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Original Article

Digital 3D Analysis of Upper and Lower Dental Arches: Assessing Bolton's Index and Orthodontic Arch Compatibility

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ABSTRACT

The evolution of digital systems, particularly computer-aided design (CAD) and computer-aided manufacturing (CAM), has made virtual dental modeling a practical component of orthodontic analysis and treatment planning. Prior literature has consistently demonstrated the dependability of digital assessments for measuring anterior teeth and the overall Bolton ratio. The present work aimed to compare mean arch lengths of the upper and lower jaws with a theoretical nickel–titanium wire, while also validating the precision of digital determinations of the anterior and total Bolton coefficients. This retrospective investigation included 138 Caucasian adolescents. Their dental casts were digitized with an extraoral scanner, and all evaluations were performed using Ortho3Shape software. The data recorded included both measured and ideal arch lengths, as well as the anterior and total Bolton indices. Findings revealed that the mean anterior Bolton value aligned with prior reports, supporting the accuracy of digital methods. Consequently, CAD/CAM-generated models can serve as dependable alternatives to plaster ones, simplifying their storage and accessibility. For future research, intraoral scanners (IOS) are recommended, as they require fewer steps and provide higher precision and patient comfort.

Keywords: Digital dentistry, Bolton ratio, Orthodontic software, 3D scanning

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Introduction

Modern digital dentistry, particularly through CAD/CAM applications, has transformed orthodontic diagnostics and treatment workflows by simplifying complex procedures.

The digital workflow generally follows three sequential phases: (1) acquisition of virtual scans of the dental arches, (2) processing these images through specialized orthodontic software, and (3) generating printable 3D model files [1].

Digital orthodontic models assist clinicians in assessing treatment requirements and parameters such as the Bolton index. Previous studies confirm that traditional plaster casts can be accurately reconstructed as three-dimensional virtual images [2].

Originally introduced in 1958 by Wayne Bolton, the Bolton analysis quantifies discrepancies between upper and lower tooth proportions by calculating ideal mesiodistal relationships between the teeth from central incisors to first molars in both arches.

Virtual dental models can effectively support diagnostic and planning decisions [3, 4], and numerous publications have validated the precision of digital tools for computing both anterior and total Bolton ratios [5, 6].

Existing research [7] also indicates that tooth movement—both rotational and translational—can be virtually simulated with high accuracy. In complex orthodontic interventions, such virtual preplanning minimizes errors and enhances predictability of final outcomes.

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The integration of artificial intelligence into digital workflows further strengthens early diagnostic planning by allowing real-time simulation of complete treatment stages [8].

Additionally, 3D printing technologies now enable the production of personalized clear aligners directly from digital designs, offering improved precision, fit, and performance compared with traditional orthodontic appliances [9].

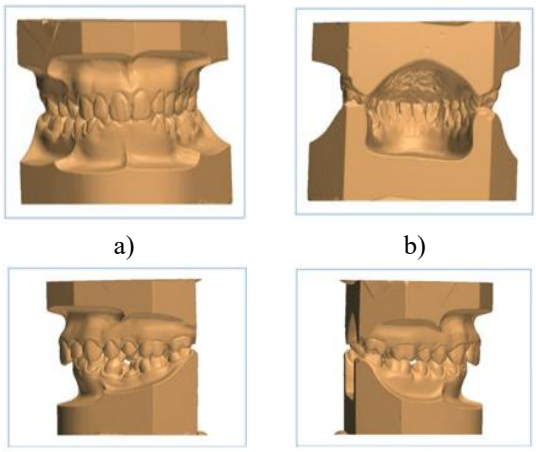
In this investigation, we compared mean arch lengths of adolescent patients' maxillary and mandibular arches with those of a simulated nickel–titanium wire using an extraoral scanner and specialized software. Furthermore, we assessed the accuracy of the anterior and total Bolton indices obtained digitally.

Since the research was retrospective and existing casts were available, an extraoral scanner was chosen instead of an intraoral scanner.

The study aimed to determine average upper and lower arch lengths and to calculate anterior and total Bolton coefficients in an Italian adolescent sample, while testing the reliability of digital measurements.

Materials and Methods

All measurements were performed by a single calibrated examiner using the Ortho3Shape software to analyze 138 digital dental casts **(Figure 1)**.



a) b) c) d)

Figure 1. Example of 3D-rendered digital dental models.

The recorded parameters included: (a) current arch lengths, (b) simulated nickel–titanium wire length, and (c) anterior and total Bolton ratios.

Selection criteria

Inclusion parameters

- Individuals of Caucasian descent;
- Fully erupted permanent teeth;
- Class I occlusal relationship and absence of notable malocclusion;
- No record of tooth extraction or large-scale restorative dental work;
- No prior surgical procedures involving the maxillofacial area;
- No history of fixed or removable orthodontic appliances;
- Availability of 3D digital dental models processed with Ortho3Shape software.

Exclusion parameters

- Presence of primary (deciduous) teeth;
- Teeth showing pronounced rotation;
- Congenital absence of one or more teeth (dental agenesis);
- Oligodontia diagnosis.

Clinical procedures

In this investigation, the mesiodistal width of teeth spanning from the right to the left canine was assessed for both the maxillary and mandibular arches to determine the anterior Bolton ratio.

To compute the overall Bolton coefficient, the same measurements were extended from the right molar to the left molar.

Using digital impressions analyzed in Ortho3Shape, the average length of a virtual nickel–titanium orthodontic archwire was calculated for the upper and lower jaws.

These averages were then compared with the actual lengths of the respective dental arches.

To ensure precision and reliability, both anterior and total Bolton indices derived in this study were contrasted with the findings published by A. Anand Kumar *et al*. [10].

Statistical analysis

The sample size was determined considering a 95% confidence level, 80% statistical power, a population variance of 1000, and a hypothesized difference of 10, referencing the Bolton ratio data presented by A. Anand Kumar *et al*. [10].

Each measurement was taken twice by the same examiner, maintaining a two-week gap between the two assessments. Cohen's Kappa statistic was used to determine intra-examiner reliability, yielding coefficients between 0.90 and 0.97.

The mean digital cast values were evaluated through Student's t-test, adopting a significance level of $p < 0.05$.

All statistical processing was performed using SPSS

version 22.0 (Statistical Package for the Social Sciences, Chicago, IL, USA).

The anterior and total Bolton measurements were compared to those reported by A. Anand Kumar *et al*. [10] to identify possible deviations.

The comparative study by A. Anand Kumar *et al*. was based on 50 adult subjects who satisfied similar inclusion requirements:

- Fully developed permanent dentition from the right to left first molar in both arches;
- No previous or ongoing orthodontic intervention;
- No severe crowding of the dentition [10].

Student's t-test ($p < 0.05$) was employed to determine statistically relevant differences between the datasets.

Results and Discussion

Findings from this research are summarized in **Tables 1-4**, while **Table 5** illustrates a comparison between the mean anterior and total Bolton ratios of this study and those reported by A. Anand Kumar *et al*. [10], evaluated through both CBCT imaging and dental cast analysis.

Table 1. Upper arch measurements of orthodontic wire and digital dental casts.

Upper Arch Measurement	Hypothetical Nickel Titanium Orthodontic Wire Upper Arch Length (mm)	Upper Arch Length (mm)
Maximum Value	124.33	108.07
Minimum Value	80.03	66.47
Mean Value	103.79	92.13

Table 2. Lower arch measurements of orthodontic wire and digital dental casts.

Lower Arch Measurement	Hypothetical Nickel Titanium Orthodontic Wire Lower Arch Length (mm)	Lower Arch Length (mm)
Maximum Value	109.91	107.63
Minimum Value	75.32	68.47
Mean Value	94.71	88.26

Table 3. Anterior Bolton ratio calculated in this research.

Bolton Analysis Metric	Maxillary Teeth Width (mm)	Mandibular Teeth Width (mm)	Bolton Ratio
Maximum Value	45.54	35.69	1.16
Minimum Value	24.33	22.58	0.62
Mean Value	38.16	30.10	0.79

Table 4. Total Bolton ratio obtained in this research.

Bolton Analysis Metric	Maxillary Teeth Width (mm)	Mandibular Teeth Width (mm)	Bolton Ratio
Maximum Value	89.25	88.78	1.21
Minimum Value	58.10	53.39	0.68
Mean Value	78.99	73.77	0.94

Table 5. Comparative anterior and total Bolton coefficients from this research and the dataset of A. Anand Kumar *et al*. [10].

Measurement	A. Anand Kumar *et al*.'s Study Mean	Current Study Mean	p-Value
Anterior Bolton ratio	0.76	0.79	0.0028
Total Bolton ratio	0.91	0.94	0.0009

Analysis of digital dental casts

The measurement of the upper dental arch yielded a length of 92.13 mm, whereas the estimated length of a virtual nickel–titanium orthodontic archwire for the same arch averaged 103.79 mm **(Table 1)**.

Thus, the simulated wire was 11.66 mm longer than the dimension derived from the 3D dental cast.

For the lower arch, the cast measurement was 88.26 mm, while the computed mean length of the virtual nickel–titanium archwire amounted to 94.71 mm **(Table 2)**.

Consequently, the theoretical wire length exceeded the cast-derived lower arch measurement by 6.45 mm.

Comparative bolton analysis: current study vs. A. Anand Kumar et al. [10]

Anterior Bolton ratio: In the research conducted by A. Anand Kumar *et al*., the mean anterior coefficient among 50 participants measured 0.76 using both CBCT and cast-based assessments. In contrast, our study produced a mean value of 0.79 **(Table 5)** [10].

Total Bolton ratio: Their study reported a mean total coefficient of 0.91, while our investigation obtained a value of 0.94 **(Table 5)** [10].

Comparison of anterior and total bolton ratios between studies

Using Student's t-test, a statistically significant variation was found between the two studies for both parameters—anterior ratio ($p = 0.0028$; $p < 0.05$) and total ratio ($p = 0.0009$; $p < 0.05$).

In this research, dental models were digitized using a 3D extraoral scanner, generating STL (stereolithography) files through CAD/CAM systems. This technology preserves surface morphology as three-dimensional digital representations of the arches [11–13].

Such STL data provide clinicians with rapid access to diagnostic insights [14], including arch width, inter-arch discrepancies, Bolton index differences, overjet, and overbite measurements. They can also simulate tooth movement [15, 16], streamlining the digital orthodontic workflow and saving time for practitioners [17, 18].

Moreover, previous research has highlighted the precision of computer-aided design and manufacturing (CAD/CAM) systems in indirect bonding procedures, ensuring high levels of accuracy and reproducibility [19].

Digital casts may also be displayed with symmetrical virtual bases, enhancing the evaluation of arch asymmetries and improving measurement precision [20].

In this study, STL files of the dental casts were examined, and the arch lengths were compared with ideal nickel–titanium archwire dimensions in a cohort of adolescent participants.

The results revealed that the ideal upper archwire was 11.66 mm longer than the mean upper arch measurement from the digital casts, while the lower archwire was 6.45 mm longer than the lower cast measurement.

A comparison with A. Anand Kumar *et al*. [10], who analyzed 50 subjects, demonstrated comparable mean values for both anterior and total Bolton ratios. This consistency supports the reliability of digital measurements performed using orthodontic design software.

The findings can help establish reference values for arch dimensions and Bolton indices in Italian adolescents.

One limitation of this study was the use of an extraoral scanner on wax models instead of intraoral scanning. Future investigations employing intraoral scanners (IOSs) may allow for faster and more direct arch measurement with improved precision.

Conclusion

The outcomes of this investigation demonstrate that 3D digital orthodontic modeling using dental scanners is an effective tool for diagnosis and treatment planning. These observations are consistent with previous reports [17, 18] and contribute to defining average arch lengths and Bolton ratios in an Italian adolescent population.

In our analysis, the anterior Bolton index closely matched that of A. Anand Kumar *et al*. [10], reaffirming the accuracy and dependability of digital assessments.

For future studies, employing intraoral scanning technology is recommended, as it provides greater precision, simplifies the process, and enhances patient comfort compared to extraoral techniques.

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