25. Uysal T, Yagci A, Ozer T, Veli I, Ozturk A. Mandibular anterior bony support and incisor crowding: Is there a relationship? Am J Orthod Dentofacial Orthop. 2012;142:645-653.
26. Vasseur L. Racial differences in mandibular symphyseal morphology. J Dental Research. 1977;56:346.
27. Linjawi AI, Afify AR, Baeshen HA, Birkhed D, Zawawi KH. Mandibular symphysis dimensions in different sagittal and vertical skeletal relationships. Saudi J Biol Sci. 2021;28:280-285.
28. Marghalani HYA, Guan G, Hyun P, Tabbaa S, Linjawi AI, Al-Jewair T. Relationship between mandibular symphysis dimensions and skeletal pattern in adults. Folia Morphol (Warsz). 2021 May 6. doi: 10.5603/FM.a2021.0045. Online ahead of print.
29. Evangelista K, Silva MAGS, Normando D, Valladares-Neto J. Factors associated with the morphology of the mandibular symphysis and soft tissue chin. Dental Press J Orthod. 2021;26:e2119347.
30. Mense C, Saliba-Serre B, Ferrandez AM, Hüe O, Ruquet M, Lalys L. Cone beam computed tomography analysis of the edentulous mandibular symphysis. J Dent Sci. 2021;16:115-122.
31. Mangla R, Singh N, Dua V, Padmanabhan P, Khanna M. Evaluation of mandibular morphology in different facial types. Contemp Clin Dent. 2011;2:200-206.
32. Lestrel PE, Takahashi O, Kanazawa E. A quantitative approach for measuring crowding in the dental arch: Fourier descriptors. Am J Orthod Dentofacial Orthop. 2004;125:716-725.
33. Iuliano-Burns S, Hopper J, Seeman E. The age of puberty determines sexual dimorphism in bone structure: a male/female co-twin control study. J Clin Endocrinol Metab. 2009;94:1638-1643.
34. Alves JM. Study to define a new formula for craniofacial skeletal classification: Thesis - Faculty of Medicine of Porto University; 2012.
35. Gousman J, Park JH, Chae JM. Evaluating mandibular symphysis bone density according to various skeletal patterns with CBCT. Orthod Craniofac Res. 2021;24:70-77.
36. Jain S, Puniyani P, Saifee A. Mandibular symphysis morphology and lower incisor angulation in different anteroposterior jaw relationships and skeletal growth patterns - a cephalometric study. Med Pharm Rep. 2020;93:97-104.
37. Watnick SS. lnheritance of craniofacial morphology. Angle Orthod. 1972;42:339-351.
38. Salemi F, Farhadian M, Ebrahimi M. Anatomical Variations of the Mandibular Symphysis in a Normal Occlusion Population Using Cone-Beam Computed Tomography. Maedica (Bucur). 2021;16:230-238.
39. Wehrbein H, Bauer W, Diedrich P. Mandibular incisors, alveolar bone, and symphysis after orthodontic treatment. A retrospective study. Am J Orthod Dentofacial Orthop. 1996;110:239-246.
40. Yu Q, Pan XG, Ji GP, Shen G. The association between lower incisal inclination and morphology of the supporting alveolar bone--a cone-beam CT study. Int J Oral Sci. 2009;1:217-223.
41. Yamada C, Kitai N, Kakimoto N, Murakami S, Furukawa S, Takada K. Spatial relationships between the mandibular central incisor and associated alveolar bone in adults with mandibular prognathism. Angle Orthod. 2007;77:766-772.
42. Jones JD. The eruption of the lower incisor and the accompanying development of the symphysis and point B. Angle Orthod. 1966;36:358-362.
43. Lin H, Zhu P, Lin Q, Huang X, Xu Y, Yang X. Comprehensive Analysis of Mandibular Residual Asymmetry after Bilateral Sagittal Split Ramus Osteotomy Correction of Menton Point Deviation. PLoS One. 2016;11:e0161601.
44. Torres HM. Radiographic evaluation of the influence of mentoplasty on the pharyngeal air space in patients undergoing maxillomandibular advancement. 2014.91f. Thesis - Goias Federal University; 2014.

45. Al-Ani MH, Mageet AO. Extraction Planning in Orthodontics. J Contemp Dent Pract. 2018;19:619-623.
46. Bolas-Colvee B, Tarazona B, Paredes-Gallardo V, Arias-De Luxan S. Relationship between perception of smile esthetics and orthodontic treatment in Spanish patients. PLoS One. 2018;13:e0201102.
47. Moreira A. Optimization of aesthetics in orthodontic treatments and orofacial rehabilitation. Thesis - Faculty of Dental Medicine of Porto University; 2013.
48. Gkantidis N, Christou P, Topouzelis N. The orthodontic-periodontic interrelationship in integrated treatment challenges: a systematic review. J Oral Rehabil. 2010;37:377-390.
49. Blatz MB, Chiche G, Bahat O, Roblee R, Coachman C, Heymann HO. Evolution of Aesthetic Dentistry. J Dent Res. 2019;98:1294-1304.
50. Ricketts RM. The keystone triad: I. Anatomy, phylogenetics, and clinical references. American Journal of Orthodontics. 1964;50:244-264.

6. Martins E, Silva JC, Pires CA, Ponces MJ, Lopes JD. Sagittal joint spaces of the temporomandibular joint: Systematic review and meta-analysis. Rev Port Estomatol Med Dent Cir Maxilofac. 2015;56(2):80-88.

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Review

Sagittal joint spaces of the temporomandibular joint: Systematic review and meta-analysis

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ABSTRACT

The aim of this study was to perform a systematic review and meta-analysis on the sagittal joint spaces measurements of the temporomandibular joint. An electronic database search was performed with the terms “condylar position”; “joint space” AND “TMJ”. The risk of bias of each study was assessed with “*Cochrane risk of bias tool*”. The values used in the meta-analysis were the joint space measurements and their differences between the right and left joint.

From the initial search 2706 articles were retrieved. Eighteen articles classified for final review. Only one study was classified as having high level of evidence. Seventeen of the reviewed studies were included in the meta-analysis concluding that the mean sagittal joint space values were: anterior joint space 1.86 mm, superior 2.36 mm and posterior 2.22 mm. However, the analysis also showed high levels of heterogeneity. Right and left comparison has shown statistically significant differences.

Espaços articulares sagitais da articulação temporomandibular: revisão sistemática e meta-análise

Palavras chave:
Articulação temporomandibular
Revisão
Meta-análise

RESUMO

O objetivo deste estudo foi realizar uma revisão sistemática e meta-análise sobre os espaços articulares sagitais da articulação temporomandibular. Foi realizada uma pesquisa eletrónica com os termos “condylar position”, “joint space”AND”TMJ”. O nível de evidência de cada estudo foi avaliado com “Cochrane risk of bias tool”. Os valores sumariados na meta-análise foram os espaços articulares e a diferença entre a articulação direita e esquerda.

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Da pesquisa inicial resultaram 2076 artigos dos quais 18 foram selecionados para a revisão. Apenas um estudo foi considerado de elevado nível de evidência. Foram incluídos na meta-análise 17 dos artigos da revisão concluindo-se que, os valores médios para os espaços articulares sagitais foram: 1.86 mm para o anterior, 2.36 mm para o superior e 2.22 mm para o posterior. No entanto, a análise revelou ainda grande heterogeneidade nos resultados dos estudos avaliados. Verificaram-se diferenças estatisticamente significativas entre as articulações esquerda e direita.

Introduction

The mandibular condyle position has been at the centre of a long lasting controversy among gnathologists and orthodontists. The ideal concept of the mandibular condyle position has changed from the most retruded position of the condyle in the glenoid fossa to the most superior position of the condyle. Nowadays it is accepted as the most anterosuperior position of the mandibular condyle in the glenoid fossa with the articular disk placed in between.[1–4] The literature also shows a great confusion concerning the relationship between dental occlusion and the temporomandibular joints. It is possible to find articles proving the relationship between these two variables, while others achieved contrary results with no relationship being suggested.[5–8] The major focus of the discussion usually is the ideal mandibular condyle position and the effects of its variation.[4,9,10] With the evolution of radiographic exams like computerized tomographies (CT), including the new 3D cone-beam computed tomography (CBCT) and magnetic resonance imaging (MRI) it is now possible to radiographically examine the position of the condyle.[11–13] The most common method found in the literature to determine this position is the assessment of the joint space measurements, which are the radiographic space found between the condyle and the glenoid fossa where the articular disk is placed.[14] A variation on the values of these measurements suggest a displacement of the condyle and so, the determination of the "gold standard" for these values would be a very important tool to determine any variation to the condyle position. The aim of this study is to perform a systematic review and meta-analysis on the sagittal joint space measurements of the temporomandibular joint to assess the mean values for these measurements.

Methods

Search strategy

A comprehensive electronic database search to identify relevant publications was conducted, and the reference lists in relevant articles were searched manually for additional literature. No language restrictions were set, although no attempt was made to explore the informally published literature, like conference proceedings and abstracts of researches presented at conferences and dissertations. The research extended to the following databases: Medline (Pubmed), Lilacs, Scopus, Ebsco (Host by University of Porto) and Cochrane Central Register of Controlled Clinical Trials.

The search terms were "condylar position" and "joint space" AND "TMJ" with no year of publication restriction in order to include the highest number of articles (to 22 April 2014). No restriction to study design was applied.

Faculty of Dental Medicine of University of Porto and Portuguese Society of Dentofacial Orthopedics' libraries were also consulted for printed articles not available online.

Critical evaluation

At the first stage, two reviewers screened independently the titles of the retrieved records, and only the titles related to TMJ joint space assessment were included. Joint space was defined as the radiographic image between the mandibular condyle and the glenoid fossa where the disk is interposed. Next, the abstracts of the retrieved publications were read by the two reviewers and categorized according to the radiographic procedure used to assess the joint space. An article had only to be justified by one reviewer to be included in the second selection phase. Eligibility of the retrieved articles was determined by applying the following inclusion criteria: (1) tomographic examination of the TMJ (2) determination of sagittal joint space measurements at least on two different points (anterior and posterior). The main reasons for exclusion were: mandible fractures, studies not performed in living humans, surgical interventions, studies with patients with syndromes or chronic diseases (including degenerative pathology of the TMJ), samples containing patients only in the primary or mixed/early permanent dentition, clinical only evaluation of the mandibular condyle position, 2D radiograph or magnetic resonance imaging, previous orthodontic or splint therapy, case reports, discussion or debate articles. All not published studies were also excluded.

The analysis was based on primary materials. When an abstract was considered by at least one author to be relevant, it was read in full text. At the second stage, the full texts were retrieved and critically examined. Reference lists from the articles selected on the second stage were screened and articles related to joint space measurements were hand-searched.

Data gathering

The following data were extracted from the selected articles: year of publication, study type, study method, sample description, joint space measurements on the sagittal plane, error analysis method, statistical analysis and author's conclusion. This method was pilot-tested on ten randomly selected included articles and then refined. One reviewer author then extracted the mentioned data from the included articles and the second author checked. Any disagreement was resolved with discussion between the two authors until a consensus was reached. The risk of bias was assessed according to the "Cochrane risk of bias tool"[15] as suggested by the "PRISMA statement for reporting systematic reviews and meta-analyses of studies that evaluate health care interventions: explanation and elaboration".[16]

Meta-analysis

The values studied in this meta-analysis were the sagittal joint space measurements (anterior, superior and posterior joint space) and the differences between the right and left joints. As not all the included articles presented the values for all the spaces from the right and left joints, the analysis were performed including all the data presented in each selected study. For the comparative analysis between the right and left joints, mean and standard deviation values from the samples of each article were used. For global joint space assessment, mean and standard deviation of the total sample (including both the values from the right and left joints) were used.

The restricted maximum-likelihood (REML) method was used to estimate de variability between the studies. Inverse variance method was used to assess the weight of each study.

Heterogeneity was determined using the Q Cochran test and the I^2 statistics by Higgins and Thompson.[17]

Statistical analysis was performed using "R", version 2.15.2 from "The R Project for Statistical Computing", available from http://www.r-project.org.

Results

Search results

The initial search strategy allowed retrieving 916 articles from Medline (Pubmed), 1114 from Scopus, 158 from EBSCOhost,

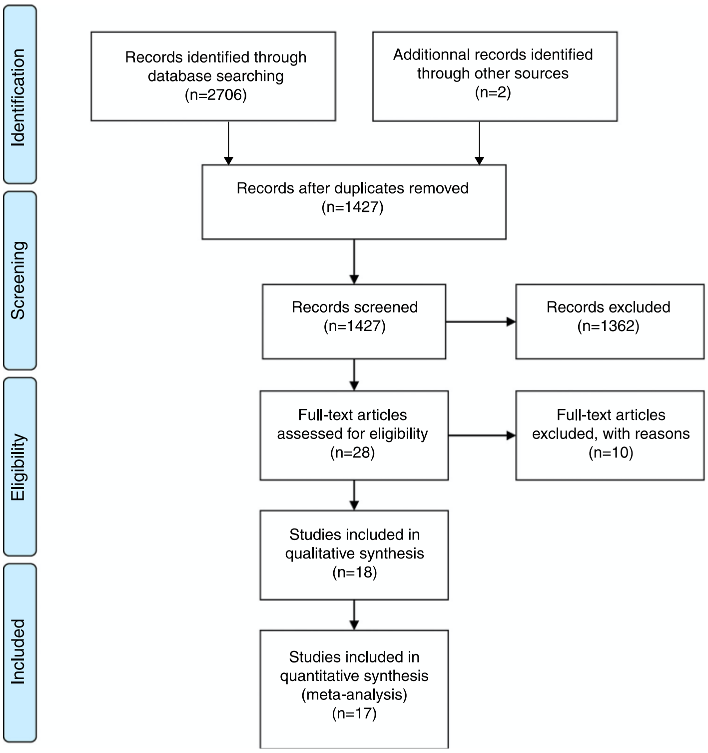

Fig. 1 – Flow diagram illustrating the search strategy results.
***Source*: Adapted from: Moher D, Liberati A, Tetzlaff J, Altman DG, The PRISMA Group (2009). Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement. PLoS Med 6(6): e1000097. doi:10.1371/journal.pmed1000097.**

19 from Lilacs and none from the Cochrane Central Register of Controlled Clinical Trials. The number of articles reviewed in each phase of this systematic review is presented in the PRISMA flow diagram (Fig. 1). After excluding 978 duplicates, 1230 articles remained for review. In the first phase selection, the observers screened the articles by reading titles and abstracts. Articles that were not eligible because of irrelevant aims and were not directly related to this systematic review were excluded, thus 61 articles remained for further reading. 28 articles were assessed for eligibility. After screening all the articles full text according to the inclusion/exclusion criteria, 18 articles classified for final review.

Type of study and method used for joint space assessment

A Randomized Clinical Trial (RCT)[18] was found. Aditionally, six prospective[19–24] and eleven retrospective[25–35] studies were found that fullfilled the elegibility criteria defined for this review. Six of the selected articles[22,25,27,32–34] used CBCT to assess the TMJ joint space while nine[18–21,23,26,28,30,35] used conventional CT and three [24,29,31] used linear tomography.

Twelve of the selected studies[19–21,23,24,26,28–30,32,33,35] assessed the joint space measurements by determining the closest distance between the mandibular condyle and the glenoid fossa surface.

Table 1 – Summary of the quality analysis of the 18 included studies.

	Estimation of sample size	Sample description	Error analysis	Normality tests	Adequate statistics provided	Randomization	Statistical analysis	Level of evidence
1[25]	No/Not known	Yes	No	Yes	Yes	No	Adequate	Low
2[32]	No/Not known	Yes	No	No information N > 30	Yes	No	Adequate (correlation)	Low
3[26]	No/Not known	Yes	Yes	No information	Yes	No	Adequate	Low
4[19]	No/Not known	Incomplete	No	No information N > 30	Yes	No	Adequate (correlation)	Low
5[27]	No/Not known	Yes	Yes	No information	Yes	No	Adequate	Low
6[18]	No/Not known	Yes	Yes	Yes	Yes	Yes	Adequate	Moderate
7[28]	No/Not known	Incomplete	Yes	No information	Yes	No	Adequate	Low
8[29]	No/Not known	Yes	No	No information N > 30	Incomplete	No	Adequate (correlation)	Low
9[33]	Yes	Yes	Yes	No information Non-parametric tests	Yes	No	Adequate	Low
10[20]	No/Not known	Incomplete	Yes	No information N > 30	Yes	No	Adequate	Low
11[21]	No/Not known	Incomplete	Yes	No information	Yes	No	Adequate (correlation)	Low
12[22]	No/Not known	No	Yes	No information	Yes	No	Adequate	Low
13[31]	No/Not known	Yes	No	No information N > 30	Yes	No	Adequate	Low
14[23]	No/Not known	Incomplete	No	No information	Yes	No	Adequate	Low
15[34]	No/Not known	Yes	No	No information	Incomplete	No	Adequate	Low
16[24]	No/Not known	Yes	No	No information	Incomplete	No	Adequate (correlation)	Low
17[30]	No/Not known	Yes	No	No information	Incomplete	No	Adequate	Low
18[35]	No/Not known	Incomplete	No	No information N = 30	Yes	No	Adequate (correlation)	Low

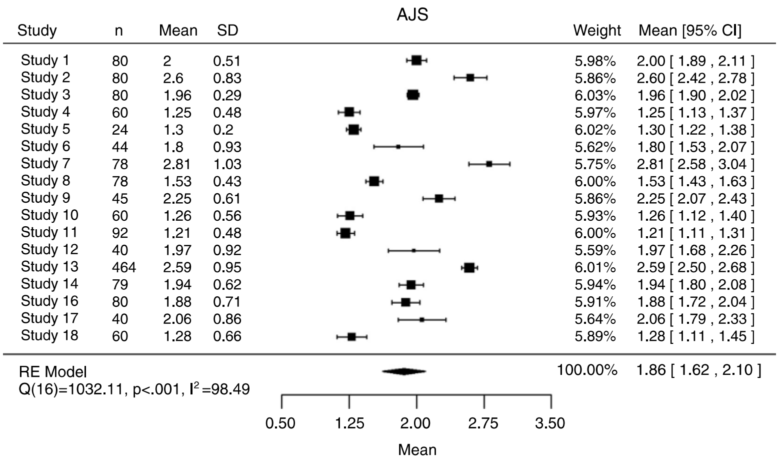

Fig. 2 – Mean anterior joint space in each study and globally.

On the other hand, four articles[25,27,31,34] used a geometrical construction to assess the joint space measurements. Different authors used the Frankfurt horizontal line or the true horizontal line as a reference plane to determine the most superior point of the glenoid fossa. Following, the distance between this point and the highest point of the condyle (determined by the same method) was measured, resulting the value of the sagittal joint space. After this, starting from the most superior point of the glenoid fossa, two tangent lines were traced to the most anterior and posterior point of the condyle respectively. The distance between each of these points and the point where a perpendicular line to the tangents crosses the surface of the glenoid fossa was the anterior and posterior joint space respectively.

Two studies[18,22] used a similar method to the one described above, but used the centre of the mandibular condyle as the reference point.

Quality assessment

The summary of the quality analysis of the selected articles is presented in Table 1.

In general, the statistical analysis performed was adequate to the objectives defined on each study and the statistical data are adequately presented in most cases. Apart from this, nine of the included articles[21–24,26–28,30,34] used parametric tests (T Student or ANOVA) in small samples (less than 30), with no information on the normality of the data.

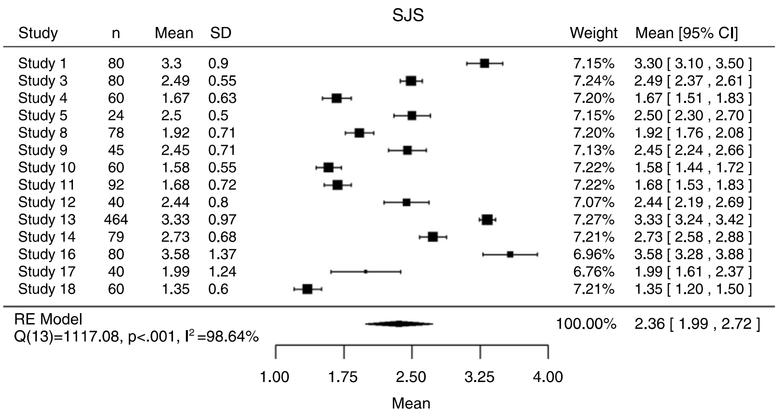

Fig. 3 – Mean superior joint space in each study and globally.

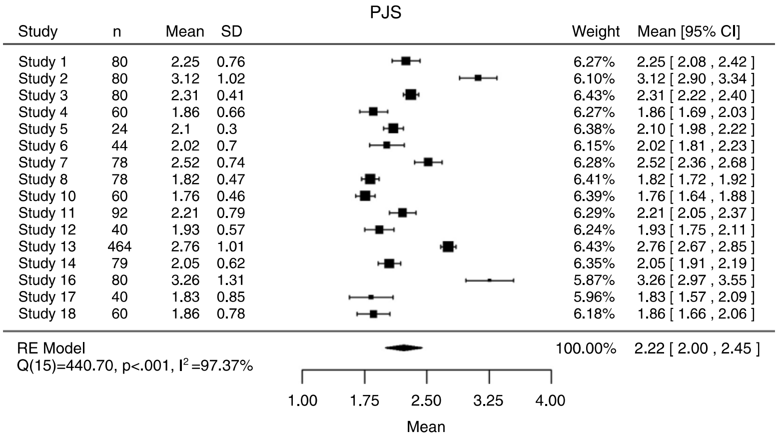

Fig. 4 – Mean posterior joint space in each study and globally.

Pearson correlation was used by six authors,[19,21,24,29,32,35] with no mention to the linear relation between the variables, which is necessary to the use and interpretation of this coefficient. Seven studies[19–23,28,35] did not present an adequate sample description, with no information about the age or gender. The other eleven[18,24–27,29–34] showed at least, the number of patients from each gender and data concerning the age of the included sample (mean, standard deviation, minimum and maximum values). The error analysis was presented in seven of the articles.[18,21,22,26–28,33] Only one study presented the estimation of sample size.[33] Randomization was used by Tsuruta et al.[18] and none of the retrieved articles presented blinding in measurements. Only one[18] of the studies was classified as moderate level of evidence, as it presents randomization and adequate statistics but fails to presents blinding in measurements. All the other articles were classified as low level of evidence.

Meta-analysis results

Seventeen of the studies presented on the review were included in this meta-analysis. One study[34] did not present standard deviation values and so, statistical comparison with other studies was not possible.

The mean anterior joint space from the 17 considered studies was 1.86 mm (95% CI: 1.62–2.10), although high levels of heterogeneity were found among the studies ($Q(16) = 1032.11$; $P < 0.001$; $I^2 = 98.49\%$) (Fig. 2).

The superior joint space presented a mean value of 2.36 mm (95% CI: 1.99–2.72), also with high levels of heterogeneity between the 14 articles that presented this value ($Q(13) = 1117.08$; $P < 0.001$; $I^2 = 98.64\%$) (Fig. 3).

The posterior joint space also presented high heterogeneity among the 16 included samples ($Q(15) = 440.70$; $P < 0.001$; $I^2 = 97.37\%$) with a mean value of 2.22 mm (95% CI: 2.00–2.45) (Fig. 4).

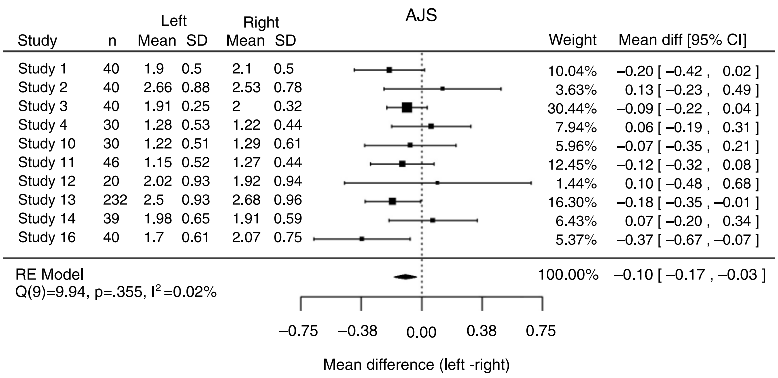

Fig. 5 – Mean difference between the anterior joint space on the right and left joints for each study and globally.

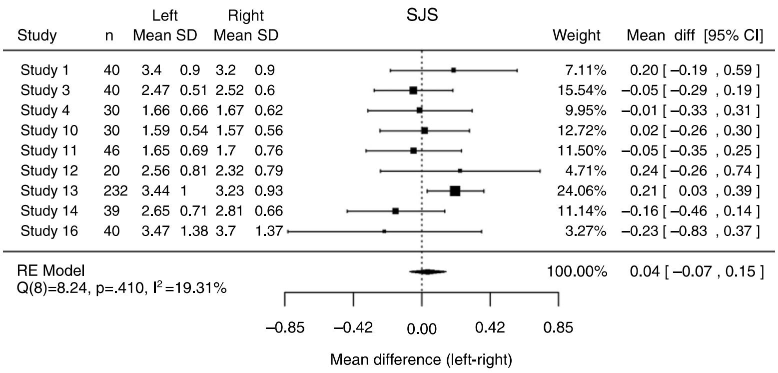

Fig. 6 – Mean difference between the superior joint space on the right and left joints for each study and globally.

The mean global differences and the differences among the studies between the right and left anterior, superior and posterior joint spaces are show in Figs. 5–7 respectively. In all of the comparisons, the difference is close to zero.

For the anterior joint space, the mean difference is −0.10 mm (95% CI: −0.17; −0.03), without heterogeneity between the included samples ($Q(9) = 9.94$; $P = 0.355$; $I^2 = 0.02\%$) (Fig. 5).

As for the mean difference between the right and left superior joint spaces, the value was 0.04 mm (95% CI: −0.07; 0.15), presenting low heterogeneity among the differences found on the different studies considered ($Q(8) = 8.24$; $P = 0.410$; $I^2 = 19.31\%$) (Fig. 6).

The posterior joint space of the right and left joints showed moderate heterogeneity between the samples ($Q(9) = 21.07$; $P = 0.012$; $I^2 = 56.48\%$) with a mean global difference of −0.04 mm (95% CI: −0.17; 0.10) (Fig. 7).

Discussion

Joint space measurements have been used to assess the mandibular condyle position radiographically since this method was used in laminographies.[36] Since then the technology has evolved so much that it is now possible to assess the joint space in 3D radiographic imaging with CT, CBCT and MRI. Therefore, a systematic review to assess the relevance of these methods and their scientific evidence is necessary. In the present study, all the articles about joint space assessment on 2D radiographic examination of the TMJ were excluded as these methods have proven lower accuracy both in the image acquisition process and in measurements, than 3D radiographic methods.[37] MRI was also excluded because this exam is not indicated to assess hard structures and, as both the mandibular condyle and the glenoid fossa joint space limits are mainly bone and cartilage, this is not the best exam for

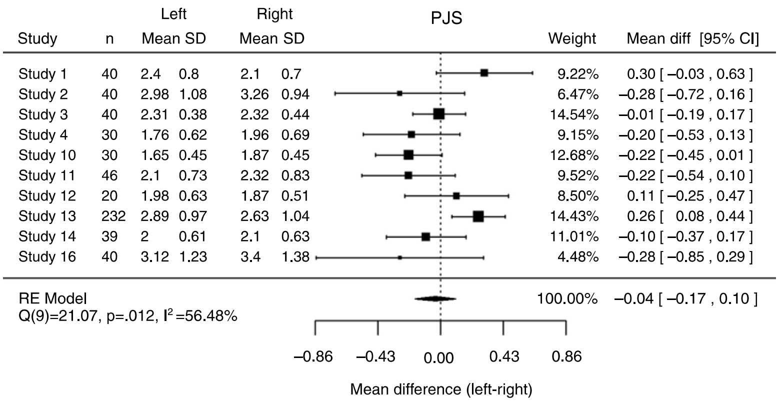

Fig. 7 – Mean difference between the posterior joint space on the right and left joints for each study and globally.

accurately determine joint space measurements.[38] Furthermore, all the articles including extensive treatment that could significantly influence the joint space, like orthodontic treatment and splint therapy, have been excluded. Finally, studies with samples exclusively on the mixed and early permanent dentition were excluded as, according to some authors, the mandibular condyle is not completely formed before the end of the growth, in other words until 15–16 years old.[39] The exclusion of studies that only assessed the joint space in less than two separate points of the TMJ was due to the definition of the position of an object in space depending on three coordinates. According to this, joint space analysis done only on one point does not provide enough information to determine the position of the mandibular condyle in the glenoid fossa.

The meta-analysis showed high levels of heterogeneity among the selected studies what is possibly explained by the high heterogeneity between the selected studies: the sample sizes varies between 24[27] and 464 patients,[31] there are different samples from carefully selected normal joints[19,27] to patients presenting malocclusions[21,26,31–33,35] or temporomandibular disorders[23,24] and different methods[19,25,27] were used to determine the joint spaces (as showed during the systematic review). All these factors may have contributed to high heterogeneity between the samples.

The results from this investigation also showed statistically significant differences between the right and left joints for the anterior joint space (AJS), while the opposite was found for the posterior joint space (PJS). However, the mean difference was −0.10 mm (95% CI: −0.17; −0.03) and, therefore, it is very close to 0. Moreover, comparison of the AJS and the PJS between the right and left joints was performed on 10 of the retrieved articles, and only two showed statistically significant differences for the AJS. The fact that one of the studies had the biggest sample ($n = 232$) with a power of 16.30% on the meta-analysis might explain the statistically significant result for the AJS. A previous study suggested that this asymmetry would be related to normally asymmetric cranial bases or side preferences during mastication.[31] Moreover, most patients show a centric relation-centric occlusion discrepancy, usually caused by a posterior interference that is unilateral in most cases.[40–43] As an adaptation, the condyles might move asymmetrically and while the contra-lateral condyle moves sagittaly, the ipsilateral rotates to establish a more balanced dental occlusion. The absence of statistically significant differences between right and left joints for the PJS may be explained by stabilization of the TMJ posteriorly by the articular disk.

Conclusion

There is insufficient scientific evidence concerning sagittal joint spaces of the TMJ, as there are no articles with high level of evidence and only one study presents moderate level of evidence.

Although no high level of evidence studies were found, the authors decided to perform a meta-analysis of the mean sagittal joint spaces of the TMJ and the differences between the right and left joints. The mean anterior joint space was 1.86 mm (CI 95%: 1.62–2.10), the superior joint space was 2.36 mm (CI 95%: 1.99–2.72) and the posterior was 2.22 mm (CI 95%: 2.00–2.45). However, a high level of heterogeneity was found, meaning that these results must be considered with care. However, the results of the meta-analysis suggest that the posterior joint space is larger than the anterior joint space. This result is in accordance to the concept in use that the mandibular condyle must be on the most superior-anterior position in the glenoid fossa.[5,8–10]

The analysis of the difference between the right and left sagittal joint spaces showed statistically significant differences between the two joints in the anterior joint space, but not in the superior and posterior joint spaces.

More research with more solid methodology is needed on this topic.

Conflicts of interest

The authors have no conflicts of interest to declare.

REFERENCES

1. Posselt U. Studies in the mobility of the human mandible. Acta Odontol Scand. 1952;10 Suppl. 10:19–27.
2. Dawson PE. Evaluation diagnosis and treatment of occlusal problems. St Louis: Mosby; 1989.
3. Van Blarcom C, Campbell S, Can A. The glossary of prosthodontic terms. 7th ed. St Louis: Mosby; 1999.
4. Rinchuse DJ, Kandasamy S. Centric relation: a historical and contemporary orthodontic perspective. J Am Dent Assoc. 2006;137:494–501.
5. Dawson PE. A classification system for occlusions that relates maximal intercuspation to the position and condition of the temporomandibular joints. J Prosthet Dent. 1996;75:60–6.
6. Roth RH. Occlusion and condylar position. Am J Orthod Dentofac Orthop. 1995;107:315–8.
7. Rinchuse DJ. A three-dimensional comparison of condylar change between centric relation and centric occlusion using the mandibular position indicator. Am J Orthod Dentofac Orthop. 1995;107:319–28.
8. Okeson J. Management of temporomandibular disorders and occlusion. 6th ed. Mosby Elsevier; 2008.
9. Dawson PE. Centric relation. Its effect on occluso-muscle harmony. Dent Clin N Am. 1979;23:169–80.
10. Dawson PE. New definition for relating occlusion to varying conditions of the temporomandibular joint. J Prosthet Dent. 1995;74:619–27.
11. Kandasamy S, Boeddinghaus R, Kruger E. Condylar position assessed by magnetic resonance imaging after various bite position registrations. Am J Orthod Dentofac Orthop. 2013;144:512–7.
12. Honey OB, Scarfe WC, Hilgers MJ, Klueber K, Silveira AM, Haskell BS, et al. Accuracy of cone-beam computed tomography imaging of the temporomandibular joint: comparisons with panoramic radiology and linear tomography. Am J Orthod Dentofac Orthop. 2007;132:429–38.
13. Hilgers ML, Scarfe WC, Scheetz JP, Farman AG. Accuracy of linear temporomandibular joint measurements with cone beam computed tomography and digital cephalometric radiography. Am J Orthod Dentofac Orthop. 2005;128:803–11.
14. White S, Pharoah M. Oral radiology principles and interpretation. 5th ed. Los Angeles: Mosby; 2009.
15. Collaboration TC. Cochrane reviewers' handbook; 2004. Available from: http://www.cochrane.org/resources/handbook
16. Liberati A, Altman DG, Tetzlaff J, Mulrow C, Gotzsche PC, Ioannidis JP, et al. The PRISMA statement for reporting

systematic reviews and meta-analyses of studies that evaluate health care interventions: explanation and elaboration. PLoS Med. 2009;6:e1001000.
17. Higgins JP, Thompson SG, Deeks JJ, Altman DG. Measuring inconsistency in meta-analyses. BMJ. 2003;327:557–60.
18. Tsuruta A, Yamada K, Hanada K, Hosogai A, Kohno S, Koyama J, et al. The relationship between morphological changes of the condyle and condylar position in the glenoid fossa. J Orofac Pain. 2004;18:148–55.
19. Vitral RW, da Silva Campos MJ, Rodrigues AF, Fraga MR. Temporomandibular joint and normal occlusion: is there anything singular about it? A computed tomographic evaluation. Am J Orthod Dentofac Orthop. 2011;140:18–24.
20. Rodrigues AF, Fraga MR, Vitral RW. Computed tomography evaluation of the temporomandibular joint in Class I malocclusion patients: condylar symmetry and condyle-fossa relationship. Am J Orthod Dentofac Orthop. 2009;136:192–8.
21. Rodrigues AF, Fraga MR, Vitral RW. Computed tomography evaluation of the temporomandibular joint in Class II Division 1 and Class III malocclusion patients: condylar symmetry and condyle-fossa relationship. Am J Orthod Dentofac Orthop. 2009;136:199–206.
22. Henriques JC, Fernandes Neto AJ, Almeida Gde A, Machado NA, Lelis ER. Cone-beam tomography assessment of condylar position discrepancy between centric relation and maximal intercuspation. Braz Oral Res. 2012;26:29–35.
23. Okur A, Ozkiris M, Kapusuz Z, Karacavus S, Saydam L. Characteristics of articular fossa and condyle in patients with temporomandibular joint complaint. Eur Rev Med Pharmacol Sci. 2012;16:2131–5.
24. Pereira LJ, Gavião MB. Tomographic evaluation of TMJ in adolescents with temporomandibular disorders. Braz Oral Res. 2004;18:208–14.
25. Dalili Z, Khaki N, Kia SJ, Salamat F. Assessing joint space and condylar position in the people with normal function of temporomandibular joint with cone-beam computed tomography. Dent Res J (Isfahan). 2012;9:607–12.
26. Prabhat K, Kumar V, Maheshwari S, Ahmad I, Tariq M. Computed tomography evaluation of craniomandibular articulation in Class II Division 1 malocclusion and Class I normal occlusion subjects in North Indian Population. ISRN Dent. 2012;2012:312031.
27. Ikeda K, Kawamura A. Assessment of optimal condylar position with limited cone-beam computed tomography. Am J Orthod Dentofac Orthop. 2009;135:495–501.
28. Seren E, Akan H, Toller MO, Akyar S. An evaluation of the condylar position of the temporomandibular joint by computerized tomography in Class III malocclusions: a preliminary study. Am J Orthod Dentofac Orthop. 1994;105:483–8.
29. Gianelly AA, Petras JC, Boffa J. Condylar position and Class II deep-bite, no-overjet malocclusions. Am J Orthod Dentofac Orthop. 1989;96:428–32.
30. Christiansen EL, Thompson JR, Zimmerman G, Roberts D, Hasso AN, Hinshaw DB Jr, et al. Computed tomography of condylar and articular disk positions within the temporomandibular joint. Oral Surg Oral Med Oral Pathol. 1987;64:757–67.
31. Cohlmia J, Ghosh J, Sinha P, Nanda R, Currier GF. Tomographic assessment of temporomandibular joints in patients with malocclusion. Angle Orthod. 1996;66:27–36.
32. Uzel A, Özyürek Y, Öztunç H. Condyle position in Class II Division 1 malocclusion patients: correlation between MPI records and CBCT images. J World Fed Orthodont. 2013;2:e65–70.
33. Arieta-Miranda JM, Silva-Valencia M, Flores-Mir C, Paredes-Sampen NA, Arriola-Guillen LE. Spatial analysis of condyle position according to sagittal skeletal relationship, assessed by cone beam computed tomography. Prog Orthod. 2013;14:36.
34. Alves N, Deana NF, Schilling QA, González VA, Schilling LJ, Pastenes RC. Assessment of TMJ condylar position and joint space in chilean individuals with temporomandibular disorders. Int J Morphol. 2014;32:32–5.
35. Vitral RW, Telles Cde S, Fraga MR, de Oliveira RS, Tanaka OM. Computed tomography evaluation of temporomandibular joint alterations in patients with class II division 1 subdivision malocclusions: condyle-fossa relationship. Am J Orthod Dentofac Orthop. 2004;126:48–52.
36. Rickets RM. Present status of laminagraphy as related to dentistry. J Am Dent Assoc. 1962;65:56–64.
37. Quintero JC, Trosien A, Hatcher D, Kapila S. Craniofacial imaging in orthodontics: historical perspective, current status, and future developments. Angle Orthod. 1999;69:491–506.
38. Commission E. Radiation protection n° 172. In: Protection D-GfEDDNEUDR, editor. Cone beam CT for dental and maxillofacial radiology: evidence-based guidelines. 2012. Luxemburg.
39. Enlow DH. Facial growth. 3rd ed. Philadelphia: Saunders; 1990.
40. Crawford SD. Condylar axis position, as determined by the occlusion and measured by the CPI instrument, and signs and symptoms of temporomandibular dysfunction. Angle Orthod. 1999;69:103–15, discussion 15-6.
41. Cordray FE. Three-dimensional analysis of models articulated in the seated condylar position from a deprogrammed asymptomatic population: a prospective study. Part 1. Am J Orthod Dentofac Orthop. 2006;129:619–30.
42. Cordray FE. The importance of the seated condylar position in orthodontic correction. Quintessence Int. 2002;33: 284–93.
43. Ponces MJ, Tavares JP, Lopes JD, Ferreira AP. Comparison of condylar displacement between three biotypological facial groups by using mounted models and a mandibular position indicator. Korean J Orthod. 2014;44:312–9.

7. Rodrigues HM, Botelho PC, Vaz P, Mesquita P, Ponces MJ. Artrogryposis multiplex congenita associated with intraoral changes – Multidisciplinary approach. Rev Port Estomatol Med Dent Cir Maxilofac. 2015;56(3):182-187.

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Clinical case

Artrogryposis multiplex congenita associated with intraoral changes – Multidisciplinary approach

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Arthrogryposis

A B S T R A C T

This article presents the clinical case of 21 years old female patient reporting history of Arthrogryposis Multiplex Congenita (AMC). The extraoral examination disclosed clinical AMC pathognomonic signs. The intraoral examination revealed slight compression of the maxillary arch, conical upper lateral incisors, absence of 17 and 35, 53 persistence, upper cuspids inclusion and agenesis of third molars. Additionally, there was a severe generalized shortening of the tooth roots, with a general 1:1 root/crown proportion. The extraction of 23 was planned due to its maxillary position. Relatively to the 13, the orthodontical traction with a microimplant was the option. Treatment planning established orthodontics to restore esthetics and function followed by rehabilitation with implants. Finally, the esthetic composite restorations of 12 and 22 were programmed, given the limited prognosis presented by fixed prosthesis in the cases of root/crown low proportions.

Artrogripose Múltipla Congénita associada a alterações – intraorais abordagem multidisciplinar

Palavras-chave:
Raiz dentária
Curta
Ortodontia
Artrogripose

R E S U M O

Este artigo apresenta um caso clínico de uma paciente de 21 anos, do sexo feminino, que relatou história de Artrogripose Múltipla Congénita (AMC). O exame extraoral revelou sinais clínicos patognomónicos de AMC. O exame intraoral revelou compressão da arcada maxilar, incisivos laterais superiores conoides, ausência do 17 e do 35, persistência do 53, inclusão dos caninos superiores e agenesia dos terceiros molares. Adicionalmente, verificou-se um encurtamento radicular severo generalizado, com a maioria das proporções raís/coroa 1:1. Foi planeada a extracção do 23, dada a sua posição na maxila. Relativamente ao 13, a tração ortodôntica com um microimplante foi a opção eleita. Planeou-se o recurso

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à ortodontia para restabelecer estética e função, seguida de reabilitação com implantes. Finalmente, planearam-se restaurações estéticas a compósito nos dentes 12 e 22, dado o limitado prognóstico oferecido pela prótese fixa em casos de baixas proporções raíz/coroa.

Introduction

Arthrogryposis Multiplex Congenita (AMC) is a rare congenital disorder,[1] affecting 1 in 3000[2–4] to 1 in 12,000[5] newborns. It involves the presence of multiple non-progressive,[1,3] symmetric joint contractures,[1,3,4] sometimes associated with muscle weakness and fibrosis.[1]

This disease can present an isolated form or it can also be associated with other congenital anomalies, as part of a syndrome, with or without central nervous system involvement.[6]

This condition's etiology is considered multifactorial and may be presented as a monogenic disease (autosomal recessive transmission, autosomal dominant or associated with the X chromosome), as a chromosomal disorder or as a congenital malformation (involving various organs).[7] AMC may also be associated with environmental factors such as infections, drugs administration, trauma, chronic diseases, oligohydramnios or abnormal uterus structure (affecting the mother and the developing fetus).[7] These factors described in the etiology of AMC are also common to approximately 7% of the congenital abnormalities in general.[3]

In the recognition of early clinical signs of AMC, in the last months of pregnancy, decreased fetal movement (fetal akinesia) is considered a common denominator to all AMC affected individuals, conditioning a variety of minor fetal deformities. It is important to notice the absence of movement, essential for joints and periarticular tissues development, leads to an increase of connective tissue around the immobilized joint with rippling of the skin covering the joint, muscle atrophy and changes in the joint surface depending on the position of the immobilization.[3,8]

The involvement of the temporomandibularjoint (TMJ) is a common AMC complication, conditioning the mandibular kinetics.[2,9] Other common features include the presence of micrognathia,[2,8] slightly shortened limbs, intrauterine growth restriction, pulmonary hypoplasia and short and/or immature bowel.[8] Some cases of AMC were also found associated with the presence of upper lateral conoid incisors,[10] hypodontia[11] and delayed tooth eruption.[2]

This paper focused on the presentation of a clinical case of AMC, emphasizing oral and craniofacial abnormalities and proposing a treatment approach.

Case report

A female patient, 21 years old, attended a dental appointment to assess orthodontic treatment need, referring the closure of existing dental gaps in the upper anterior arch as a priority. During the anamnesis, the patient reported an AMC history, diagnosed since childhood.

The extraoral clinical examination (Fig. 1) revealed pathognomonic clinical signs of AMC: multiple joint contractures, short stature, low set ears and dysplasia of the fingernails and toenails deployment. The analysis stressed a thin hypertonic upper lip and a low smile line TMJ clinical examination (by palpation, auscultation and mandibular kinetics evaluation) discarded clinical signs of temporomandibular disorder. The intraoral clinical examination (Fig. 2) showed a slight compression of the maxillary arch with anterior cross bite on teeth 12 and 22, Class II molar, decreased vertical overbite, upper lateral conoid incisors, absence of 18, 17, 13, 23, 28, 38, 35 and 48 and persistence of 53. In order to assess dental arch discrepancy, Bolton analysis[12] revealed a discrepancy with excess on lower anterior arch (Fig. 3).

Panoramic X-ray (Fig. 4A) complemented by a retroalveolar X-rays *status* (Fig. 4B) revealed the inclusion of upper cuspid, agenesis of third molars (upper and lower), absence of 17 and 45 and a generalized severe dental root shortening.

Ricketts cephalometric analysis (Fig. 4C and D) revealed a skeletal Class II, with a retro and micrognatic mandible, an orthopositioned maxilla, a mesocephalic facial type, proclined and orthopositioned upper and lower incisors, a decreased interincisal angle and a lip retraction. Functional analysis according to Multifunction System (MFS) classification[13] showed type 1 nasal collapse (narrow nostrils without collapse), type 2 adenoids (slightly convex), type 2 tonsils (appear slightly), normal swallowing, nasal breathing, type 1 tongue mobility level (tongue touches the palate). In order to improve

Fig. 1 – Facial appearance at rest – (A) right side, (B) left side, (C) front, (D) smile.

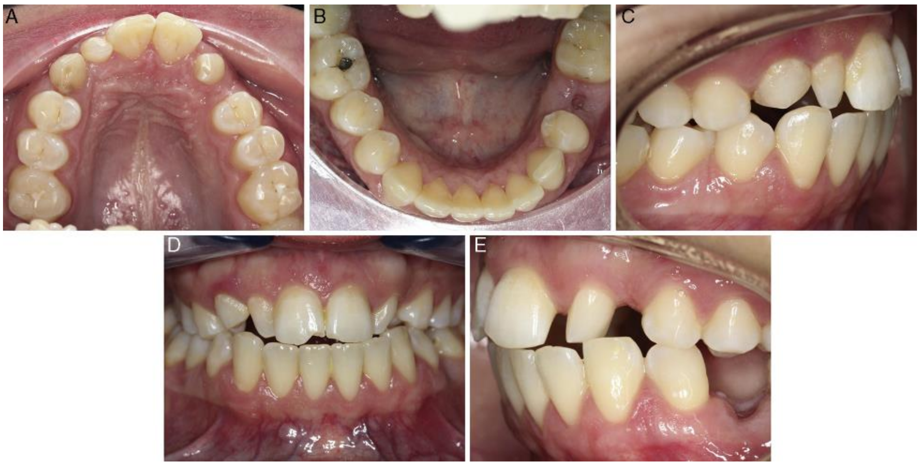

Fig. 2 – Intraoral photographic status (A) upper occlusal, (B) lower occlusal, (C) right side, (D) front side, (E) left side.

the perception of cuspid location, a computed tomography (CT) was requested (Fig. 5).

Discussion and conclusions

Root shortening is a rare finding occurring in about 1.3% of general population, more frequent in females and involves mostly premolars and maxillary incisors[14] with no reports of its association with AMC.

There are several radiographic measurement techniques of root/crown ratio (R/C) described in literature. In the present study the Lind method[15] was the one selected for the assessment. According to it, the interproximal concavities between root and crown correspond to *x* and *y* points, being *m* the midpoint of *x*-*y* segment. The relative root length is calculated from the apex to *m* point and the relative coronal length is the distance between *m* point and the midpoint of the incisal edge. The performed evaluation revealed that most of the patient's teeth had a R/C ratio $\leq$1.0 (Fig. 6). According to Jakobsson et al.,[16] roots are considered short when R/C $\leq$1.1.

In AMC cases, despite the limitations caused by dental morphology, orthodontic treatment can be considered in order to

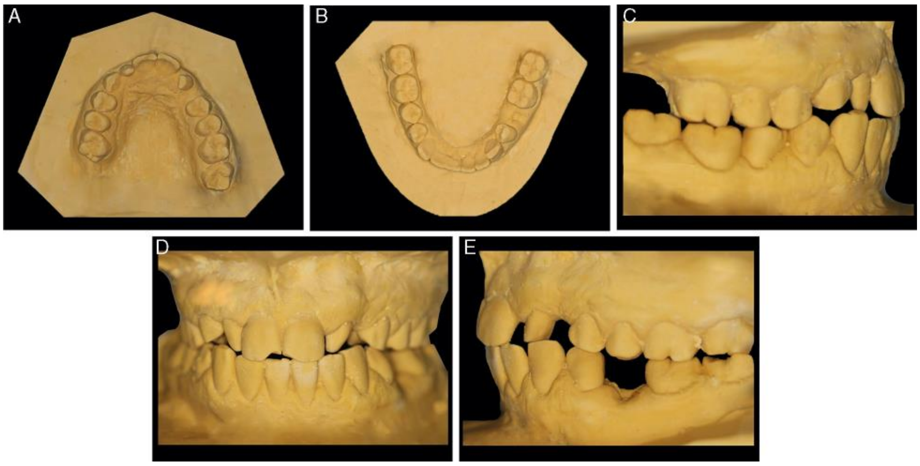

Fig. 3 – Dental casts (A) upper occlusal, (B) lower occlusal, (C) right side, (D) front side, (E) left side.

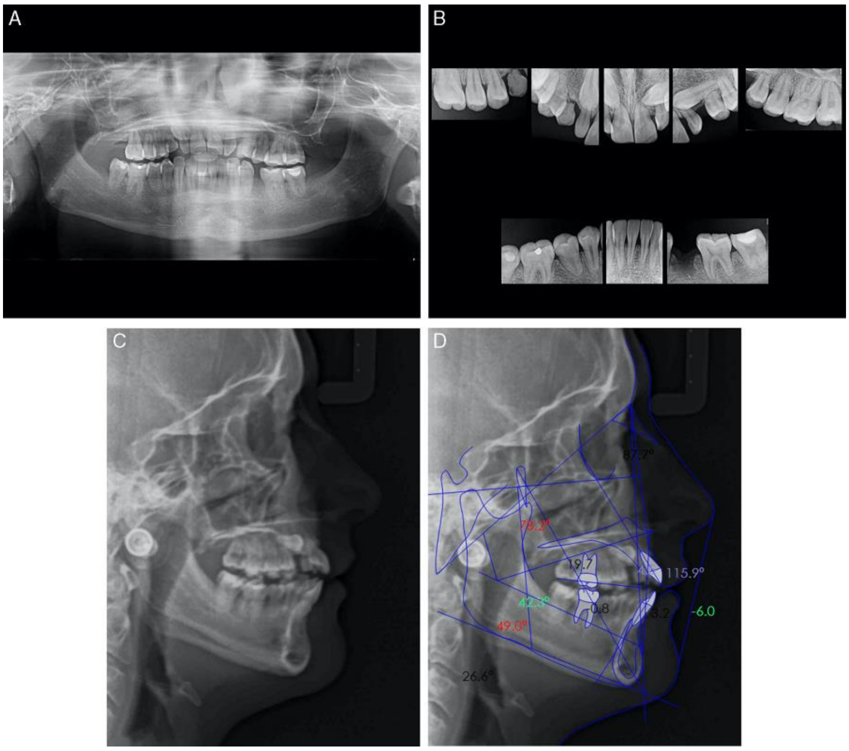

Fig. 4 – Diagnostic records (A) panoramic X-ray, (B) periapical radiographs, (C) cephalometric radiography, (D) ricketts cephalometric tracing.

enable opening spaces for rehabilitation with dental implants in an attempt to restore the appearance and function. Partial fixed appliances may be used to avoid compromising periodontal structures of adjacent teeth while opening spaces for rehabilitation. However, partial appliances do not fix all dental positions and may pledge reaching goals related to the establishment of an ideal functional occlusion. Relative position and possibility of orthodontic traction of impacted teeth should be carefully considered prior to treatment. Bringing the impacted canine into a normal position is important in achieving a functional occlusion and final esthetics of orthodontic treatment, but factors such as height of the impacted canine, angulation of the long axis to the upper midline, canine mesiodistal position of the tip relative to the midline, adjacent incisors and the anteroposterior position of the canine root apex should also be considered.

In this particular case, the left canine presented a horizontal position and was in proximity with the roots of adjacent teeth. Therefore, extraction seems to be the most suitable option. As for the right canine, a more conservative approach would be adequate and it seems that the use of a mini-screw as a traction auxiliary device would be indicated (to be possible to traction using a mini-screw) (Fig. 7).

This may avoid loss of anchorage and outline periodontal limitations. Patients should be informed about the limitations of these procedures, such as, tooth ankylosis, possible compromise of adjacent teeth during root repositioning and the anatomy and position of the remaining teeth. The decision of tooth traction or extraction should be decided with the patient.

Rehabilitation phase can be done based on implant supported rehabilitation or using a removable partial acrylic denture. Dental-supported prosthesis has a limited prognosis in cases of low R/C ratio. As skeletal prosthesis require too much support on the abutment teeth, this option should be discarded.

In order to improve dental esthetics of conoid teeth, when present, esthetic restorations with composite resin may be held due to the already mentioned limited prognosis offered by fixed prosthesis.

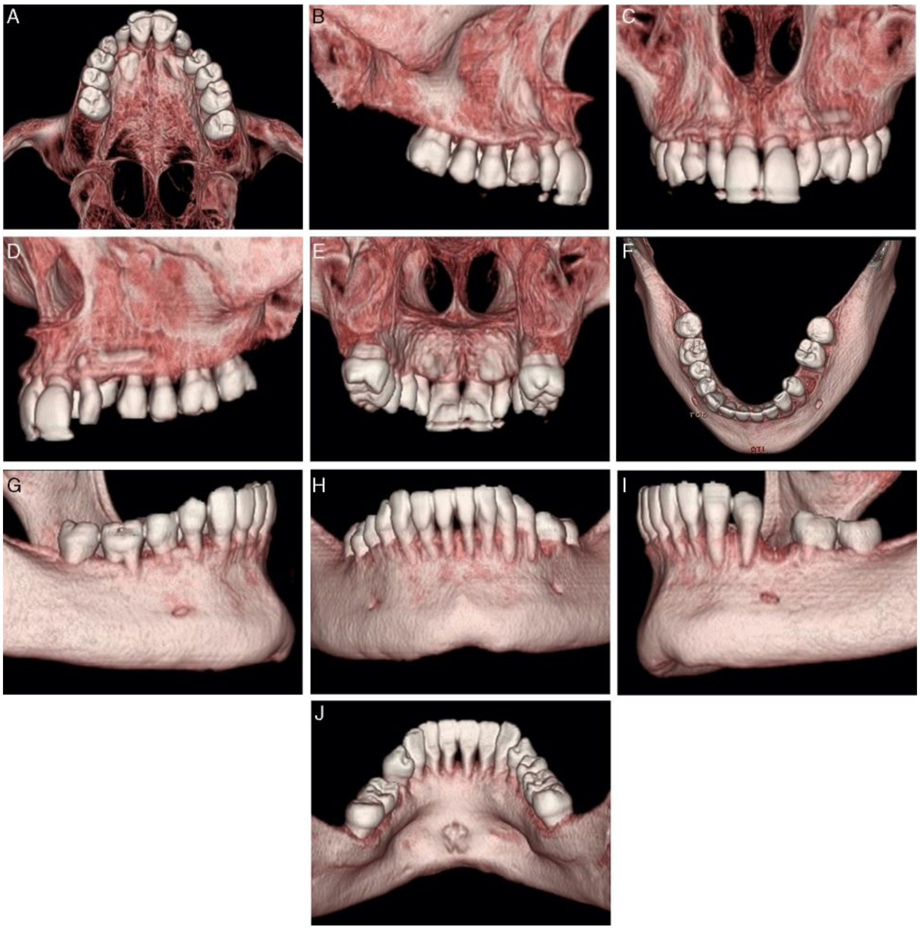

Fig. 5 – Computed tomography, 3D reconstruction – upper (A) occlusal, (B) right side, (C) front side, (D) left side, (E) posterior side and lower, (F) occlusal, (G) right side, (H) front side, (I) left side, (J) posterior side.

In conclusion, a multidisciplinary approach is essential to solve this type of cases, covering areas such as genetics, oral surgery, orthodontics, implantology and esthetic dentistry. Comprehensive treatment must be individualized and adjusted to patient needs and, when required, subjected to adjustments in face of individual clinical response. R/C ratio may represent an important determinant and may affect the dental prognosis and complicate the orthodontic treatment and rehabilitation planning, if considering factors such as anchorage and functional and mechanical principles. Especially in orthodontic patients, this problem is emphasized and gets critical dimension, due to the high rate of root resorption in patients with previous root shortenings.

Ethical disclosures

Protection of human and animal subjects. The authors declare that no experiments were performed on humans or animals for this study.

Confidentiality of data. The authors declare that they have followed the protocols of their work center on the publication of patient data

Right to privacy and informed consent. The authors have obtained the written informed consent of the patients or subjects mentioned in the article. The corresponding author is in possession of this document.

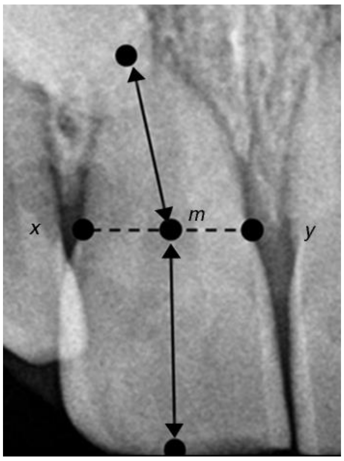

Fig. 6 – Technical procedure measure R/C ratio.

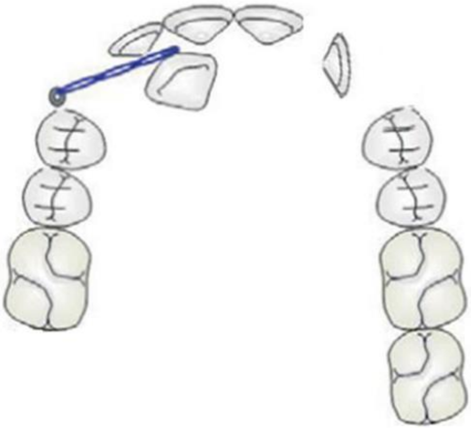

Fig. 7 – Representation of the microimplant location.

Conflicts of interest

The authors have no conflicts of interest to declare.

REFERENCES

1. Alfonso IPO, Paez JO, Grossman JAI. Arthrogryposis multiplex congenita. Int Pediatr. 2000;15:197–204.
2. Mielnik-Blaszczak M, Borowska M. Arthrogryposis multiplex congenita (AMC) – case report. Ann Univ Mariae Curie Sklodowska Med. 2002;57:437–41.
3. Binkiewicz-Glinska A, Sobierajska-Rek A, Bakula S, Wierzba J, Drewek K, Kowalski IM, et al. Arthrogryposis in infancy, multidisciplinary approach: case report. BMC Pediatr. 2013;13:184.
4. Bamshad M, Van Heest AE, Pleasure D. Arthrogryposis: a review and update. J Bone Joint Surg Am. 2009;91 Suppl. 4:40–6.
5. Hoff JM, Loane M, Gilhus NE, Rasmussen S, Daltveit AK. Arthrogryposis multiplexa congenita: an epidemiologic study of nearly 9 million births in 24 EUROCAT registers. Eur J Obstet Gynecol Reprod Biol. 2011;159:347–50.
6. Hall JG. Arthrogryposis multiplex congenita: etiology, genetics, classification, diagnostic approach, and general aspects. J Pediatr Orthop B. 1997;6:159–66.
7. Alves PV, Zhao L, Patel PK, Bolognese AM. Arthrogryposis: diagnosis and therapeutic planning for patients seeking orthodontic treatment or orthognathic surgery. J Craniofac Surg. 2007;18:838–43.
8. Hall JG. Arthrogryposis (multiple congenital contractures): diagnostic approach to etiology, classification, genetics, and general principles. Eur J Med Genet. 2014.
9. Kargel JS, Dimas VM, Chang P. Orthognathic surgery for management of arthrogryposis multiplex congenita: case report and review of the literature. Can J Plast Surg (J Can Chir Plast). 2007;15:53–5.
10. Friedman BD, Heidenreich RA. Distal arthrogryposis type IIB: further clinical delineation and 54-year follow-up of an index case. Am J Med Genet. 1995;58:125–7.
11. Beals RK, LaFranchi S. Distal arthrogryposis: a new type with distinct facial appearance and absent teeth. J Med Genet. 2001;38:E22.
12. Bolton WA. Disharmony in tooth size and its relation to the analysis and treatment of malocclusion. AJO. 1958;28:113–30.
13. Durán JCA, Ustrell JM, Echarri P, Arends MM. La estímuloterapia programada como base para el desarrollo de un protocolo de reeducación funcional oral que nos lleva al concepto de prevención en ortodoncia. Dentum. 2008;8:123–9.
14. Marques LS, Generoso R, Armond MC, Pazzini CA. Short-root anomaly in an orthodontic patient. Am J Orthod Dentofacial Orthop: Official Publication of the American Association of Orthodontists, its Constituent Societies, and the American Board of Orthodontics. 2010;138:346–8.
15. Lind V. Short root anomaly. Scand J Dental Res. 1972;80:85–93.
16. Jakobsson R, Lind V. Variation in root length of the permanent maxillary central incisor. Scand J Dental Res. 1973;81:335–8.

8. **Amaral C, Henriques M, Gomes F, Mesquita P, Ponces MJ. The Road to Sustainability in Dentistry – Is the Reuse of Sterilization Pouches Viable? Rev Port Estomatol Med Dent Cir Maxilofac. 2023;64(2):72-77.**

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Original Research

The Road to Sustainability in Dentistry – Is the Reuse of Sterilization Pouches Viable?

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abstract

Objectives: To answer the question: Can sterilized pouches be used a second time while maintaining their sterility conditions?
Methods: This investigation tested paper/plastic sterilization pouches divided into three groups: experimental group – twice-used pouches; negative control group – once-used pouches; and positive control group – environmentally contaminated pouches. In the experimental group, pouches were opened, a gauze dressing was placed into them, and they were sterilized again, representing the reuse of the pouches (second sterilization cycle). After the sterilization cycle, samples were stored for 1 day (T_0), 7 days (T_1), 31 days (T_2), and 153 days (T_3). Positive control group pouches were opened and exposed to contamination in the storage environment. After the specified storage period, the experimental and negative control groups' pouches were opened, and the gauze dressings were removed aseptically. All gauze dressings of all groups, including the positive control group, were incubated in Petri dishes with nutrient agar at 37°C for 3 days. After incubation, the Petri dishes were inspected, and the microbial contamination was assessed and classified as present or absent.
Results: The experimental group's Petri dishes showed no sign of contamination. The same happened to the negative control group. The positive control group's Petri dishes presented microbial contamination. The same results were obtained for all incubation times.
Conclusions: This study showed that sterilization pouches could be used a second time while maintaining sterility and integrity conditions, even for extended periods (153 days – 5 months of storage). (Rev Port Estomatol Med Dent Cir Maxilofac. 2023;64(2):72-77)

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O Caminho para a Sustentabilidade em Medicina Dentária – Será a reutilização de Mangas de Esterilização Viável?

R E S U M O

Objetivos: Este estudo tinha como objetivo testar se as mangas de esterilização poderiam ser utilizadas uma segunda vez mantendo as suas condições de esterilização.

Métodos: Amostras de mangas de esterilização de papel/plástico foram testadas neste trabalho sendo divididas em 3 grupos (grupo experimental – mangas reutilizadas duas vezes; grupo de controlo negativo – mangas usadas uma vez; e um grupo de controlo positivo – amostras ambientalmente contaminadas). O grupo experimental incluiu mangas que foram abertas e uma foi gaze introduzida, sendo novamente fechadas e esterilizadas, representando assim a reutilização das mangas. Após o ciclo de esterilização, todas as amostras foram armazenadas durante 1 dia (T_0), 7 dias (T_1), 31 dias (T_2) e 153 dias (T_3). Quanto às amostras do grupo de controlo positivo, após o ciclo de esterilização, estas foram abertas e expostas à contaminação presente no ambiente de armazenamento. Após cada ciclo de armazenamento, as gazes foram incubadas em placas de *Petri* com Agar Nutriente a 37°C durante 3 dias. Após o período de incubação, as placas de *Petri* foram inspecionadas e a contaminação microbiana foi verificada e classificada como presente ou ausente.

Resultados: A observação das placas de *Petri* do grupo experimental não mostrou sinais de contaminação. O mesmo aconteceu com o grupo de controlo negativo. As restantes placas de *Petri* contendo os controlos positivos apresentaram contaminação microbiana. Os mesmos resultados foram obtidos para todos os períodos de incubação.

Conclusões: Este estudo mostra que as mangas de esterilização podem ser utilizadas uma segunda vez, mantendo as suas condições de esterilidade e integridade mesmo para longos períodos de tempo (153 dias – 5 meses de armazenamento). (Rev Port Estomatol Med Dent Cir Maxilofac. 2023;64(2):72-77)

Palavras-chave:
Odontologia
Ambiente
Reutilização de equipamentos
Mangas de papel/plástico
Esterilização
Desenvolvimento sustentável
Gestão de resíduos

Introduction

Plastic in the medical sector was valued worldwide at 18.9 billion euros in 2019.[1,2] In Europe, this market is expected to reach a value of 4 billion euros by 2024 due to its growing demand.[3] The World Health Organization (WHO) explains that 85% of the health sector waste is non-infectious. However, only a small percentage is recycled, while most end up in landfills (79%) or incinerated (12%). Consequently, the medical sector represents around 4% of global greenhouse gas emissions — if it were a country, it would be the fifth most polluting country in the world.[4,5]

According to the Eco Dentistry Association (EDA), some 680 million plastic and paper protections and 1.7 billion sterilization instruments and packaging are sent to landfills or disposed of in the environment per year.[6-8] This situation raises another problem: overexposure to bisphenol A (BPA) and di(2-ethylhexyl)phthalate (DEHP) and microplastics (small particles between 100 nm and 5 mm). Recent studies show that large amounts of microplastics end up in the human diet and have been found, for example, in seafood, honey, bottled water, and alcohol, as a result of their deterioration in the environment.[3-5,9] In our body, due to the inability of our immune system to eliminate plastic, this situation can lead to chronic inflammation and cancer.[10] Also, the contact between microplastics and antibiotics in our body has adverse effects. In fact, the correlation between antimicrobial resistance and increasing plastic pollution is under investigation. The findings indicate that when in contact with antibiotics, plastics can promote genetic mutations in bacteria that cause them to acquire antibiotic resistance, creating possible threats to human health.[11,12]

Reducing plastic consumption at hospitals and medical/dental offices is a difficult task since medical areas have benefited most from its use.[13-16] Plastic is economical, heat resistant, long-lasting, versatile, biocompatible, requires less energy to be produced compared to metal or glass, and offers a sterile environment.[1,13] These assets that make plastic the ideal material for single use also make it almost impossible for nature to eliminate.[10,17] In addition, single-use plastics currently represent 85% of all plastics in health.[13] Because recycling these plastics in the health sector carries risks of cross-infection and contamination, the current destruction methods aim to provide the population with more security.[1,8,15-18]

The recently published study “Environmental sustainability practices in Portuguese dental clinics” concluded that clinical directors showed good environmental awareness and satisfactory implementation of environmental sustainability practices in dental clinics and that costs were the most reported barrier to implementing further practices. This study triggered the interest in finding a safe, easy, cheap solution for dental clinics to implement that would also be sustainable and eco-friendly, allowing the mitigation of the effects of the waste produced by single-use plastic.[17,18]

For the reasons stated above, sterilization pouches were considered the ideal specimen for this study because they do not come into contact with the patient and consist of a paper/plastic bag with one side made of medical-grade paper and the other made of a thin plastic film. They cover medical instruments before their sterilization in the autoclave and are currently thrown away after the sterilized instruments are unpacked. The problem addressed is not only the usage of plastic but also how it is discarded. One of the complications related to reusing these plastics is that they are marked as single-use by manufacturers.[19]

In the impossibility of replacing plastic with other materials because of its many assets, this study aims to question the safety and efficacy of reusing sterilization pouches without compromising their sterilization conditions.[20,21] Therefore, the question and hypothesis raised are: Can sterilization pouches be used a second time while maintaining their sterilization conditions?

Material and methods

Paper/plastic pouches were prepared from non-sterile sterilization rolls (MEDISTOCK®, France), with 7.5x15.0 cm each, and randomly selected to undergo a sterilization cycle in an autoclave at 121°C and 15 psi for 33 minutes (HS–22 K_{5+} WHITE, GENTINGE®, Sweden) to mimic their use in dental practices and hospitals. After that cycle, pouches that met the inclusion criteria were selected as the Experimental Group (EG) and opened to undergo a second sterilization cycle (n=12). The inclusion criteria were not presenting any openings, water drops inside, bends and creases, or burns. The pouches that did not pass the quality check to be reused —exclusion criterium— were discarded. A 3 cm x 2 cm non-sterilized gauze dressing (Bastos Viegas®, S. A., Portugal) was placed into each of the once-used pouches: EG pouches; Negative Control Group (NCG) – once-used pouches; and Positive Control Group (PCG) – environmentally contaminated pouches. Afterward, the NCG and the PCG pouches were sealed at 1 cm from the base and 3 cm from the top with a thermal sealer (EuroSeal® 2001, Euronda S.p.A., Italy), and the EG pouches were resealed at 6 cm from the top (because they were being reused) with the same sealer. In this step, the exclusion criteria were again applied to ensure/maintain integrity.

All pouches were arranged in a horizontal position, with the paper side of one pouch in contact with the plastic side of the next one without touching the chamber wall of the autoclave. The specimens were sterilized at 121°C and 15 psi for 33 minutes.

After the sterilization cycle, specimens were stored in an opened plastic box in a microbiology laboratory (Laboratory of Microbiology Applied to Health [LMAS], University of Minho) to recreate an open microorganism-rich environment, for 1 day (T_0), 7 days (T_1), 31 days (T_2), and 153 days (T_3) at room temperature (≅ 20°C) and humidity (≅ 40%). After each storage period, the pouches were inspected for barrier damage before being opened. Figure 1 shows the design of the study in a flow chart.

The gauze dressings were removed aseptically (MSC-Advantage™ Class II Biological Safety Cabinets, Thermo Fisher Scientific™, USA) and incubated (general incubator with built-in roller or shaker – NB-205Q, N-BIOTEK, South Korea) in nutrient agar (Research Products International – RPI, USA) in Petri dishes at 37°C for 3 days. After incubation, the Petri dish-

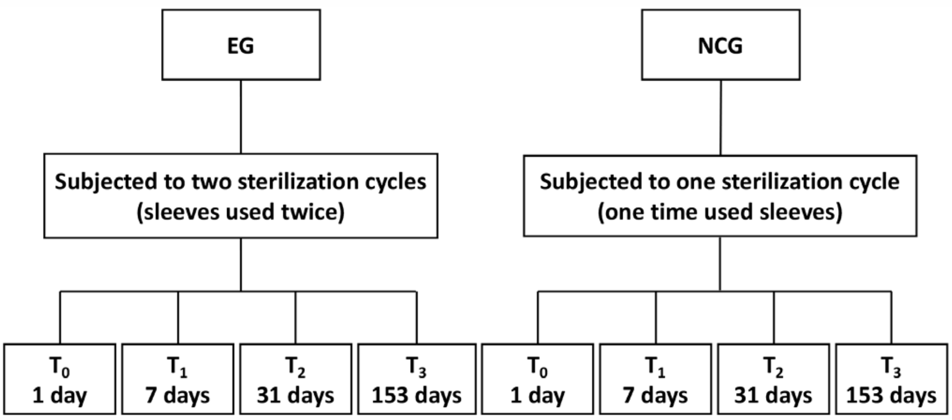

Figure 1. Study design – details of the experimental and control groups.

es were inspected, and microbial contamination was assessed and classified as present or absent based on the visible changes in color and shape of the mediums.[22] The results were compared regarding the different periods of storage and sample groups.

Lastly, the sample size determination was carried out in Microsoft Excel Spreadsheet Software, taking into consideration the following study objectives: evaluate the presence of contamination in each of the three groups (EG, NCG, and PCG) at four different times (T_0, T_1, T_2, and T_3); compare the contamination levels between the two groups at each moment; and compare the contamination levels between the four moments in each group.

Results

All pouches tested passed the reusability inspection, and none of the samples was discarded based on the exclusion criteria. Table 1 presents the results obtained after assessing the nutrient-agar Petri dishes containing the gauze dressings from the groups assayed (EG, NCG, and PCG) and for the different sample storage periods. As observed in Figure 2, the EG specimens showed no sign of contamination (≅ 0% microbial contamination), even after 5 months of the experiment, similar to the NCG (≅ 0% microbial contamination) and contrary to the PCG (≅ 100% microbial contamination).

The PCG was intentionally contaminated by exposure to a normal microbiology laboratory environment —the same environment where EG and NCG specimens were stored— and showed extensive microbial growth in all samples after the tested period. On the contrary, both EG and NCG specimens remained sterile over the storage time.

Table 1. Presence or absence of contamination in each test group

Time Point	Negative Control Group (NCG)	Experimental Group (EG)	Positive Control Group (PCG)
T_0	Absence	Absence	Presence
T_1	Absence	Absence	Presence
T_2	Absence	Absence	Presence
T_3	Absence	Absence	Presence

Discussion

This preliminary exploratory study focused on evaluating the reuse of sterilization paper/plastic pouches commonly used as packaging material in the healthcare sector. The results from this study show that sterilization pouches can be used a second time while maintaining sterility and integrity compared to once-used sterilization pouches, even for extended periods (153 days – 5 months of storage).

Avoiding cross-infection is a high priority in the healthcare sector for patients' safety, and, evidently, there should be no financial or material barriers to preventing the risk of healthcare-acquired infection.[5,6] However, nowadays, healthcare waste is causing significant environmental contamination from single-use plastics, which in turn, harms human health.[11-14] Knowing that infection control is critical, this study wanted to provide a solution that would be safe and environmentally friendly.

In the studied conditions, once-used pouches (NCG) and twice-used pouches (EG) kept sterility and integrity conditions for 5 months, showing that they can be reused at least once. The PCG samples presented microbial contamination after the whole storage period, reinforcing the storage conditions in a microbiologically contained environment. It should be noted that all sample groups were stored in the same conditions and, thus, would be prone to contamination if the pouches were compromised in terms of integrity and sterility.

The results of the present work are in line with recent investigations presented by Puangsa-Ard et al.[19] and Klumdeth et al..[23] In both studies, no microbial contamination was found in either the twice-used or the once-used pouches, and all remained sterile for up to 6 months. However, those studies' settings differ from the present ones. This study was designed and conducted to recreate the daily environment of a dental practice, considering the opinion of researchers that proper

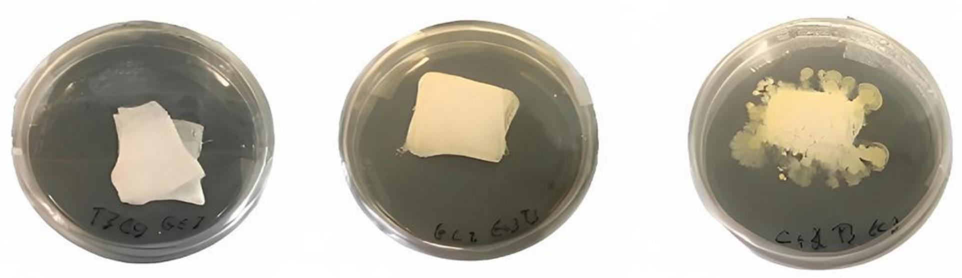

Figure 2. Microbiological result of the experimental group (EG), negative control group (NCG), and positive control group (PCG), respectively.

storage is crucial to maintain sterility and that the storage environment conditions are a more relevant factor than the type of packaging material.[24,25] Thus, sterilization pouches were stored in an environment similar to a clinical practice where samples were more susceptible to microbial contamination. Moreover, due to the possibility of damage imperceptible to the human eye, the pouches used in this study were subjected to some manipulation, making them more prone to event-related contamination. However, the material used in this assay —gauze— is less prone to compromise their reuse, unlike sharp and rough materials. These findings indicated that reusing paper/plastic sterilization pouches could be a great start on this adjustment to a more sustainable and environmental practice.

It should be emphasized that pouches must meet minimal criteria to undergo a second sterilization cycle, which requires special care. Thus, reusing paper/plastic pouches implies special handling/procedures and careful, thorough reusability inspection by healthcare workers to guarantee their sterility and reusability.

Future investigations should repeat the experiment and do other more robust microbiological tests. Because this was a preliminary experimental scientific research aimed at providing a solution that would be safe in every procedure performed in healthcare facilities, all colony-forming units visible on the Petri dishes were classified as contamination, regardless of the number of colonies. It would also be appropriate to use two types of medium and/or broth or specific/selective culture media for double-checking contamination in the future,[26] use a larger sample size, and place medical or dental instruments inside the sterilization pouches. Further research should also determine the breaking point of how many times these sterilization pouches can be reused and how long they can preserve the sterile environment.

Conclusions

Based on our study, sterilization pouches can be used a second time while maintaining sterility conditions even for extended periods.

Conflict of interest

The authors have no conflicts of interest to declare.

Ethical disclosures

Protection of human and animal subjects. The authors declare that no experiments were performed on humans or animals for this study.

Confidentiality of data. The authors declare that no patient data appear in this article.

Right to privacy and informed consent. The authors declare that no patient data appear in this article.

CRediT authorship contribution statement

Catarina Amaral: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Visualization, Writing – original draft. **Mariana Henriques:** Conceptualization, Investigation, Methodology, Project administration, Resources, Supervision, Validation, Writing – review & editing. **Fernanda Gomes:** Conceptualization, Investigation, Methodology, Project administration, Resources, Supervision, Validation, Writing – review & editing. **Pedro Mesquita:** Conceptualization, Investigation, Methodology, Project administration, Resources, Supervision, Validation, Writing – review & editing. **Maria João Ponces:** Conceptualization, Investigation, Methodology, Project administration, Resources, Supervision, Validation, Writing – review & editing.

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References

1. Oosthuysen J, Potgieter E, Fossey A. Compliance with infection prevention and control in oral health-care facilities: A global perspective. Int Dent J. 2014;64:297–311.
2. Debabrata Basu SB, Aseem Mahajan, Venkata Raman Ramanan, Mammen Chandy. Sterilization Indicators in Central Sterile Supply Department: Quality Assurance and Cost Implications. Infect Control Hosp Epidemiol. 2015;36:484-6.
3. Laneve E, Raddato B, Dioguardi M, Di Gioia G, Troiano G, Lo Muzio L. Sterilisation in Dentistry: A Review of the Literature. Int J Dent. 2019:6507286.
4. Rustagi N, Pradhan SK, Singh R. Public health impact of plastics: An overview. Indian J Occup Environ Med. 2011;15:100-3.
5. Prata JC, da Costa JP, Lopes I, Duarte AC, Rocha-Santos T. Environmental exposure to microplastics: An overview on possible human health effects. Sci Total Environ. 2020;702:134455.
6. Halden RU. Plastics and health risks. Annu Rev Public Health. 2010;31:179-94.
7. Verma R, Vinoda KS, Papireddy M, Gowda ANS. Toxic Pollutants from Plastic Waste- A Review. Procedia Environ Sci. 2016;35:701-8.
8. Smith A, Creanor S, Hurrell D, Bagg J, McCowan M. Management of infection control in dental practice. J Hosp Infect. 2009;71:353-8.
9. Volgenant CMC, de Soet JJ. Cross-transmission in the Dental Office: Does This Make You Ill? Curr Oral Health Rep. 2018;5:221-8.
10. Kamal S, Email, Kamal Sagar, Subramony B, Chaudhary P. Infection Control in Dentistry: A Review. EAS J Dent Oral Med 2020;(1):2663-7324.
11. M. Hussain, K.P. Balsara, Nagral S. Reuse of single-use devices: Looking back, looking. Natl Med J India. 2012;25:151-5.
12. Das AK, Okita T, Enzo A, Asai A. The Ethics of the Reuse of Disposable Medical Supplies. Asian Bioeth Rev. 2020;1:103-16.

13. North EJ, Halden RU. Plastics and environmental health: the road ahead. Rev Environ Health. 2013;28:1-8. 1.
14. Vázquez-Rodríguez I, Estany-Gestal A, Seoane-Romero J, Mora MJ, Varela-Centelles P, Santana-Mora U. Quality of cross-infection control in dental laboratories. A critical systematic review. Int J Qual Health Care. 2018;30:496-507.
15. DePaola LG, Grant LE. Summary of infection control in the Dental Office: A global prospective. Infection Control in the Dental Office. 2019;:213-6.
16. Neves C, Santos N, Mendes S. Environmental sustainability practices in Portuguese dental clinics. Rev Port Estomatol Med Dent Cir Maxilofac. 2022;63:213-20.
17. Cox KD, Covernton GA, Davies HL, Dower JF, Juanes F, Dudas SE. Human Consumption of Microplastics. Environ Sci Technol. 2019;53(12):7068-74.
18. Zahid S, Anam Rafiq, Zahra S. Ilyas M. Sterilization & cross infection in dentistry; patients perception. Professional Med J 2018; 25(4):557-61.
19. Puangsa-Ard Y, Thaweboon S, Jantaratnotai N, Pachimsawat P. Effects of resterilization and storage time on sterility of paper/plastic pouches. Eur J Dent. 2018;12:417-21.
20. Campanale C, Massarelli C, Savino I, Locaputo V, Uricchio VF. A Detailed Review Study on Potential Effects of Microplastics and Additives of Concern on Human Health. Int J Environ Res Public Health. 2020;17.
21. Barker CS, Soro V, Dymock D, Fulford M, Sandy JR, Ireland AJ. Time-dependent recontamination rates of sterilised dental instruments. Br Dent J. 2011;211:E17.
22. Futo M, Široki T, Koska S, Čorak N, Tušar A, Domazet-Lošo M, et al. A novel time-lapse imaging method for studying developing bacterial biofilms. Sci Rep 12. 2022;12:21120.
23. Klumdeth J, Jantaratnotai N, Thaweboon S, Pachimsawat P. Sterility maintenance of reused disposable paper/plastic sterilization pouches in actual clinical practice. Heliyon. 2020;6:e03672.
24. McAuley T. Specifications for temperature and humidity in sterile storage environments – Where's the evidence? Healthcare infection. 2009;14:131-7.
25. Luqueta GR, Santos EDd, Pessoa RS, Maciel HS. Evaluation of disposable medical device packaging materials under ozone sterilization. Res Biomed Eng. 2017;33:58-68.
26. Camilleri J, Arias Moliz T, Bettencourt A, Costa J, Martins F, Rabadijeva D, Rodriguez D, Visai L, Combes C, Farrugia C, Koidis P, Neves C. Standardization of antimicrobial testing of dental devices. Dent Mater. 2020;36:e59-e73.

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