SCIENTIFIC SECTION

Orthodontic treatment outcome: the relationship between anterior dental relations and anterior inter-arch tooth size discrepancy

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Abstract

Objective: This study investigated the pre- (T1) and post-treatment (T2) relationship between anterior (canine to canine inclusive) inter-arch tooth size ratio and various dental and skeletal variables.

Design: Retrospective longitudinal clinical study.

Setting: Swedish Health Board Clinic 2000.

Subjects: Random selection of T1 and T2 orthodontic records of 137 Swedish patients (56 male and 81 female). The sample included non-extraction (77), and four premolar extraction (60) cases across a range of dental and skeletal malrelationships.

Main outcome measures: Dental cast and lateral cephalogram measurements were recorded. Exploratory modelling investigated whether a significant relationship existed between the anterior inter-arch tooth size ratio and these measurements.

Results: Data was normally distributed with no statistically significant differences between males and females ($P = 0.88$) and extraction and non-extraction ($P = 0.52$) treatment modalities with respect to the anterior ratio. T1 bivariate regression analysis failed to show a relationship ($p < 0.05$) between variables. T2 bivariate analysis showed a statistically significant relation between three variables and anterior tooth size ratio. Multiple regression analysis led to a final model where maxillary inter-canine width ($P = 0.002$) and upper arch crowding (0.001) were statistically significantly related to the anterior inter-arch ratio. The coefficient of determination was however uniformly low ($R^2 < 0.2$) for all variables.

Conclusion: The anterior inter-arch tooth size ratio was not associated with any common pre- or post-treatment variables in the population studied, therefore measurement of an anterior tooth size ratio pre-treatment was not clinically beneficial for determining anterior dental relations post-treatment.

Index words: Bolton ratio, inter-arch tooth size ratio, tooth size, tooth size ratio.

Introduction

Andrews' six keys to normal occlusion are a widely quoted set of static occlusal goals for tooth relationships in the maximum intercuspated position.[1]

Many authors have suggested that the individual's occlusal status is further governed by specific dimensional relationships between mandibular and maxillary teeth.[2–7]

Researchers[2,8,9] have used many methods to detect inter-arch tooth size discrepancies in patients presenting for orthodontic treatment, for example, Korbitz [8] examined 100 dentitions with anatomically correct occlusion, and found that the difference between the maxillary six anterior teeth and the mandibular six anterior teeth plus one-half the width of the first premolars should be between 0 and 4 mm, corresponding to an overbite of 0–3.5 mm.

Mean ratios have also been used to describe inter-arch tooth size discrepancy, for example, Seipel[9] in 365 randomly selected cases, found a strong correlation between upper and lower tooth width sums, and established mean ratios between the upper and lower teeth for various tooth groups, and for the second molar to second molar inclusive.

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Table 1 The sample demographics are as follows

	Males	Females
Extraction	31 (55%)	29 (36%)
Non-extraction	25 (45%)	52 (64%)
	56 (100%)	81 (100%)

Using 200 orthodontic cases Neff[2] proposed that a variation in proportionate tooth size between upper and lower anterior teeth was mathematically related to the anterior overbite, and concluded that 'everything else being normal, an orthodontic or non orthodontic normal will settle to the degree of overbite indicated by the anterior coefficient'.

Bolton's inter-arch tooth size ratios were established from measurements taken from 55 cases where excellent occlusion existed,[3] which included 44 orthodontically (non-extraction) treated and 11 untreated individuals. An anterior and overall ratio of mandibular tooth material to maxillary tooth material was established.

The reported frequency of significant anterior inter-arch tooth size discrepancies is high, 22.9[10] to 30.6 per cent.[11]

Inter-arch tooth size discrepancy ratios are frequently advocated and employed as pre-treatment diagnostic and prognostic tools by clinicians planning orthodontic treatment, as identification of such a pre-treatment inter-arch tooth size discrepancy may influence treatment decisions in respect of dental extractions, use of inter-proximal enamel reduction, changes in the overjet/overbite, or utilisation of restorative procedures.

It follows, therefore, that the use of such ratios should provide prognostic information on post-treatment inter- and intra-arch relationships, across a range of malocclusions. This study examines the association between various dental and skeletal variables and anterior inter-arch tooth size ratio pre-treatment, post-treatment, and the change in these variables during treatment to assess the benefit of employing pre-treatment inter-arch tooth size ratios.

Materials and methods

The orthodontic records of 137 Swedish patients (56 male, 81 female) treated in the Orthodontic Health Board Clinic (Halmstad, Sweden) by four experienced orthodontists were obtained for this study. These patients underwent a complete course of orthodontic treatment with upper and lower pre-adjusted edgewise appliances.

The sample (137) was derived from a randomly selected sample of patients (250), and included non-extraction (77) and four premolar extraction (60) cases across a range of dental and skeletal malrelationships (Table 1). In this study, patient selection was on the basis of satisfactory lateral cephalograms and dental cast records at T1 (pre-treatment) and T2 (immediately post-treatment), records which showed absent teeth, teeth with caries, restorations, gingival interferences or dental cast imperfections that impeded proper calliper point placement were not included.

The mean age at T1 was 13 years 1 month (SD 1 year 6 months) and the mean age at T2 was 14 years 8 months (SD 1 year 5 months). The mean treatment time was 18.8 months.

Dental cast measurements

Dental casts were obtained from irreversible hydrocolloid impressions. Measurements on T1 and T2 casts were recorded to the nearest 0.01 mm using electronic digital callipers (Mauser digital 2™ Switzerland), where the straight beaks of the calliper were precision adjusted to provide pointed narrow tips to facilitate tooth width measurement and the instrument was then calibrated prior to use.

The light source was standardized for all measurements with light, eye, and callipers in approximately a straight line, thus reducing errors of parallax to a minimum.

Measurements recorded

- *Tooth width* was measured (as described by Moorrees and Reed[12]) from canine to canine inclusive. An anterior maxillary-mandibular inter-arch tooth size ratio was established by dividing the sum of the lower anterior six teeth by the sum of the upper anterior six teeth.[3]
- *Overjet*
- *Overbite*
- *Inter-canine width*
- *Little's Irregularity Index*[13]
- *Arch crowding/spacing condition*: the degree of crowding or spacing was measured as the summation of the tooth overlap in the mesiodistal direction of maxillary and mandibular canine to canine inclusive. The five mesiodistal overlap measurements were made by

measuring the linear distance between adjacent lines, each line an approximate arcadial to the arch perimeter passing through the anatomic contact point. As these lines converged lingually each linear distance described above was arbitrarily measured, midway labiolingually between the anatomic contact points.

Lateral cephalogram measurements

All lateral cephalograms had been taken using the same calibrated cephalostat with a consistent magnification factor of 10 per cent. The T1 and T2 cephalograms were assigned numbers and arranged in random order by an independent observer before being hand traced by one author. Inter-examiner calibration was performed before tracing and a high level of concordance was found. The headfilms were of uniform high quality and were traced using acetate matte tracing paper and a sharp 3H drawing pencil.

The points recorded were sella, nasion, anterior nasal spine, menton, and A and B points.

Using the 'structural method', the natural reference structures in the anterior cranial base were transferred from T1 to T2 cephalograms,[14,15] the SN line was transferred according to this method, and was used to measure the incisor inclination at T1 and T2.

The following were measured at T1 and T2: SNA, SNB, ANB, UFH, LFH, LFH/total, U1/SN, L1/SN, and inter-incisal angle; in addition, the change in T1–T2 for each dental cast and cephalogram variable was also calculated.

Data collection/statistical analysis

Error measurement involved estimation of systematic and random errors by replication of measurements, i.e. 25 radiographs and models used for the error study were drawn at random from the main series and were measured under the same conditions.

Systematic errors

A one-step Students *t*-test for each pair of replicates was performed.

The *P* value for each *t*-test was calculated. Probability values of $P < 0.05$ were regarded as statistically significant.

Random errors

The standard deviation of the differences between replicate measures is a measure of the random error.

Systematic, random and method errors were calculated.

The data was recorded in an Excel file and analysed using JMP statistical tools. Bivariate regression analyses was performed, where the dependent variable (anterior inter-arch tooth size ratio) was regressed against each dental and skeletal variable at T1, T2, and against the change in each dental and skeletal variable over the treatment period.

A multiple regression model was produced combining the statistically significant independent variables from the initial bivariate analyses to determine the influence of the least statistically significant variable on the remaining factors in a sequential manner.

Results

Error calculation

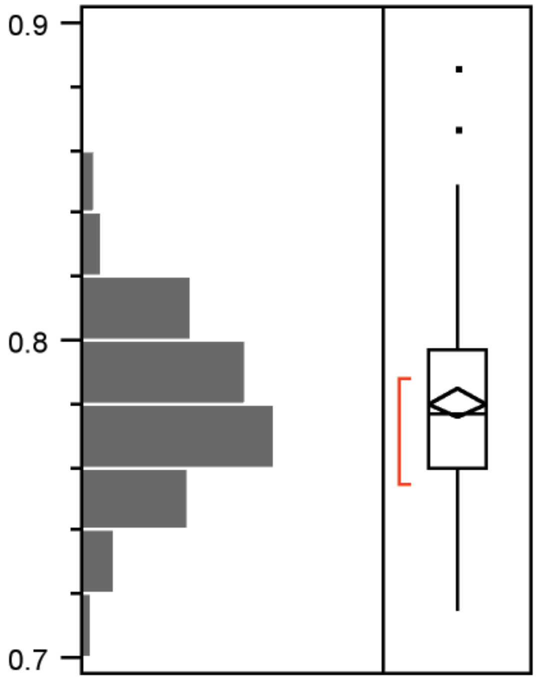
A statistically significant ($P = 0.05$) difference was noted between replicate measures for the overjet variable alone. However, the mean difference was 0.01 mm, which is probably not clinically significant. The coefficient of linear correlation for the sample was $r = 0.97$, a value that covers observations of all data, rather than merely mean differences, again suggesting that the difference in replicate measures is not clinically important.

The data for the anterior tooth size analysis ratio is normally distributed. The mean is 0.78 ± 0.03 and the range 0.72–0.89 (Figure 1).

No statistically significant difference ($P = 0.88$) exists between males and females with respect to the anterior inter-arch tooth size ratio using Student *t*-test; similarly, no statistically significant difference ($P = 0.52$) exists between extraction and non- extraction treatment modalities with respect to the anterior inter-arch tooth size ratio using Student *t*-test.

T1 regression analysis data

Bivariate regression analysis was performed for each dental and skeletal variable where the dependent variable (anterior inter-arch tooth ratio) was regressed against the pre-treatment T1 dental and skeletal variable over the treatment period. The results indicate that no statistical significance ($P < 0.05$) exists for any independent variables measured (Table 2).



Quartiles

Maximum	100.0%	0.88682
	99.5%	0.88682
	97.5%	0.84848
	90.0%	0.81673
Quartile	75.0%	0.79794
Median	50.0%	0.77735
Quartile	25.0%	0.76054
	10.0%	0.74428
	2.5%	0.72947
	0.5%	0.71565
Minimum	0.0%	0.71565
Mean		0.7807
SD		0.0290
SE of mean		0.0025
Upper 95% mean		0.7856
Lower 95% mean		0.7758
n		137.0000

Fig. 1 Histogram and Box-Whisker plot of the distribution of the anterior inter-arch tooth size ratio.

T2 regression analysis

The bivariate regression analysis suggested that three variables (T2 overjet, $P = 0.049$; T2 maxillary inter-canine width, $P = 0.0007$; and T2 upper arch analysis (crowding), $P = 0.0004$) were independently statistically significantly associated with the anterior inter-arch tooth size ratio (Table 3).

A multivariate regression model combining the statistically significant independent variables from the initial bivariate analyses was then made to determine the combined strength of the relationship with the anterior ratio: overjet, $P = 0.145$; maxillary inter-canine width, $P = 0.0043$; and upper arch analysis (crowding), $P = 0.002$ (Figure 2). On removal of the overjet variable from the model the remaining two variables maintained their statistical significance, the overjet variable therefore contributed individually to explaining the variation in the anterior ratio, but in the presence of the other variables was not useful in spite of the minimal reduction in the R^2 value when the overjet was removed from the model.

The final model included T2 maxillary inter-canine width and upper arch analysis (crowding), which, when combined, showed a significant association with the anterior inter-arch tooth size ratio. The predictive value around the mean was good ($R^2 = 0.198$), but relatively poor for values greater and less than the mean, i.e. not equally sensitive at predicting across the range of observations (Figure 3).

T1–T2 regression analysis

The results indicate that no statistical significance ($P < 0.05$) exists for any independent variables regressed against the anterior ratio except for the lower arch spacing condition between T1 and T2, which shows a $P = 0.01$, which is statistically significant, however, the R^2 value (0.08) is very low suggesting that the proportion of variation of the anterior ratio accounted for by this variable is very small, i.e. the coefficient of determination is very weak (Table 4).

Discussion

Tooth size discrepancy ratios are frequently advocated and employed as diagnostic tools by clinicians planning orthodontic treatment.[3] The intended purpose of a tooth size discrepancy ratio as a diagnostic aid is 'to gain insight into the functional and aesthetic outcome of a given case without the use of a diagnostic set-up',[3] in particular they are frequently employed in individuals who appear to have a tooth size discrepancy between the dental arches.

Table 2 Bivariate regression analysis of anterior inter-arch tooth size ratio (*Y* axis) against T1 dental and skeletal variables (*X* axis)

(Sum Wgts) observations	Independent variable	Variable estimate (linear fit)	$P > F$	R^2 value
137	Overjet	0.78023 + 0.00008	0.9323	0.000054
137	Overbite	0.7812 − 0.00014	0.9161	0.000082
103	Maxillary inter-canine width	0.83371 − 0.00159	0.1466	0.020745
129	Mandibular inter-canine width	0.74443 + 0.00135	0.3214	0.007744
137	Little's Irregularity Index	0.77691 + 0.00099	0.2204	0.011102
84	Upper arch crowding	0.77681 + 0.00033	0.8295	0.000569
62	Upper arch spacing	0.77808 + 0.00326	0.1187	0.040081
83	Lower arch crowding	0.78048 + 0.00352	0.5780	0.003836
86	Lower arch spacing	0.77939 − 0.00281	0.6295	0.002784
137	S–N–A	0.80509 − 0.0003	0.6561	0.001473
137	S–N–B	0.79179 − 0.00014	0.8390	0.000307
137	A–N–B	0.78248 − 0.00045	0.6803	0.001262
137	Lower facial height (%)	0.70081 + 0.14124	0.2222	0.011017
137	Upper incisor to S–N	0.74264 + 0.00036	0.1863	0.012903
137	Lower incisor to S–N	0.77647 + 0.00008	0.7643	0.000668
137	Inter-incisal angle	0.80956 − 0.00023	0.1490	0.015361

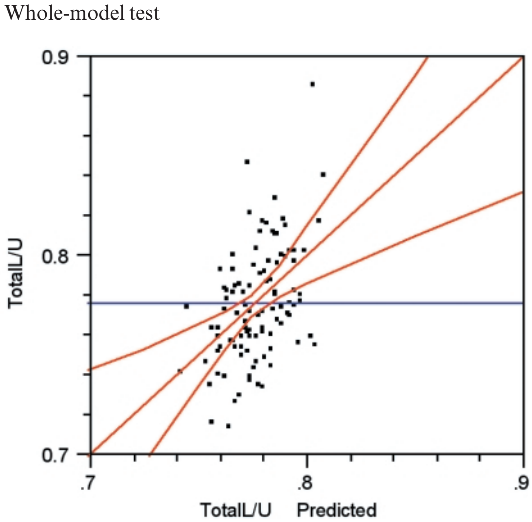
Table 3 Bivariate regression analysis of anterior inter-arch tooth size ratio (*Y* axis) against T2 dental and skeletal variables (*X* axis)

(Sum Wgts) observations	Independent variable	Variable estimate (linear fit)	$P > F$	R^2 value
137	Overjet	0.79183 − 0.0054	0.0491	0.028388
137	Overbite	0.78251 − 0.00079	0.7308	0.00088
137	Maxillary inter-canine width	0.91483 − 0.00388	0.0007	0.081482
137	Mandibular inter-canine width	0.78218 − 0.00006	0.9696	0.000011
137	Little's Irregularity Index	0.77635 + 0.00273	0.1269	0.017173
103	Upper arch crowding	0.76441 + 0.00767	0.0004	0.118186
34	Upper arch spacing	0.79314 − 0.00022	0.9450	0.000151
67	Lower arch crowding	0.77905 − 0.01215	0.1456	0.032301
73	Lower arch spacing	0.78128 − 0.00536	0.2380	0.01956
137	S–N–A	0.80311 − 0.00028	0.6804	0.00126
137	S–N–B	0.76214 + 0.00024	0.7286	0.000895
137	A–N–B	0.78534 − 0.00148	0.1959	0.012361
137	Lower facial height (%)	0.66654 + 0.20092	0.0607	0.02581
137	Upper incisor to S–N	0.77137 + 0.00009	0.7767	0.000598
137	Lower incisor to S–N	0.77983 + 0.00002	0.9575	0.000021
137	Inter-incisal angle	0.77547 + 0.00004	0.8669	0.000209

A formal measurement of at least the labial segment teeth and calculation of the Bolton ratio is thought to enable more exact and informed choice of occlusal goals for the individual patient.

It is evident that for such a ratio to be useful and effective in predicting a particular treatment outcome the ratio must be equally valid across the pre- and post-treatment periods. A ratio value calculated by division of upper into lower mesiodistal crown widths provides a convenient and readily calculated index, however the question arises as to whether a static index measurement at T1 is useful in predicting the various inter- and intra-arch relationships, across a range of malocclusions, with varying degrees of dentoalveolar compensation at T2.

As the pre- (T1) and post-treatment (T2) examination of patients in the present study failed to show common variables associated with the anterior ratio, it is suggested that the anterior inter-arch tooth size ratio measured at T1 is not clinically useful in predicting the inter- and intra-arch relations at T2.



Response: total L/U

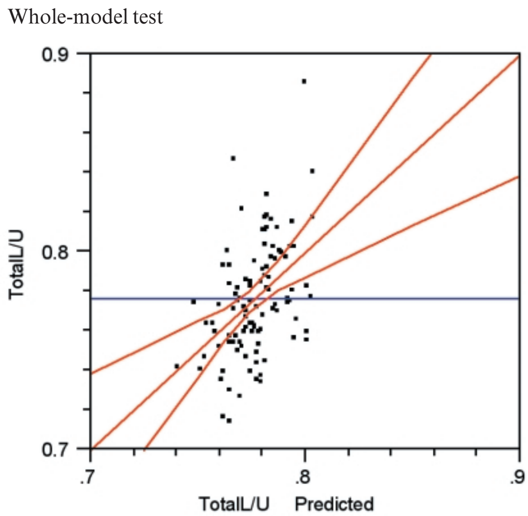
Summary of Fit

R^2	0.215511
R^2 Adj	0.191739
Root mean square error	0.025825
Mean of response	0.776661
Observations (or Sum Wgts)	103

Effect test

Source *F* ratio	Nparm $P > F$	DF	Sum of squares
T2O/J	1	1	0.00143614
2.1533	0.1454		
T2MxIC	1	1	0.00569383
8.5372	0.0043		
T2UalaC	1	1	0.00698188
10.4685	0.0017		

Fig. 2 Multivariate regression analysis model of anterior inter-arch tooth size ratio (*Y* axis) against T2 overjet, T2 maxillary inter-canine width, and T2 upper arch analysis (crowding) (*X* axis).



Response: total L/U

Summary of fit

R^2	0.198448
R^2 Adj	0.182417
Root mean square error	0.025974
Mean of response	0.776661
Observations (or Sum Wgts)	103

Effect test

Source *F* ratio	Nparm $P > F$	DF	Sum of squares
T2MxIC	1	1	0.00675536
10.0134	0.0021		
T2UalaC	1	1	0.00765656
11.3492	0.0011		

Fig. 3 Multivariate regression analysis (final model) of anterior inter-arch tooth size ratio (*Y* axis) against, T2 maxillary inter-canine width and T2 upper arch analysis (crowding; *X* axis)

Bolton[3] calculated an anterior inter-arch tooth size ratio of 77.2 ± 1.65 mm with a range of 74.5–80.4.

Some of the problems with the Bolton Analysis were identified by Smith *et al.*:[16]

- Bolton's estimates of variation were underestimated because his sample was derived from perfect CI occlusions.
- Population and sex composition of Bolton's sample was not specified, which implies potential selection bias.

The anterior ratio in many studies[7,11,17,18] is somewhat higher than Bolton's ratio,[3] possibly because of greater morphologic variability in upper incisor width than that calculated by Bolton on models in patients with an ideal occlusion. This may also be the case in the present study as a mean value of 78.07 ± 2.9 mm was calculated for the anterior inter-arch ratio, which is very similar to other studies of Scandinavian populations, e.g. 78.9 ± 0.25 mm[19] and 78.5 ± 0.13;[20] however, the mean in the present study is not statistically significantly different from the value calculated by Bolton (1958).[3]

Table 4 Bivariate regression analysis of anterior inter-arch tooth size ratio (*Y* axis) against T1–T2 dental and skeletal variables (*X* axis)

(Sum Wgts) observations	Independent variable	Variable estimate (linear fit)	$P > F$	R^2 value
137	Overjet	0.77836 + 0.00065	0.4717	0.003844
137	Overbite	0.78048 + 0.00011	0.9298	0.000058
103	Maxillary inter-canine width	0.78125 + 0.00138	0.2302	0.014225
129	Mandibular inter-canine width	0.77973 + 0.0013	0.3885	0.005861
137	Little's Irregularity Index	0.77981 + 0.00039	0.6129	0.001901
83	Upper arch crowding	0.77858 − 0.00188	0.1669	0.023449
57	Upper arch spacing	0.78574 + 0.00013	0.9487	0.000076
63	Lower arch crowding	0.77773 + 0.00755	0.0554	0.058868
86	Lower arch spacing	0.78022 − 0.00728	0.0144	0.080372
137	S–N–A	0.78074 − 0.0001	0.9434	0.000037
137	S–N–B	0.78043 − 0.00184	0.2251	0.00184
137	A-N-B	0.77914 + 0.00173	0.2551	0.009582
137	Lower facial height (%)	0.78000 − 0.24639	0.2288	0.01071
137	Upper incisor to S–N	0.77964 + 0.00023	0.3379	0.006806
137	Lower incisor to S–N	0.78039 + 0.00009	0.7690	0.000641
137	Inter-incisal angle	0.78001 − 0.00021	0.1468	0.015533

The range of the anterior ratio in many studies[10,11] using the Bolton ratio is uniformly greater than the range in the original Bolton sample.[3] This is also the case in the present study, which showed a range of 71.57–88.69.

Values outside of 2 SD from the mean of Bolton's study were considered great enough to warrant attention in the normal course of orthodontic treatment because this represented a 2–3 mm tooth size discrepancy where the SD was 1.65 mm. It might then be inferred that one SD (2.9 mm) in the present population studied would lead to tooth size discrepancies of particular clinical importance.

Exploratory modelling was undertaken in the present study to examine the relationship between the anterior tooth size ratio, and various dental and skeletal variables, the relationship and strength of relationship for these variables individually and in combination with other statistically significant factors was examined.

Exploratory modelling at T1 failed to show a significant relationship ($P < 0.05$) between the various dental and skeletal variables and the anterior tooth size ratio.

Similar regression modelling at T2 for the same individuals showed a statistically significant relationship between three variables (overjet $P = 0.049$; maxillary inter-canine width $P = 0.0007$ and upper arch analysis (crowding $P = 0.0004$) and the anterior tooth size ratio. Closer inspection of these post-treatment variables reveals that these are perhaps unsurprisingly related to the ratio, e.g. maxillary inter-canine width in a post-treatment arch might be expected to share a similar transverse relationship with a ratio of cumulative lower to upper canine to canine widths. The slope (−0.0038) of the bivariate regression line indicates a correlation between increased inter-canine width and reduced anterior tooth size ratio, i.e. relative maxillary arch tooth size excess is correlated with increased maxillary inter-canine width.

Variations in inter-arch tooth size may be compensated by corresponding deviations in the sagittal relation of the teeth. In this study the overjet was related to the ratio ($P = 0.049$) but, as indicated by the slope of the regression, an increased overjet was correlated with a reduced anterior ratio, i.e. increased overjet was related to a relative maxillary tooth excess.

Upper arch crowding was also found to be related to the anterior tooth size ratio i.e. increased upper arch length analysis (crowding) was associated ($P = 0.0007$) with an increased anterior ratio. Multiple regression analysis resulted in a model where upper arch length analysis (crowding) and maxillary inter-canine width were statistically related to the anterior ratio.

It was noted however that the proportion of the variation in the outcome measure (anterior ratio) that was accounted for by the predictor variables, individually and combined was low ($R^2 = 0.19$) for final model.

The results from the bivariate regression analysis examining the change in dental and skeletal variables between T1 and T2 in relation to anterior tooth size ratio failed to show any statistically significant associations, with the exception of the lower arch spacing condition ($P = 0.01$), which showed a low correlation of determination ($R^2 = 0.08$).

As the pre- (T1) and post-treatment (T2) examination of patients in the present study failed to show common variables associated with the anterior ratio, it is suggested that the anterior inter-arch tooth size ratio measured at T1 is not clinically useful in predicting the inter- and intra-arch relationships at T2.

Conclusions

The results of this study indicate that pre-treatment (T1) measurement of an anterior inter-arch tooth size ratio [3] may not be useful in predicting anterior dental relationships post-treatment (T2). Therefore, pre-treatment measurement of such a ratio has limited clinical usefulness as a diagnostic/prognostic aid.

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