

Three-Dimensional Digital Analysis of Tooth Size and Arch Width Relationships in Different Malocclusion



Abstract

Background

This study aims to compare tooth size ratios (Bolton anterior and overall ratios) and transverse dental arch widths among Class II Division 1, and Class II Division 2 malocclusions using three-dimensional (3D) digital models, and to evaluate their clinical relevance for individualized orthodontic planning.

Materials and methods

The study included 120 patients (mean age 14.5 ± 1.1 years) of both sexes, divided equally into three groups: Class I ($n = 40$), Class II/1 ($n = 40$), and Class II/2 ($n = 40$). Intraoral scans were obtained for both the maxillary and mandibular arches. Digital measurements were performed including the mesiodistal width of the teeth for calculating the anterior ratio (AR) and overall ratio (OR), as well as the intercanine (ICW), interpremolar (IPMW), premolar (PW), and intermolar (IMW) arch widths in both arches. Statistical analysis included independent t-tests, ANOVA, and Tukey post-hoc tests ($p < 0.05$).

Results

Males showed significantly greater maxillary and mandibular mesiodistal widths, especially in Class II/2 malocclusion. Whereas Class I subjects showed significantly greater intercanine, interpremolar, premolar, and intermolar widths compared to Class II/1 and Class II/2 groups ($p < 0.05$). Significant differences were also observed in the Bolton ratios: Class II/1 showed the highest AR and OR values, while Class II/2 showed the lowest ratios.

Conclusion

Three-dimensional digital analysis revealed significant differences in tooth size and transverse arch width between Class I, Class II/1, and Class II/2 malocclusions. These findings highlight the need for individualized orthodontic planning of tooth size ratios and arch dimensions during the treatment of Class II malocclusions.

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Keywords

Class II malocclusion, Bolton ratio, arch width, 3D digital model, intraoral scanner, orthodontic diagnosis.

INTRODUCTION

Orthodontic analysis and measurements on study models are essential for determining the need for orthodontic treatment. Technological advances have enabled the transformation from conventional models to three-dimensional digital models, allowing clinicians to perform efficient and individualized treatment planning (1). Achieving optimal function and aesthetic results from orthodontic treatment is essential (2,3). One of the most important factors in attaining a satisfying anterior and posterior occlusion is the proper ratio of mesiodistal widths between the maxillary and mandibular teeth (4,5).

The Bolton analysis remains one of the most widely used methods for assessing the relationship between the mesiodistal widths of the maxillary and mandibular teeth (6). Discrepancies between the mesiodistal widths of the maxillary and mandibular teeth are known as tooth size discrepancy (TSD) (7). If these changes occur, they can cause significant clinical problems in the later stages of orthodontic treatment. (8). Previous research has shown that the presence of larger teeth in one jaw tends to have more crowding compared to the other jaw (9), while smaller teeth tend to have more space (10).

Furthermore, studies have shown that gender influences tooth size, with males having larger absolute tooth sizes (11,12), although there are studies that show no gender discrepancy (13–15). In addition to the discrepancy in tooth size, the transverse dimensions of the maxillary and mandibular dental arches play an important role in both occlusal function and patient aesthetics. (16). Pont suggested that tooth size and arch width have a constant relationship (17), and Alam et al. (18) also showed significant variations in tooth sizes based on arch width dimensions. The literature states that the main point for measuring the width of the dental arch is the intercanine width, therefore the intercanine distance is known as the width of the dental arch. It varies between individuals due to the influence of environment, nutrition, genetics and gender (19). Staley et al. (20) best demonstrated that the maxillary intercanine width is greater than the mandibular intercanine width and is usually comparable in males to the intercanine width of females. When comparing intercanine widths between classes, the results of the study by Patel et al. showed that the intercanine width of Class II Division 2 malocclusion was wider than that of Class II, Division (19).

Historically, these measurements have been made by conventional cast measurements. However, with the introduction of digital technology and artificial intelligence, it may be possible to take digital measurements and develop a virtual plan for each individual case simultaneously for all treatment steps, as they can be made in the early stages of the clinical examination (21).

This study aims to evaluate the relationship tooth size ratios (anterior and overall Bolton ratios) and transverse dental arch widths between Class II Division 1 and Class II Division 2 malocclusions, and to determine their clinical significance for individual orthodontic planning using three-dimensional digital models.

MATERIAL AND METHOD

This cross-sectional observational study was conducted at the University Dental Clinical Center of Kosovo, Department of Orthodontics between January 2021 and December 2021. The project has been approved by the Ethics Committee with reference number (protocol number # 4068, 17.07.2020).

Sample Selection

A total of 120 patients aged 13–17 years, of both sexes, participated in this study. Participants were divided into three main groups according to Angle's classification: Group first: Class I malocclusion, group second: Class I (n=40), Class II Division 1 (n=40), and Class II Division 2 (n=40).

Inclusion criteria:

- Age between 13 and 17 years,
- Presence of all permanent teeth from first molar to first molar,
- Class I, class II division 1 and class II division 2.

Exclusion criteria:

- Previous orthodontic or surgical treatment,
- Congenital tooth anomalies or missing teeth,
- Asymmetry of the arches,
- Extensive prosthetic restorations or caries affecting mesiodistal width,
- Prosthetic restorations.

Digital Impression Acquisition (Prime Scanner)

For all patients, digital impressions of both the maxillary and mandibular arches were obtained using the Prime Scanner (Dentsply Sirona, Germany). This intraoral digital scanner provides high-precision three-dimensional imaging, including: all dental surfaces, the palate, and the intercuspidal relationship between the upper and lower arches.

The PrimeScan intraoral scanner was used to take digital impressions of the dental arches. This device represents the new generation of CAD/CAM systems designed for accurate three-dimensional scanning of the oral cavity. It enables a full dental arch scan within 15-30 seconds and is also easily integrated with the Maestro 3D dental Studio digital orthodontic analysis software.

Software Processing (Maestro 3D Dental Studio)

The digital models were analyzed for tooth width measurements, Bolton analysis and transverse arch width

Fig. 1A

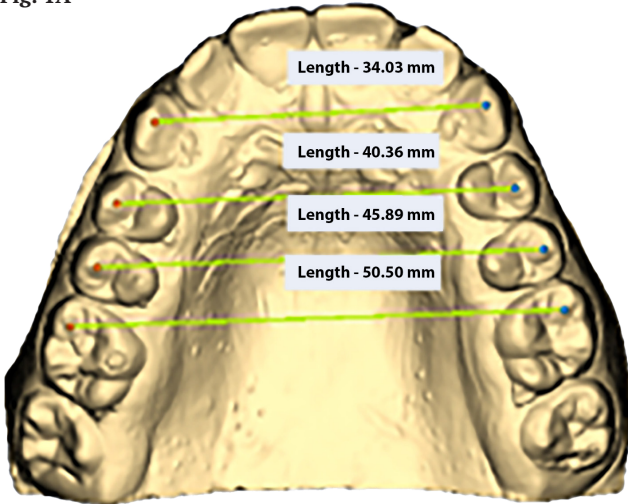


Fig. 1B

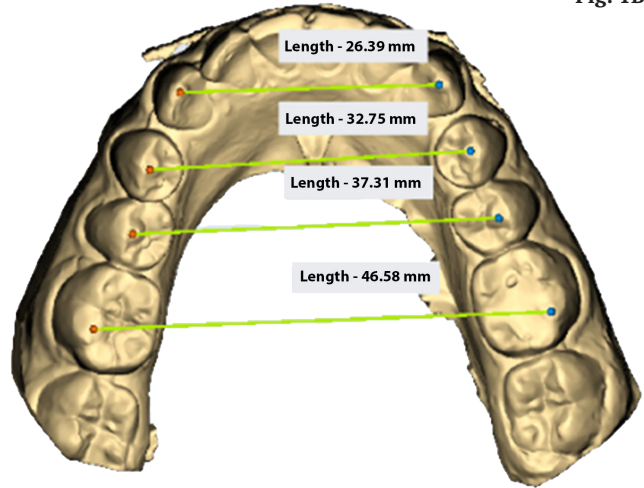


Fig. 1A, 1B Digital measurements of maxillary and mandibular arch widths (intercanine, inter-premolar, premolar, and intermolar) using the Maestro 3D Dental Studio software.

Fig. 2A

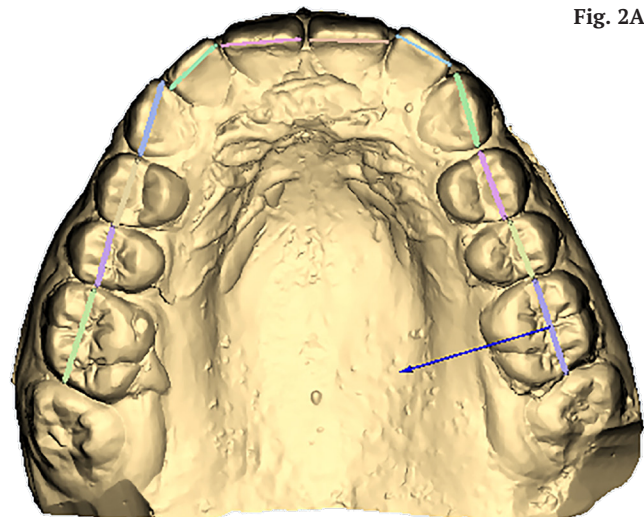
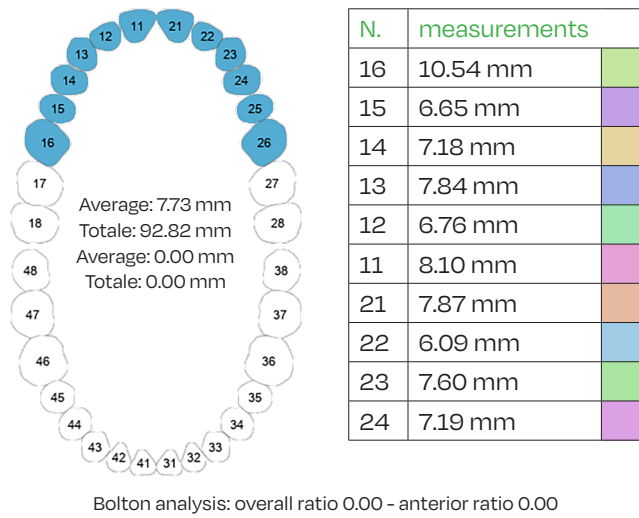


Fig. 2B

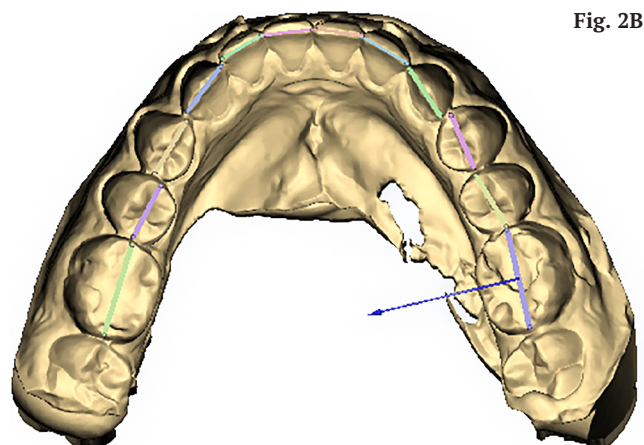
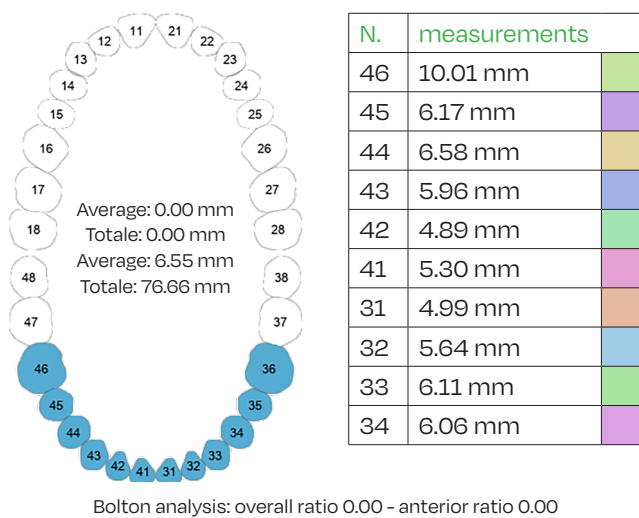


Fig. 2A, 2B Digital measurements of maxillary and mandibular mesiodistal tooth dimensions for Anterior Ratio and Overall Ratio using Maestro 3D Dental Studio software.

Maxillary arch	Class of malocclusion	Mean, SD		95% CI	t-value	p-value
		Male	Female			
N-40	Class I					
	U-16	10.02±0.29	9.97±0.43	-0.2989 to 0.1989	0.40	0.68
	U-15	6.39±0.44	6.22±0.32	-0.4131 to 0.0731	-1.416	0.16
	U-14	6.83±0.42	6.59±0.37	-0.4951 to 0.0151	-1.904	0.06
	U-13	7.23±0.54	7.09±0.60	-0.5170 to 0.2370	-0.752	0.45
	U-12	6.44±0.55	6.30±0.62	-0.6182 to 0.3382	-0.604	0.55
	U-11	8.13±0.42	7.85±0.58	-0.6964 to 0.1364	-1.388	0.17
	U-21	7.99±0.38	7.74±0.72	-0.7283 to 0.2283	-1.079	0.29
	U-22	6.26±0.53	5.90±0.60	-0.8220 to 0.1020	-1.608	0.12
	U-23	7.35±0.55	7.08±0.41	-0.6591 to 0.1191	-1.432	0.16
	U-24	6.76±0.46	6.67±0.62	-0.4421 to 0.2621	-0.528	0.6
	U-25	6.46±0.55	6.31±0.58	-0.6099 to 0.3099	-0.673	0.5
U-26	10.20±0.30	10.4±0.59	-0.1892 to 0.5892	1.061	0.2	
N-40	Class II/1					
	U-16	9.88±0.5	9.73±0.47	-0.5291 to 0.2291	-0.813	0.42
	U-15	6.24±0.42	6.35±0.5	-0.2572 to 0.4772	0.616	0.54
	U-14	6.49±0.63	6.26±0.51	-0.6726 to 0.2126	-1.068	0.29
	U-13	7.13± 0.29	6.85±0.68	-0.7116 to 0.1516	-1.333	0.19
	U-12	6.27±0.73	5.85±0.68	-0.9707 to 0.1307	-1.568	0.12
	U-11	8.04±0.45	8.13±0.73	-0.4022 to 0.5822	0.376	0.71
	U-21	8.05±0.49	7.87±0.66	-0.6463 to 0.2863	-0.793	0.43
	U-22	8.06±0.48	7.89±0.65	-0.6285 to 0.2885	-0.762	0.45
	U-23	5.85±0.67	6.05±0.66	-0.3214 to 0.7214	0.788	0.43
	U-24	6.76±0.38	7.03±0.43	-0.0515 to 0.5915	1.726	0.09
	U-25	6.41±0.43	6.34±0.52	-0.4499 to 0.3099	-0.379	0.7
U-26	6.33±0.28	6.26±0.41	-0.3532 to 0.2132	-0.508	0.61	
N-40	Class II/2					
	U-16	10.16±0.63	9.79±0.39	-0.7874 to 0.0474	-1.829	0.079
	U-15	6.44±0.29	6.50±0.63	-0.3488 to 0.4688	0.303	0.7
	U-14	6.64±0.25	6.55±0.31	-0.3207 to 0.1407	-0.805	0.42
	U-13	7.84±0.38	7.12±0.34	-1.0114 to -0.4286	-5.100	0.00*
	U-12	6.64±0.69	6.39±0.41	-0.7015 to 0.2015	-1.143	0.26
	U-11	8.02±0.39	7.76±0.53	-0.6394 to 0.1194	-1.414	0.17
	U-21	8.02±0.14	7.84±0.23	-0.3375 to -0.0225	-2.358	0.02*
	U-22	7.57±0.35	7.14±0.42	-0.7462 to -0.1138	-2.806	0.009*
	U-23	6.80±0.22	6.64±0.39	-0.4226 to 0.1026	-1.258	0.22
	U-24	6.42±0.42	6.51±0.46	-0.2690 to 0.4490	0.517	0.6
	U-25	9.89±0.41	9.77±0.47	-0.4801 to 0.2401	-0.688	0.49
U-26	10.32±0.49	9.91±0.66	-0.8876 to 0.0676	-1.772	0.08	
<i>p-value ≤0.05, significant level,SD-Standard deviation</i>						

Tab. 1 Comparison between males and females across three Classes of malocclusion for maxillary tooth widths.

Mandibular arch	Class of malocclusion	Mean, SD		95% CI	t-value	p-value
		Male	Female			
N-40	Class I					
	L-46	10.41±0.43	10.21±0.53	-0.5221 to 0.1221	-0.159	0.21
	L-45	6.77±0.31	6.71±0.43	-0.3629 to 0.1929	-0.409	0.68
	L-44	6.55±0.70	6.35±0.35	-0.6180 to 0.2180	-0.993	0.32
	L-43	6.46±0.58	5.86±0.35	-0.8972 to -0.3028	-3.404	0.002*
	L-42	5.57±0.39	5.29±0.24	-0.4813 to -0.0787	-2.347	0.02*
	L-41	4.90±0.33	4.68±0.33	-0.4790 to 0.0390	-1.746	0.09
	L-31	4.82±0.34	4.80±0.45	-0.3396 to 0.2996	0.129	0.88
	L-32	5.51±0.61	5.17±0.55	-0.7923 to 0.1123	-1.545	0.13
	L-33	6.30±0.35	5.92±0.34	-0.6502 to -0.1098	-2.890	0.007*
	L-34	6.45±0.58	6.30±0.37	-0.5193 to 0.2193	-0.835	0.41
	L-35	6.41±0.86	6.44±0.54	-0.5145 to 0.5746	0.221	0.91
	L-36	10.05±0.56	10.18±0.58	-0.3187 to 0.5787	0.596	0.55
N-40	Class II/1					
	L-46	10.03±0.27	9.94±0.33	-0.3302 to 0.1502	-0.770	0.44
	L-45	6.63±0.45	6.32±0.34	-0.6164 to -0.0036	-2.080	0.04*
	L-44	6.66±0.61	6.23±0.54	-0.8780 to 0.0180	-1.973	0.05*
	L-43	6.18±0.38	5.79±0.64	-0.8181 to 0.0381	-1.873	0.07
	L-42	5.51±0.39	5.34±0.41	-0.4853 to 0.1453	-1.108	0.27
	L-41	5.17±0.47	5.06±0.99	-0.7472 to 0.5272	-0.355	0.77
	L-31	5.09±0.47	5.03±0.89	-0.6424 to 0.5224	-0.212	0.83
	L-32	5.29±0.43	5.12±0.33	-0.4648 to 0.1248	-1.185	0.24
	L-33	6.18±0.43	5.79±0.43	-0.7275 to -0.0525	-2.375	0.02*
	L-34	6.45±0.42	6.11±0.34	-0.6351 to -0.0449	-2.368	0.02*
	L-35	6.66±0.52	6.43±0.27	-0.5405 to 0.0805	-1.523	0.13
	L-36	10.22±0.45	9.73±0.28	-0.7740 to -0.2060	-3.546	0.001*
N-40	Class II/2					
	L-46	10.32±0.66	9.94±0.52	-0.8379 to 0.0779	-1.706	0.1
	L-45	6.78±0.52	6.27±0.39	-0.8629 to -0.1571	-2.970	0.006*
	L-44	6.66±0.45	6.47±0.52	-0.5759 to 0.1959	-1.012	0.32
	L-43	6.32±0.34	6.10±0.39	-0.5102 to 0.0702	-1.558	0.13
	L-42	5.18±0.22	5.20±0.33	-0.2066 to 0.2466	0.181	0.85
	L-41	4.96±0.27	5.03±0.23	-0.1244 to 0.2644	0.740	0.46
	L-31	5.03±0.42	5.10±0.29	-0.2055 to 0.3455	0.522	0.6
	L-32	5.24±0.31	5.16±0.30	-0.3188 to 0.1588	-0.688	0.49
	L-33	6.41±0.56	5.95±0.43	-0.8440 to -0.0760	-2.462	0.02*
	L-34	6.52±0.42	6.24±0.23	-0.5345 to -0.0255	-2.261	0.03*
	L-35	6.56±0.63	6.02±0.56	-1.0036 to -0.0764	-2.394	0.02*
	L-36	10.32±0.66	9.94±0.52	-0.8379 to 0.0779	-1.706	0.1

p-value ≤0.05, significant level, SD-Standard deviation

Tab. 2 Comparison between males and females across three Classes of malocclusion for Mandibular tooth widths.

using the Maestro 3D Dental Studio software (AGE Solutions, Pisa, Italy). This software provides extremely accurate measurements for the digital assessment of transverse arch dimensions.

Digital Measurements of Arch Width

Transverse arch measurements were performed in both jaws according to the following parameters (fig.1a, 1b):

- Inter canine width: measured between the cusp tips of the right and left canines.
- First interpremolar width: measured between the buccal cusp tips of the right and left first premolars.
- Second premolar width: measured between the buccal cusp tips of the right and left second premolars.
- Intermolar width: measured between the mesiobuccal cusp tips of the right and left first molars.

Parameters	Class I Oclusion N- 40		Class II /1 Oclusion N-40		Class II/2 Oclusion		p-value
	Mean±SD	SEM	Mean±SD	SEM	Mean±SD	SEM	
Maxillary/mandibular IC widths	58.6 ± 2.8	0.44	57.30 ± 1.75	0.28	57.4 ± 2.3	0.36	0.02
Maxillary/mandibular IPM widths	72.5 ± 2.6	0.41	70.25 ± 2.0	0.32	70.5 ± 2.2	0.35	0.0001
Maxillary/mandibular PM widths	83.2 ± 2.3	0.36	81.50 ± 2.2	0.35	81.0 ± 2.5	0.40	0.002
Maxillary/mandibular IM widths	95.9 ± 2.9	0.46	94.40 ± 2.7	0.43	94.7 ± 2.3	0.36	0.03
Bolton ratio AR	76.5 ± 3.4	0.54	77.50 ± 2.0	0.63	75.4 ± 3.1	0.49	0.006
Bolton ratio OR	89.7 ± 1.6	0.25	90.70 ± 3.1	0.49	88.8 ± 2.5	0.40	0.003

p-value ≤0.05-significance level, SEM-Standard erros mean, IC-Inter canine widths,IPM-interpremolar widths,PMpremolar widths,IM-intermolar widtsh,AR-Anterior ratio,OR-Overall ratio

Tab. 3 Mean, standard deviation and standard error means of the sum of maxillary and mandibular tooth widths, Bolton Ratio.

Class Group comparision widths	Mean difference	SEM	p-value
Inter canine widths			
Class I vs Class II/1	+1.3	0.52	0.05
Class I vs Class II/2	+1.2	0.55	0.06
Class II/1 vs Class II/2	-0.1	0.48	0.9
Interpremolar widths			
Class I vs Class II/1	+2.25	0.60	0.001
Class I vs Class II/2	+2.0	0.62	0.002
Class II/1 vs Class II/2	-0.25	0.58	0.72
Premolar widths			
Class I vs Class II/1	+1.7	0.58	0.004
Class I vs Class II/2	+2.2	0.60	0.002
Class II/1 vs Class II/2	+0.5	0.55	0.34
Intermolar widths			
Class I vs Class II/1	+1.5	0.65	0.03
Class I vs Class II/2	+1.2	0.62	0.04
Class II/1 vs Class II/2	-0.3	0.60	0.61
Bolton AR			
Class I vs Class II/1	-1.0	0.65	0.08
Class I vs Class II/2	+1.1	0.70	0.07
Class II/1 vs Class II/2	+2.1	0.62	0.006
Bolton OR			
Class I vs Class II/1	-1.0	0.58	0.05
Class I vs Class II/2	+0.9	0.60	0.09
Class II/1 vs Class II/2	+1.9	0.55	0.003

Tab. 4 Multiple comparisons of Tooth widths between three class malocclusions.

Tooth Size Measurements

The mesiodistal dimensions of the teeth were measured from the first molar on one side to the first molar on the opposite side, in the mesiodistal diameter of each tooth (Fig. 2a, 2b), (7). To assess reliability, several models were randomly selected for re-measurement.

Statistical Analysis

Data analysis was conducted using IBM SPSS Statistics for Windows, Version 22.0 (IBM Corp., Armonk, NY, USA). Descriptive statistics for continuous variables were presented as Mean \pm Standard deviation (SD). The Shapiro Wilk test was applied to evaluate the normality of distribution for each variable, including tooth size measurements (mesiodistal diameters) and transverse arch dimensions (intercanine, interpremolar, premolar, and intermolar widths). Based on the distributional properties, parametric tests were employed. Differences in tooth widths between genders within each malocclusion Class were assessed using the Independent Samples T-test. Comparisons among the three malocclusion groups (Class I, Class II Division 1, and Class II Division 2) were performed using One-Way analysis of variance (ANOVA). When ANOVA indicated statistically significant differences, Tukey's HSD Post Hoc Test was applied to identify pairwise group differences. All statistical tests were two-sided, and the threshold for statistical significance was set at $p < 0.05$.

RESULTS

The study included 120 patients divided into three groups. The first group with class I malocclusion ($n=40$), the second group with class II malocclusion of division 1 ($n=40$) and the third group with class II malocclusion of division 2 ($n=40$). The patients who participated in the study were aged 13 - 16 years, mean age 14.5 ± 1.1 . 60.0% were female and male 40%. Impressions of all examinees were taken with an intraoral scanner, while the dental studio software program Mastro 3D was used for the analysis of digital models. Measurements included tooth width to calculate AR and OR in percentage and arch width. In table 1 the results show no statistically significant differences in maxillary tooth widths between males and females in Class I malocclusion. Although males tend to have slightly wider teeth on average, these differences are not clinically significant according to the statistical analysis. There are no statistically significant differences in maxillary tooth widths between males and females in Class II/1 malocclusion. Some teeth, such as U-24, have p-values close to the threshold ($p \leq 0.09$), but do not exceed the level of statistical significance. These results suggest that the average differences are not clinically significant for this malocclusion class.

In Class II/2 of malocclusion there are statistically significant differences in certain teeth such U-13 (right canine) suggests that males have a noticeably greater width ($p \leq 0.001$), in U-21 and U-22 (left incisors) males have significantly wider teeth ($P \leq 0.02$ respectively $p \leq 0.009$). For the other teeth, there are no statistically significant differences.

In table 2 results shows that there are statistically significant differences in certain teeth in Class I of malocclusion, L-43 ($p \leq 0.002$), L-42 ($p \leq 0.02$), and L-33 ($p \leq 0.007$) are noticeably wider in males. For the other teeth, there are no statistically significant differences. There are statistically significant differences in Class II/1 of malocclusion of certain teeth L-45 ($p \leq 0.04$), L-44 ($p \leq 0.05$), L-33 ($p \leq 0.02$) L-34 ($p \leq 0.02$), and L-36 ($p \leq 0.006$), are noticeably wider in males. For the other teeth, there are no statistically significant differences. There are also statistically significant differences in certain individual teeth in Class II/2 of malocclusion, L-45 ($p \leq 0.006$), L-33 ($p \leq 0.02$), L-34 ($p \leq 0.03$), and L-35 ($p \leq 0.02$), where are noticeably wider in males. For the other teeth, there are no statistically significant differences.

Table 3 presents the results of the One-Way ANOVA, which revealed that all dento-alveolar dimensions exhibited statistically significant differences across Class I, Class II/1, and Class II/2 groups. Significant variations were observed in the intercanine (IC, $p \leq 0.02$), interpremolar (IPM, $p \leq 0.0001$), premolar (PM, $p \leq 0.002$), and intermolar (IM, $p \leq 0.03$) widths. Furthermore, the Bolton ratios, both anterior AR ($p \leq 0.006$) and overall OR ($p \leq 0.003$), demonstrated significant discrepancies, indicating disproportions in tooth size relationships. These findings confirm the presence of disproportion between anterior and posterior teeth, as well as in the overall maxillary/mandibular tooth ratio.

Table 4 presents the results of the Post Hoc Tukey test, which was applied following the One-Way ANOVA to identify statistically significant differences among the groups and to determine which specific pairwise comparisons accounted for these differences. The analysis revealed that Class I vs Class II/1 in maxillary/mandibular IC widths showed a statistically significant difference ($p \leq 0.05$), indicating that patients with Class I occlusion exhibit greater IC width. In contrast, Class I vs Class II/2 demonstrated a difference but not significant ($p \leq 0.06$), while Class II/1 vs Class II/2 showed no significant difference ($p \leq 0.9$). For IPM widths, Class I vs Class II/1 revealed a highly significant difference ($p \leq 0.001$), with Class I patients presenting greater IPM width. Similarly, Class I vs Class II/2 also showed a statistically significant difference ($p \leq 0.01$), whereas Class II/1 vs Class II/2 did not demonstrate significant variation ($p \leq 0.8$).

The Post Hoc Tukey analysis demonstrated that PM widths differed significantly between Class I and Class

II/1 ($p \leq 0.01$), with Class I occlusion showing greater values. A similar significant difference was observed between Class I and Class II/2 ($p \leq 0.01$), whereas no significant variation was found between Class II/1 and Class II/2 ($p \leq 0.5$). For IM widths, Class I vs Class II/1 revealed a statistically significant difference ($p \leq 0.05$), indicating wider IM dimensions in Class I. In contrast, Class I vs Class II/2 ($p \leq 0.06$) and Class II/1 vs Class II/2 ($p \leq 0.8$) did not demonstrate significant differences. Regarding Bolton ratios, the AR showed significant differences across all comparisons, Class I vs Class II/1 ($p \leq 0.05$), Class I vs Class II/2 ($p \leq 0.01$), and Class II/1 vs Class II/2 ($p \leq 0.04$). Similarly, the OR, revealed significant differences in the same group comparisons ($p \leq 0.05$, $p \leq 0.01$, and $p \leq 0.04$, respectively), confirming disproportion in tooth size relationships across occlusal classes.

DISCUSSION

For a long time, diagnosis and orthodontic treatment planning on plaster models have provided effective support in clinical assessment. However, with the advancement of digital technology particularly using intraoral scanners and three-dimensional (3D) digital models, it has become possible to replace traditional plaster models with digital ones (22).

Some studies have used extraoral scanners, though these have certain limitations, as they may slightly affect individual measurement parameters (23). Nevertheless, as digital methods have become more widespread, their advantages have been clearly demonstrated, particularly in terms of time efficiency and accuracy (24,25).

In the present study, tooth size and arch width characteristics among Class I, Class II/1, and Class II/2 malocclusions in a Kosovar population were assessed in 3D digital models using Maestro 3D Dental Studio software. The main aim was to determine whether changes in tooth size are associated with changes in transverse arch width and tooth size discrepancies between different types of sagittal malocclusion.

Gender-related tooth size differences

The present findings confirmed the presence of sexual dimorphism in mesiodistal tooth dimensions, but with a tooth- and class-specific pattern. In the maxillary arch, no statistically significant differences were observed between males and females in Class I and Class II/1 malocclusions, whereas in Class II/2 males showed significantly larger widths in selected teeth, namely the (U-13) and (U-21, U-22). In the mandibular arch, more pronounced gender-related differences were detected: several teeth in Class I (L-43, L-42, L-33), Class II/1 (L-45, L-44, L-33, L-34, L-36), and Class II/2 (L-45, L-33, L-34, L-35) were significantly wider in males than in females. These results are

consistent with reports from studies in Indian, Turkish and Iranian populations where males tended to exhibit larger mesiodistal tooth diameters (2,11,28).

If we look at it from a clinical perspective, such dimorphism is quite important due to the coordination of space and adequate planning, especially in cases where we are allowed or not an interproximal reduction of enamel or in cases of extractions. In addition, the observation that dimorphism is more evident in specific mandibular teeth supports the concept that lower anterior and premolar segments may play a critical role in achieving optimal interdigitation and final occlusal fit. The anterior and overall Bolton ratios in our study showed comparable variations to those reported in previous digital studies conducted in different populations, regarding either the absence (29) or presence (4,5) of variations among different malocclusion groups. These differences reflect specific ethnic dental morphologies. The impact of genetic and environmental factors on tooth and dental arch morphology was supported by similar findings reported in populations groups. In a study by Abdulaziz et al.(38) which aimed to determine variations in tooth size discrepancies between orthodontic patients and individuals with normal occlusion in Saudi Arabia using three-dimensional scanning of study models, their results showed that the anterior ratio (AR) and posterior ratio (OR) in malocclusion cases, as well as the anterior ratio in the control group, were significantly higher than Bolton standards. According to the authors, this indicates the influence of genetics and ethnic background on tooth and jaw size. Our results also showed similar findings where the anterior ratio (AR) and overall ratio (OR) compared to Class I, Class II division 1 and Class II division 2 exceeded Bolton standards.

Transverse arch width differences among malocclusion classes

Three-dimensional digital analysis revealed significant transverse discrepancies among the three malocclusion classes. Subjects with Class II Division 1 and Class II Division 2 malocclusion exhibited narrower maxillary intercanine and premolar widths compared with Class I subjects. One-way ANOVA and post-hoc Tukey analysis demonstrated that Class I patients had significantly greater intercanine, interpremolar, premolar, and intermolar widths than Class II/1, and similar significant differences were observed between Class I and Class II/2 for most transverse measurements. Our results show that the intercanine width and premolar width are narrower in the transverse direction, confirming a characteristic of Class II malocclusions compared to Class I malocclusion where it is closer to normal.

Previous 3D morphometric studies also reported reduced maxillary transverse dimensions in Class

II malocclusions. Unal et al. (31) and Petrović et al. (32) found narrower intercanine and interpremolar widths in Class II patients using digital models, while Gallottini et al. (33) emphasized that digital arch width assessment offers high diagnostic accuracy and should be used in orthodontic evaluation. Our results agree with these findings and further extend them by demonstrating that all dento-alveolar transverse dimensions, including intermolar width, show statistically significant differences between Class I and Class II malocclusions in this Kosovar sample.

Bolton ratios and tooth size discrepancies

Depending on the population or the methodology used, various studies have reported the presence or absence of significant differences in Bolton ratios between malocclusion groups. In line with our findings, various studies have also been reported (26, 35, 36), with significant differences in both anterior and overall ratios. However, the findings of Mujagić A. et al. (37) contradict the idea that Bolton ratios are always different between classes.

The anterior (AR) and overall (OR) Bolton ratios in the present study showed significant variation among malocclusion groups. Class II/1 patients exhibited higher AR and OR values compared with Class II/2 patients, indicating a relatively greater mandibular tooth mass in the anterior and overall segments. The anterior (AR) and overall (OR) Bolton ratios in the present study showed significant variation among malocclusion groups. Class II/1 patients exhibited higher AR and OR values compared with Class II/2 patients, indicating a relatively greater mandibular tooth mass in the anterior and overall segments, underlining the importance of population-specific reference data.

Clinically, deviations from the Bolton standards may complicate the achievement of midline discrepancy, overbite or overlap. Especially in class II division 1 where there is a discrepancy in tooth size and narrowing of the dental arch in the transverse direction. Therefore, in such cases, clinicians should consider Bolton analysis on 3D digital models to avoid any discrepancy in tooth size with the dental arches.

Clinically relevant and regional contribution

Overall, our findings highlight the importance of 3D digital models in enabling clinicians to design personalized orthodontic treatment protocols by providing comprehensive information on tooth size, arch width, and tooth size discrepancies. Documented sexual dimorphism in specific teeth, narrower maxillary arches in Class II malocclusions, and differences in Bolton ratios between classes are all parameters that should be systematically assessed before initiating treatment in adolescents aged 13-17 years. This is particularly important when orthodontic

treatment is planned with or without tooth extraction to improve functional and aesthetic outcomes.

Regional studies for the Western Balkan population have been conducted mainly on orthodontic patient samples, not clearly defining age, and separately assessing tooth size or dental arch dimensions.

Limitations and Future Directions

The study sample size and single center sampling may limit the broad applicability of the findings. Future research should include studies with larger multicenter samples. The integration of artificial intelligence-driven digital technology into 3D model analysis will further improve diagnostic accuracy.

CONCLUSION

Significant differences were identified in both dental arch width and tooth size, especially gender-related differences were limited to selected teeth. Therefore, these findings indicate that orthodontic planning should be individualized, especially when there is a discrepancy in tooth size and transverse dental arch in patients with Class II malocclusion.

Abbreviations

TSD- tooth size discrepancy

AR- anterior ratio

OR- overall ratio

ICW- intercanin width

IPW- interpremolar width

PW- premolar width

IMW- intermolar width

Ethical Approval

This study was approved by the Ethics Committee of the University of Prishtina (Protocol No. 4068, 17/07/2020). Information consent was obtained from all participants and their guardians.

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