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Title: A Comparative Study to Investigate the Effect of Orthodontic Treatment on the Uniqueness of the Human Anterior Dentition

Author names and affiliations:

Miss Alice Elizabeth Catherine Dyke[ad]

Professor Susan Cunningham[b]

Professor Nigel Hunt[b]

Dr Clifford Ruff[c]

[a] Eastman Dental Hospital, 256 Grays Inn Road, London, WC1X8LD, England

[b] Eastman Dental Institute, 256 Grays Inn Road, London, WC1X8LD, England

[c] University College London, 235 Euston Road, Fitzrovia, London, NW12BU, England

[d] Corresponding author: email: a.dyke@nhs.net

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Highlights

Key Messages:

- Orthodontic treatment reduces the uniqueness of the human anterior dentition.
- Full Procrustes analysis created a large number of false positive matches and is therefore unsuitable for this type of forensic work.
- Further research is necessary to investigate the uniqueness of the human anterior dentition within a larger population.

A COMPARATIVE STUDY TO INVESTIGATE THE EFFECT OF ORTHODONTIC TREATMENT ON THE UNIQUENESS OF THE HUMAN ANTERIOR DENTITION

AIM

The human dentition contains many features which can be used to identify an individual from the dentition or from bite marks created and bite mark evidence may be used to link a suspect to a crime.

The aim of this research was to investigate the effect of orthodontic treatment on the uniqueness of the human anterior dentition by comparison of the number of dental shape matches between pre- and post-treatment dental casts for a group of patients who have undergone orthodontic treatment (dental braces) to improve the alignment of their teeth.

METHOD

This comparative study utilised pre- and post-orthodontic treatment dental casts from 36 patients. The dental casts were scanned and the anterior 6 teeth landmarked with 24 landmarks in total. The dental casts were divided into 4 groups: pre-orthodontic upper jaw (maxillary) and lower jaw (mandibular) and post-orthodontic maxillary and mandibular. Partial and full Procrustes analyses were undertaken to investigate the similarity between dental casts within each group and whether any of the comparisons were similar enough to be classified as a match. A landmarking repeatability study performed on a set of digitised dental casts determined the error of the landmarking procedure and allowed a proposed match threshold to be established.

RESULTS

Orthodontic treatment reduced the uniqueness, and increased the similarity, between dentitions, as evidenced by a reduction in the maximum partial Procrustes distances in the post-orthodontic dental cast groups. None of the dental cast comparisons in the pre- or post-orthodontic maxillary or mandibular groups were classified as a match with the partial Procrustes analysis. However, many false positive matches (between 35 and 61) were identified within the post-orthodontic maxillary and mandibular groups using the full Procrustes analysis.

CONCLUSIONS

Orthodontic treatment reduced the uniqueness of the human anterior dentition between different patients. There were no matches identified with the partial Procrustes analysis, but a large number of false positive matches were identified using the full Procrustes analysis. It is therefore proposed that full Procrustes analysis is unsuitable for this type of work and that only partial Procrustes analysis should be utilised.

Key-words: Odontology; Bite mark; Human; Dentition; Orthodontic; Uniqueness

Introduction

Bitemark evidence is the most common form of dental evidence presented in criminal court (Rai *et al*., 2006 [1]). It is well known that during a variety of crimes such as sexual attacks and rape, assailants often bite their victims as an expression of rage, dominance and animalistic behaviour (Webb *et al*., 2000 [2]). Similarly, defensive bitemarks may be left on an assailant by the victim, providing evidence of contact (Furness, 1981 [3]).

Over the past century bitemark evidence has been used to obtain numerous criminal convictions but, unfortunately, there have also been at least 24 known cases of wrongful conviction based on bitemark evidence and this has called its validity into question (Lussenhop, 2016 [4]).

The uniqueness of the human dentition has been investigated and debated for decades but there has been little research dedicated to orthodontic ("fixed brace") treatment and bitemark analysis. As orthodontic treatment aims to reduce irregularities within the dentition, it can also create occlusal similarities between the dentitions of different orthodontic patients. These similarities may cause the dentitions to be less distinguishable than before treatment and may potentially cause the bitemarks they create to be indistinguishable.

Typically, bitemarks are caused by the anterior six teeth (Riviello, 2010 [5]) and a match is only possible if there are individual characteristics present in the dentition which are translated and recorded accurately in the bitemark. If these individual characteristics are not present, or if they are not recorded accurately in the bitemark, the overall forensic importance of the bitemark is reduced (Rothwell, 1994 cited in Sweet and Pretty, 2001 [6, 7]).

Previous studies investigating the uniqueness of the human anterior dentition include those by Kieser *et al*. (2007) [8] and Sheets *et al*. (2011) [9] who utilised a combination of analytical techniques, such as Procrustes analyses and principal component analyses.

Kieser *et al*. (2007) [8] concluded that the incisal edges of the anterior dentition are unique. However, the study by Sheets *et al*. (2011) [9] identified increased numbers of matches between dentitions of orthodontically treated patients and subsequently concluded that the anterior dentition may not be unique.

Aim

The aim of this study was to investigate the effect of orthodontic treatment with dental braces on the uniqueness of the human anterior dentition by comparison of the number of dental shape matches between the pre- and post-treatment dental casts.

Patients and Methods

This research utilised the pre- and post-treatment dental casts from 36 patients who had undergone a course of orthodontic treatment with fixed dental braces at the Eastman Dental Hospital, UCLH Foundation Trust and who had been discharged from the department (144 dental casts in total). A 3D dental cast scanner (Ortho Insight 3D™ Scanner by Motion View Software) was used to scan and digitise the dental casts, which were then landmarked using a bespoke landmarking software program developed by the University College London Hospital Medical Physics department.

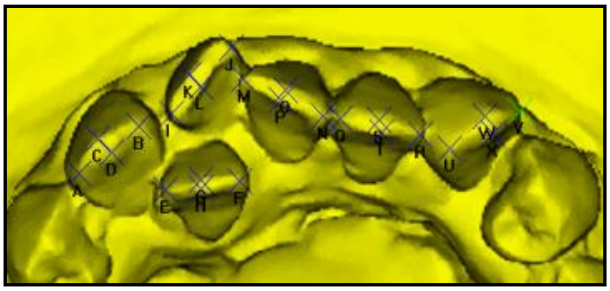
Patients who had completed treatment between 1999 and 2013 and who were presented as examination cases were identified from the hospital laboratory records. The cohort consisted of examination cases in order to ensure that the orthodontic treatment had been completed to a high quality of finish. The pre-orthodontic and post-orthodontic dental casts were retrieved and unsuitable cases were excluded based on the criteria shown in Table 1. A total of 36 patients were selected, providing two maxillary (upper jaw) and two mandibular (lower jaw) dental casts for each patient (144 dental casts in total).

Table 1: Inclusion and exclusion criteria for the dental casts

Inclusion	Exclusion
• Completed orthodontic treatment • Discharged patients • Undamaged pre- and post-orthodontic dental casts available • Unrestored maxillary and mandibular canines and incisors	• Developmental absence/ hypodontia of the maxillary or mandibular canines or incisors • Dental anomalies e.g. transposition of teeth, microdontia etc. • Dental casts with damaged maxillary or mandibular canines or incisors • Partially erupted maxillary or mandibular canines or incisors

The dental casts were scanned using the Ortho Insight 3D™ Scanner and the images saved in STL format. Customised software was then used to landmark the incisal edges of the anterior six teeth on each digitised dental cast with the most mesial, distal, medial labial and medial palatal/lingual points on each tooth (Figure 1). This was a similar landmarking system to that used by Kieser *et al*. (2007) [8].

Figure 1: Screenshot of a landmarked digitised dental cast showing the 24 landmarks placed on the anterior six teeth



Repeatability Study

In order to ascertain the intra-operator repeatability of this method, the anterior six teeth (canines and incisors) of one maxillary and one mandibular dental cast were landmarked 10 times each, with a minimum wash out period of 24 hours between landmarking sessions. The dental casts used for the repeatability study met the inclusion/ exclusion criteria but were not included in the main study.

Statistical Analysis

The standard deviation of each landmark from the repeatability study was used as a measure of the repeatability of the landmarking procedure.

A partial and a full Procrustes analysis were then performed on the landmarked dental casts from the main study and on the repeatability study data. Procrustes analysis was used as it provides a measure of the similarity between two shapes, which contain landmark points (Gower, 2015 [10]). The partial Procrustes analysis maintains information regarding shape and size of the dental casts. For the full Procrustes analysis, in addition to translation and rotation of one dental cast about another, size scaling is also conducted. This removes some information about the differing sizes of the dental casts and allows comparisons based purely on the shape of the teeth and dental arches. Both analyses were undertaken to determine the number of matches and to determine which was most suitable for this type of comparative work.

The Procrustes distance provides a measure of the similarity between the landmarks of two dental casts, with lower scores indicating greater similarity and higher scores showing less similarity. In the case of the partial Procrustes analysis, this distance is in the same units as the measurement system used (mm) and in the case of the full Procrustes analysis, the distance is an arbitrary measurement, with no units.

Results

Repeatability study

The standard deviations (SDs) for each landmark over the 10 landmarking procedures ranged between 0.093mm and 0.288mm for the maxillary landmarks and between 0.085mm and 0.331mm for the mandibular landmarks. This showed good repeatability for landmark placement.

Partial Procrustes Analysis of the landmarking of the maxillary and mandibular dental casts

Figure 2: Accumulative totals of the partial Procrustes distances between the pre-orthodontic maxillary dental casts and the post-orthodontic maxillary dental casts, with the partial Procrustes repeatability data marked at 2 and 4 Standard Deviations

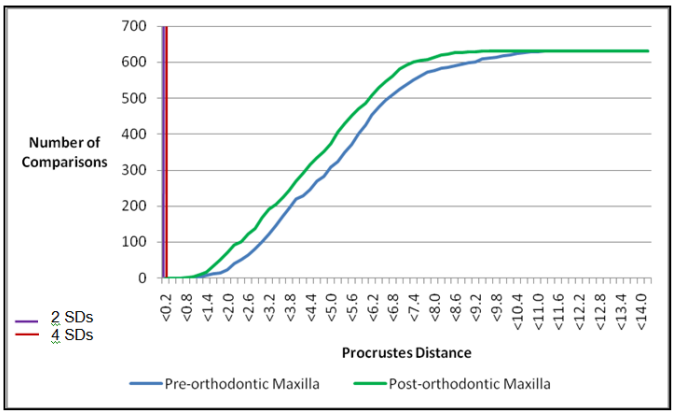
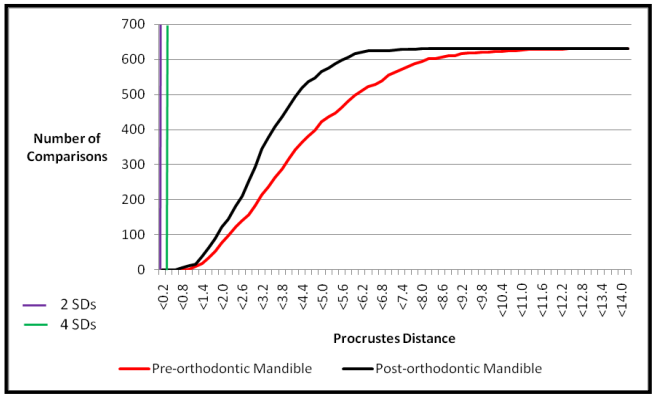


Figure 3: Accumulative totals of the partial Procrustes distances between the pre-orthodontic mandibular dental casts and the post-orthodontic mandibular dental casts, with the partial Procrustes repeatability data marked at 2 and 4 Standard Deviations



Figures 2 and 3 show that the curves for the post-orthodontic maxillary and mandibular groups are shifted to the left (green line in Figure 2 and black line in Figure 3). This indicated that the post-treatment dental casts had lower partial Procrustes distances, hence greater similarity, compared with those of the pre-orthodontic casts.

The maximum partial Procrustes distances in the post-orthodontic groups were reduced compared with the corresponding pre-orthodontic groups, by 1.68mm in the maxilla and 5.42mm in the mandible. Orthodontic treatment therefore reduced the maximum Procrustes distance for both groups, indicating that the dentitions were more similar and less unique following treatment than prior to treatment.

Determination of matches between the dental casts in the four groups subjected to a partial Procrustes analysis

It was necessary to identify a cut-off point, where dental cast comparisons with a Procrustes distance below this value would be similar enough to be classified as a "match". In order to determine the proposed cut-off point where a match could be said to exist, the repeatability study data was also subjected to a partial Procrustes analysis. This was based on the premise that "*two objects match when the difference between them is no larger than would be expected to arise from repeated measurements of a single specimen*" (Sheets, 2015 [11]). The analysis produced comparable values to the data from the four dental cast groups which had been subjected to partial Procrustes analysis.

The partial Procrustes analysis of the repeatability data was used to determine whether at different standard deviations it was possible to identify dental cast comparisons which could be classified as a match (Figure 2 and 3).

The number of matches identified is represented on the graph where the curves of the graph and the vertical standard deviation lines intersect.

Within a normal distribution it would be expected that 99.9% of values fall within 4 standard deviations. Therefore, 4 standard deviations was felt to be the maximum appropriate match cut-off point. Figures 2 and 3 show that even at 4 SDs of the partial Procrustes analysis for the repeatability data (red and green vertical lines in Figures 2 and 3 respectively), no matches were identified for the maxillary or mandibular dental casts.

Full Procrustes Analysis of the landmarking of the maxillary and mandibular dental casts

Figure 4: Line graph of the accumulative totals of the full Procrustes distances between the four dental cast groups

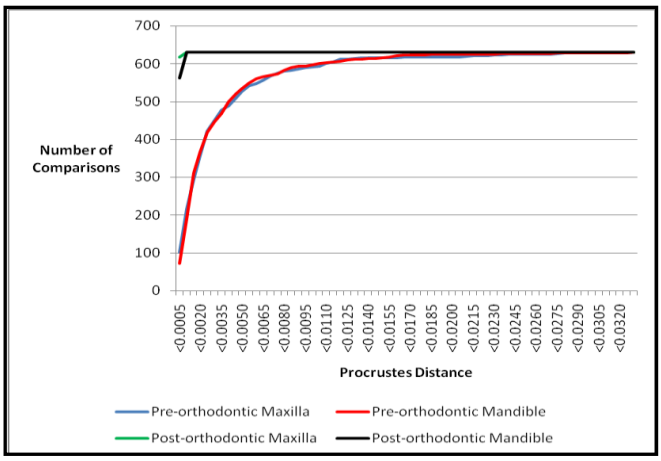


Figure 4 shows that, again, the post-orthodontic maxillary and mandibular curves are shifted to the left of the graph, with lines which had much steeper gradients (green and black lines). As expected, this indicated that following orthodontic treatment the dentitions were more similar than prior to treatment.

For the pre-orthodontic maxillary and mandibular groups, all of the 630 comparisons fell below a full Procrustes distance of 0.0302 and 0.0330 respectively. However, for the post-orthodontic maxillary and mandibular groups all 630 comparisons fell below a full Procrustes distance of less than 0.0010. This showed that the post-orthodontic maxillary and mandibular groups had smaller full Procrustes distances and that the digitised dental casts within these groups showed greater similarity to each other than in the respective pre-orthodontic groups. This pattern was also identified in the partial Procrustes analysis.

It was not possible to use the data from the repeatability study to determine match cut-off values for the pre-orthodontic maxillary and mandibular full Procrustes processed data. This was due to the fact that the repeatability study was done on post-orthodontic dental casts and the centroid size scaling during the full Procrustes processing was different

for each dental cast group. Therefore, the full Procrustes repeatability study data could only be used to determine match cut-off values accurately for the post-orthodontic full Procrustes processed maxillary and mandibular data.

Determination of matches between the dental casts in the post-orthodontic maxillary and mandibular groups subjected to a full Procrustes analysis

In order to determine a proposed match cut-off point the repeatability study data was subjected to full Procrustes analysis. It was then possible to use the full Procrustes repeatability data to determine at what standard deviation dental cast comparisons were identified with full Procrustes distances which were lower than those of the measurement error from the repeatability data and which were therefore similar enough to be classified as a match (Figures 5, 6 and 7).

Figure 5: Accumulative totals of the full Procrustes distances between the post-orthodontic maxillary dental casts, with the full Procrustes analysed repeatability data marked at 2 and 4 Standard Deviations

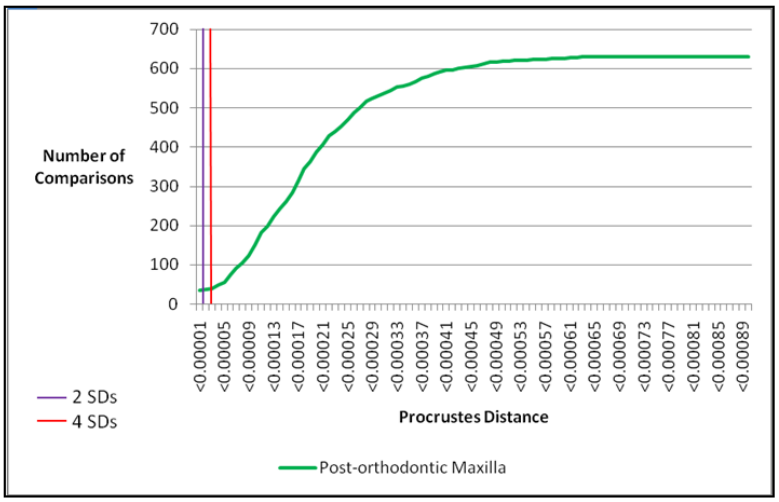


Figure 6: Accumulative totals of the full Procrustes distances for the post-orthodontic mandibular dental casts, with the full Procrustes analysed repeatability data marked at 2 and 4 Standard Deviations

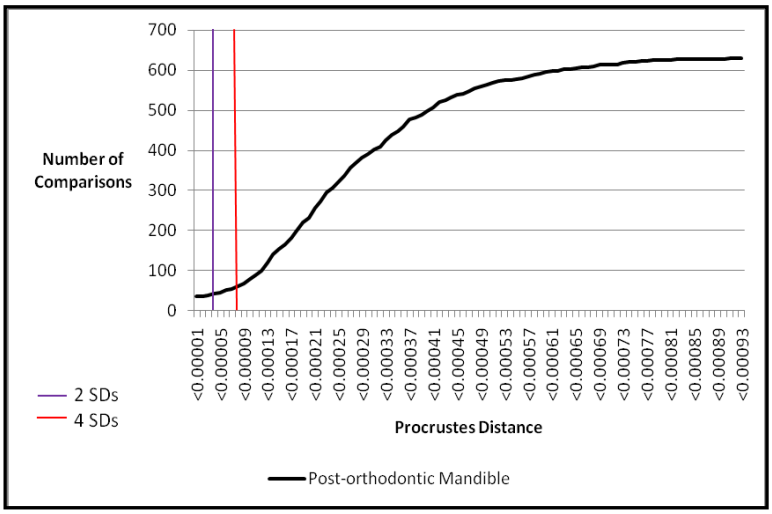
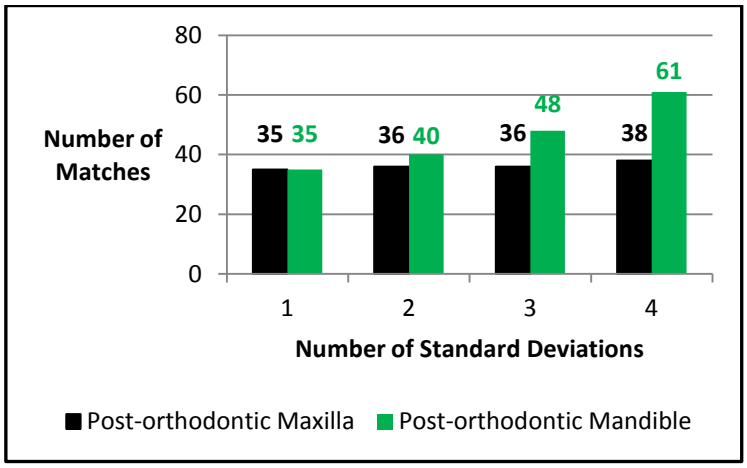


Figure 7: The number of matches in the post-orthodontic maxillary and mandibular groups based on the Standard Deviations of the full Procrustes analysed repeatability data



For both the post-orthodontic maxillary and mandibular groups, the full Procrustes analysis identified a number of comparisons which fell below the Procrustes values of the respective repeatability data at 1 to 4 SDs. These were therefore classified as matches, with between 35 and 38 matches in the maxillary group and 35 and 61 matches in the mandibular group (Figure 7). This number of matches was high and using a full Procrustes analysis created false positive matches which was not the case with the partial Procrustes analysis.

This, could potentially result in false accusations and convictions if used in a real life situation.

In comparison, the same data subjected to the partial Procrustes analysis produced no matches even at 4 SDs. This may be attributed to the fact that, during the full Procrustes analysis, size differences between the digitised dental casts were removed and therefore there was one less differentiating feature. The full Procrustes analysis is likely to have falsely increased the similarities between the digitised dental casts and produced false positive matches. This was particularly true of the post-orthodontic mandibular group as more matches were identified in this group compared with the post-orthodontic maxillary group. This was perhaps not surprising as the standard deviations from the repeatability study were higher in the mandible, thus creating lower match thresholds compared with those from the maxillary repeatability study.

Discussion

This study showed that orthodontic treatment reduced the uniqueness and increased the similarity between dentitions. The results also showed that at the given match threshold determined by the repeatability study, no matches were identified using a partial Procrustes analysis but a high number of false positive matches were identified with the full Procrustes analysis.

The findings from this study were comparable with some aspects of previous studies (Kieser *et al*., 2007; Sheets *et al*., 2011 [8, 9]). Sheets *et al*. (2011) [9] used full Procrustes analyses to investigate the dental shape matches of 410 non-treated and 110 orthodontically treated lower anterior dentitions. The percentages of dental shape matches were found to be 1.46% and 42.7% in the non-treated and orthodontically treated groups respectively. These results showed that orthodontic treatment increased the similarity between dentitions and increased the percentage of dental matches. However, it must be acknowledged that these matches were identified using full Procrustes analyses where centroid size scaling was performed, and this is likely to have increased the matches compared with a partial

Procrustes analysis where shape and size remain for comparison. The current study also identified that orthodontic treatment increased the similarity between dentitions and that using a full Procrustes analysis produced false dental matches. In contrast to the study by Sheets *et al*. (2011) [9] where separate cohorts of patients were used, the current study used pre- and post-orthodontic dental casts from the same cohort of patients in an attempt to determine the true effect of orthodontic treatment on the uniqueness of the human anterior dentition.

Kieser *et al*. (2007) [8] used a combination of Procrustes analyses and principal component analysis to investigate the uniqueness of the human anterior dentition of 33 maxillary and 49 mandibular dental casts from orthodontically treated patients. The study did not identify any dental matches but showed that when shape and size were considered together, the differences between the dentitions increased. This finding was also true of the current study; during the partial Procrustes analysis no matches were identified, however, with the full Procrustes analysis, which included centroid size scaling, a number of false positive matches were produced.

The current study had a sample size of 36 patients, which was similar to the sample size used by Kieser *et al*. (2007) [8]. Neither study identified any matches, which may be partly attributed to the sample size. Previous studies have shown that the larger the sample size the more chance it will contain dentitions which are similar enough to be classified as a match (Sheets *et al*., 2011) [9]. It is proposed that with an increasing sample size, for every new dental cast added to the sample there is an increased likelihood that it will be similar enough to one of the existing dental casts within the sample to be considered a match. It would be very interesting to determine at what sample size threshold each new dental cast added matches one of the existing dental casts within the sample.

Conclusions

Orthodontic treatment increased the similarity between the dentitions within the sample, as evidenced by a reduction in the partial Procrustes distances of the post-treatment

groups compared with the pre-orthodontic groups. Although the dentitions were more similar and less unique in the post-orthodontic groups, none of the dental cast comparisons had partial Procrustes distances which were sufficiently low to be classified as a match, regardless of the different match thresholds investigated.

Full Procrustes analysis removed size differences between the landmarked dental casts, thereby reducing the number of features available for discrimination and producing a high number of false positive matches. In forensic odontology, size is an important factor in the examination of a bitemark and the identification of a suspect, therefore, it is proposed that full Procrustes analysis is unsuitable for this type of work and that only partial Procrustes analysis should be utilised.

Further research is necessary to investigate the uniqueness of the human anterior dentition within a larger population.

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