Three-dimensional analysis of the change in the curvature of the smiling line following orthodontic treatment in incisor class II division 1 malocclusion

Michael Mah*, Wei Chuan Tan**, Sim Heng Ong**, Yiong Huak Chan*** and Kelvin Foong*

*Discipline of Orthodontics, Faculty of Dentistry, National University of Singapore, **Department of Electrical and Computer Engineering, National University of Singapore, and ***Biostatistics Unit, Faculty of Medicine, National University of Singapore, Singapore

Correspondence to: Michael Mah, Discipline of Orthodontics, Faculty of Dentistry, National University of Singapore, 11 Lower Kent Ridge Road, Singapore 119083. E-mail: michaelmah@nus.edu.sg

SUMMARY

OBJECTIVES: To investigate the different effects of changes in the occlusal plane, incisors inclination, and maxillary intercanine width on the curvature of the smiling line.

MATERIALS: Records of 46 subjects (28 females and 18 males, mean age 16.6 ± 4.2 years) with incisor class II division 1 malocclusions were selected. All subjects had four premolar extractions and were treated with preadjusted edgewise appliances.

METHODS: Pre- and post-treatment maxillary dental digital models were virtually aligned via corresponding landmarks to the respective lateral cephalograms. Subsequent two-dimensional superimposition of the aligned cephalograms facilitated the three-dimensional superimposition of the pre- and post-treatment models. This process allowed the quantification of the curvature from a frontal perspective of the models. The change in curvature was then correlated with changes in the cephalometric inclination of the anterior occlusal plane (AOP), functional occlusal plane (FOP), maxillary central incisor (U1), and the intercanine width.

RESULTS: Orthodontic correction in this sample resulted in the clockwise rotation of the anterior occlusal plane (5.84 degrees), reduction in proclination of the incisors (−14.39 degrees), increase in intercanine width (2.48 mm), and a corresponding increase in the curvature of the smiling line (6.83 degrees).

CONCLUSIONS: The change in curvature of the smiling line in these subjects was found to be related more significantly to the magnitude of difference in the inclination between the pre-treatment AOP and FOP than to the change in the inclination of the maxillary incisors. With orthodontic treatment, the smiling line can be correlated with cephalometric data to improve or maintain the curvature.

Introduction

The ‘smiling line’, described by Frush and Fisher (1958) as the curve that traces along the maxillary incisal edges and onwards to the canine cusps, has been shown to be important in assessing the harmony of the smile (Lombardi, 1973). The degree of harmony is assessed by evaluating the relationship between the smiling line and the curvature of the upper border of the lower lip. This relationship is designated as the smile arc (Sarver, 2001). In a harmonious smile, the smiling line should ideally be in consonance with the curvature of the lower lip and this relationship is described as a parallel or consonant smile arc (Sarver, 2001). Conversely, a flat smile arc is characterized by a smiling line that is reduced in curvature compared with the curvature of the lower lip. This presentation has been found to be less attractive than a parallel smile arc (Parekh et al., 2006; Springer et al., 2011). In light of the importance of the smile arc, many investigators have advocated that the smiling line be orthodontically assessed to improve the attractiveness of the smile (Hulsey, 1970; Sarver, 2001; Ackerman and Ackerman, 2002). Interestingly, studies have reported that orthodontic treatment with fixed appliances may, however, lead to flattening of the curvature of the smiling line (Hulsey, 1970; Lindauer et al., 2005). Thus, proper orthodontic control to maintain or increase the curvature of the smiling line is important to ensure a harmonious smile is attained.

Variables that have been reported to influence the curvature of the smiling line include: 1. orientation of the occlusal plane, 2. incisors inclination, and 3. maxillary intercanine width. To increase the curvature of the smiling line, the occlusal plane has been recommended to be orientated superiorly as it progresses posteriorly (Lombardi, 1973). Similarly, Ackerman and Ackerman (2002) reported...
that in the natural head posture, the curvature can be improved by increasing the angle of the maxillary occlusal plane to the Frankfort horizontal plane. In addition to modifying the occlusal plane to improve the curvature of the smiling line, Janzen (1977) also emphasized that proper incisor inclination is necessary for a harmonious smile. In contrast, excessive incisor proclination or flaring would result in flattening of the curvature of the smiling line (Sarver, 2001) and lead to poorer smile aesthetics (Işıkşal et al., 2006). The maxillary intercanine width has also been reported to influence the curvature of the smiling line. In instances where the maxillary dental arch was expanded orthodontically to decrease the width of the buccal corridor, the intercanine width also correspondingly increased. The space gained anteriorly may thus lead to a subsequent reduction in the curvature of the smiling line (Sarver and Ackerman, 2003).

Significant dental changes occur during fixed orthodontic appliance treatment of malocclusions with proclined maxillary incisors in class II division 1 (British Standards Institution London, 1983) relationships. The maxillary incisors and canines undergo positional changes to be corrected to an incisor class I relationship. Thus, all three mentioned variables that have been reported to influence the curvature of the smiling line are also modified in varying degrees. Therefore, the aim of this study was to investigate the different effects of changes in the occlusal plane, incisors inclination, and maxillary intercanine width on the curvature of the smiling line in the treatment of incisor class II division 1 malocclusions.

Materials and methods

Ethical approval for this retrospective study was obtained from the Institutional Review Board of the university. The inclusion criteria were as follows: 1. normodivergent class II skeletal relationship (PP-MP = 26±5 degrees; ANB > 4 degrees); 2. incisor class II division 1 malocclusion (U1-PP > 118 degrees; overjet > 4 mm); 3. permanent dentition; 4. pre-treatment crowding less than 6 mm in each arch; 5. treatment with fixed orthodontic appliances, and 6. complete pre- and post-treatment lateral cephalometric radiographs and orthodontic study models. Exclusion criteria were subjects with craniofacial anomalies, facial asymmetry, and hypodontia. A total of 46 subjects (28 females and 18 males, mean age 16.62±4.19 years; mean overjet 6.48 mm ± 1.65 mm) who fulfilled the inclusion criteria were identified. These subjects were treated under the supervision of three faculty orthodontists at the university clinic. All subjects had bilateral maxillary first premolar extractions and bilateral mandibular premolar extractions [mandibular first premolars removal (n = 20) and mandibular second premolars removal (n = 26)] and were treated with preadjusted edgewise appliances (Victory Series .022 in. Brackets, MBT prescription, 3M Unitek).

To analyse changes in the curvature of the smiling line, virtual superimposition of the pre- and post-treatment maxillary dental models and lateral cephalograms were acquired. All dental models were scanned using a non-contact surface laser scanner (Minolta Vivid 900, Minolta Corporation, Japan). Each model was scanned at two different orientations to the laser scanner to ensure accurate three-dimensional (3D) reproduction. At 60-degree intervals of rotation on the scan table for each different orientation, all areas were virtually reproduced without undercuts. Twelve datasets of the scan intervals were then merged using 3D modelling software (Rapidform 2006, INUS Technology, Korea) to produce the 3D digital models. The 1:1 scale digital models were saved in virtual reality modelling language format. Pre- and post-treatment standardized lateral cephalograms in the natural head position were obtained using the same radiographic machine (Siemens Orthoceph, 10s cephalometer, Germany). All cephalograms were of good quality and were digitally scanned with a flatbed scanner (Epson Expression 1640XL, Japan) at 150 dots per inch.

A customized 3D modelling software was used for the virtual superimposition process (Figure 1) and is described sequentially below:

1. For anterior–posterior and vertical alignment, the maxillary dental digital models were virtually aligned with the respective lateral cephalograms via the following landmarks:
   (a) Incisal edge of the most anterior central incisor;
   (b) Mesiobuccal cusp tip of the first molar.
2. Correction of the magnification of the lateral cephalogram was also performed simultaneously with digital correspondence of the above landmarks.
3. For transverse horizontal alignment, three points were selected uniformly along the median palatine raphe of the maxillary model. Using the least squares method of plane fitting, this allowed the lateral cephalogram (corresponding to the mid-sagittal plane) to be aligned transversely with the palatine raphe of the model.

Subsequent two-dimensional (2D) superimposition of the aligned cephalograms on reference anatomical structures facilitated the 3D superimposition of the pre- and post-treatment digital models. Cephalometric superimposition was based on anterior cranial base and maxillary anatomical structures. These included the anterior contours of the sella turcica (Melsen, 1974), the cribiform plate (Nelson, 1960), the internal outline of the frontal bone, and anterior contours of the maxillary zygomatic process (Björk and Skjeller, 1977). With the superimposition, the pre- and post-treatment curvatures of the smiling line were then quantified for all subjects from a frontal perspective of the maxillary dental digital models.

To quantify the curvature of the smiling line, 14 occlusal points were selected on each of the pre- and post-treatment digital models to define the curvature (Figure 2). The points
Curve fitting was defined by a fourth-order polynomial, using the least squares method for a best-fit curve to the selected points (Ferrario et al., 1994; Alharbi et al., 2008). To obtain the mean value of the curvature of the smiling line in degrees, 100 equidistant points were initially sampled on the fitted curvature. The magnitude of any point on the curvature is thus equivalent to the reciprocal of the radius of an osculating circle. An osculating circle is one that presents with the same curvature when joined to the point on the curvature. This circle has its centre lying on the inner normal line to that point. Thus, the measurement in degrees of each sampled point on the curve written in the form $y = f(x)$ can be calculated using the following equation:

$$
\kappa = \frac{d^2y}{dx^2} \div \left[ 1 + \left( \frac{dy}{dx} \right)^2 \right]^{1/2}
$$

The calculated mean value of the 100 sampled points was then taken to represent the magnitude of the curvature of the smiling line. For all subjects, the curvature was measured at the level of the maxillary central incisal edge from a frontal horizontal distance of 50 cm. Orientation of the lateral cephalogram was fixed with the true vertical. The post-treatment change in the curvature of the smiling line for each subject was then correlated with the changes in the cephalometric inclination of the occlusal plane and maxillary central incisors, and changes in the maxillary intercanine width. Both the cephalometric analysis and measurements of the intercanine width were performed by a specialist orthodontist with more than 5 years of experience. Seven pre- and post-treatment cephalometric measurements representing skeletal and dental components (Figure 3) were measured using a digital measuring software (EasyDent V4 Viewer, Version 4.1.2, 2008, VATECH & E-WOO, Korea). The brightness, contrast, and size of the cephalograms were adjusted as required to aid the identification of the landmarks. The maxillary intercanine widths of the pre- and post-treatment models were measured at the level of the canine cusp tips using a 3D measuring software (Rapidform 2006, INUS Technology, Korea). Each measurement was repeated twice and the average value was recorded.

Statistical analysis

Descriptive statistics of the variables was presented as mean [Standard deviation (SD)] and if normality assumptions were satisfied, paired $t$-test was used to analyse pre–post differences; otherwise, the non-parametric Wilcoxon signed-rank test was used. To account for the simultaneous changes in the inclination of the anterior occlusal plane, incisors, and intercanine width due to fixed orthodontic treatment, principal components analysis was used to evaluate the multidimensional differential of the curvature of the smiling line. All statistical analyses were performed with IBM SPSS Statistics 19.0 (IBM). Significance for all statistical tests was predetermined at $P < 0.05$.

For method error (ME) estimation, 25 subjects were randomly selected to repeat the curvature quantification, and measurements of the cephalograms and maxillary intercanine width. These were performed at monthly intervals and by the same examiner. Dahlberg’s formula: ME = $\sqrt{\sum d^2 / 2n}$ (Dahlberg, 1940) was used to calculate
random errors, where $d$ is the difference between two measurements and $n$ is the number of repeat measurements. Paired $t$-test was used to evaluate systematic errors (Houston, 1983).

Results

Descriptive analyses and statistics for measurements are shown in Table 1. The normodivergent class II skeletal relationship of this sample was indicated by the PP-MP (mean, 26.58 degrees; SD, 2.96 degrees), ANB (mean, 5.57 degrees; SD, 0.62 degrees), and face height ratio (mean, 53.93 per cent; SD, 0.96 per cent).

Pre- and post-treatment changes

The angular and linear changes brought about by treatment are also presented in Table 1. Pre- and post-treatment comparisons showed that the inclination of the anterior occlusal plane (AOP) increased (mean, 5.84 degrees; SD, 4.77 degrees) and became almost congruent with the functional occlusal plane (FOP). Although the change in the inclination of the FOP was statistically significant, the difference (mean,
−0.19 degrees; SD, 0.36 degrees) was clinically insignificant compared with the inclination change in the AOP. Therefore, in this sample, orthodontic treatment had the effect of reducing the difference in pre-treatment inclination between the AOP and FOP [AOP-FOP] (mean, −6.03 degrees; SD, 4.86 degrees). Additionally, with the retraction of the maxillary anterior teeth, there was a reduction in the incisors inclination [U1-PP] (mean, −14.39 degrees; SD, 5.46 degrees) and an increase in the maxillary intercanine width (mean, 2.48 mm; SD, 1.58 mm). Overall, there was a corresponding increase in the curvature of the smiling line (mean, 6.83 degrees; SD, 6.48 degrees). No significant skeletal changes were found.

Principal components influence on the curvature of the smiling line

Using the principal components of the pre-treatment difference in AOP-FOP inclination, incisors inclination and maxillary intercanine width influence on the change in curvature of the smiling line (Table 2), the significant predictors identified were the magnitude of the difference in inclination between the pre-treatment AOP and FOP ($P < 0.001$), and the change in incisors inclination ($P < 0.001$). The magnitude of the difference between the pre-treatment AOP and FOP inclination had a stronger influence on the change in the curvature of the smiling line compared with the change in incisors inclination (as shown by a higher absolute beta, standardized coefficients). In this study, a 1 degree inclination variation between the pre-treatment AOP and FOP brought about a greater change in the curvature of the smiling line ($B = −6.08$ degrees) than a 1 degree variation in incisors inclination ($B = −1.44$ degrees). The increase in the maxillary intercanine width, however, did not influence significant changes in the curvature of the smiling line.

Table 2  Principal components influence on the curvature of the smiling line.

<table>
<thead>
<tr>
<th>Model</th>
<th>Coefficientsa</th>
<th>95% confidence interval for B</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Unstandardized coefficients</td>
<td>Standardized coefficients</td>
</tr>
<tr>
<td>Constant</td>
<td>6.83</td>
<td>0.26</td>
</tr>
<tr>
<td>Pre-treatment anterior and functional occlusal plane difference (°)</td>
<td>−6.08</td>
<td>0.26</td>
</tr>
<tr>
<td>Maxillary incisor inclination (°)</td>
<td>−1.44</td>
<td>0.26</td>
</tr>
<tr>
<td>Maxillary intercanine width (mm)</td>
<td>0.33</td>
<td>0.26</td>
</tr>
</tbody>
</table>

aDependent variable: curvature of the smiling line (°).

* $P < 0.05$. 

For the measurements of the curvature of the smiling line, the mean error value was 0.43 degrees (range, 0.01–0.85 degrees). For the measurements of the cephalometric angles, U1-PP, the mean error value was 0.33 degrees (range, 0.10–0.50 degrees). For PP-AOP, the mean error value was 0.31 degrees (range, 0.01–0.85 degrees).
degrees (range, 0.10–0.60 degrees). For PP-FOP, the mean error value was 0.24 degrees (range, 0.10–0.50 degrees). For linear measurements of the maxillary intercanine width, the mean error value was 0.38 mm (range, 0.11–0.56 mm). No systematic errors were detected for the curvature of the smiling line and the measurements of the cephalometric analysis and intercanine width.

Discussion

Photographs and static video frames of smiles have been used to characterize the changes in the curvature of the smiling line with respect to the curvature of the lower lip (Frush and Fisher, 1958; Janzen, 1977; Tjan et al., 1984; Mackley, 1993; Ackerman and Ackerman, 2002; Lindauer et al., 2005; Işiksal et al., 2006). However, to date no studies are known to have reported correlating changes in magnitude of the curvature of the smiling line with cephalometric and dental changes. With bilateral removal of the maxillary first premolars, orthodontic correction of the incisor class II division 1 malocclusion in this sample resulted in the following: 1. clockwise rotation of the anterior occlusal plane, 2. reduction in proclination of the incisors, and 3. increase in maxillary intercanine width. No clinically significant change in inclination occurred in the functional occlusal plane. The cephalometric occlusal plane as defined by Downs (1952) is a line bisecting the overlapping regions of the maxillary and mandibular first molars cusps and incisors. However, in malocclusions with incisors that are proclined or presenting with an accentuated Curve of Spee, the anterior reference point becomes variable. In these instances, the occlusal plane has been defined by tracing two separate lines posteriorly and anteriorly. The posterior or functional occlusal plane is defined by a line bisecting the overlapping regions of the first molars and premolars cusps (Riolo et al., 1974). Separately, the AOP has been defined by a line that intersects the maxillary second premolar cusp tip and the maxillary central incisal edge (Fushima et al., 1996; Tanaka and Sato, 2008). In this study, the same reference points were similarly used to define both the FOP and AOP.

With the retraction of the maxillary anterior teeth to attain an incisor class I relationship, the canine also distalized correspondingly to occupy a broader region of the maxillary dental arch. This resulted in a significant increase in the maxillary intercanine width and similar increases have also been reported by other studies (Bishara et al., 1997; Işik et al., 2005). This increase, however, did not significantly influence changes in the curvature of the smiling line compared with the other variables. The curvature of the smiling line was, instead, found to be only significantly influenced by the following two variables: 1. magnitude of difference in inclination between the pre-treatment AOP and FOP, and 2. the change in incisors inclination. Analysis of the results indicated that the larger the difference in inclination between the pre-treatment AOP and FOP, the greater the propensity for a resultant clockwise rotation change in the AOP post-treatment. The change in the AOP would then translate into a significant increase in the curvature of the smiling line post-treatment. This relationship between the occlusal plane inclination and curvature of the smiling line is in agreement with what has been reported in other studies (Lombardi, 1973; Ackerman and Ackerman, 2002). The reduction in inclination of the incisors, however, had a smaller influence on the change in curvature. This influence is also in agreement with that found in other studies (Janzen, 1977; Sarver, 2001; Işiksal et al., 2006). The difference in influence between the inclination of the anterior occlusal plane and incisors on the curvature of the smiling line also demonstrates that although both variables may change simultaneously, the change does not proceed in a linear relationship.

In this study, there was an overall increase in the curvature of the smiling line (Figure 4). This finding is not in agreement with other studies that reported flattening of the curvature of the smiling line instead after orthodontic treatment (Hulsey, 1970; Lindauer et al., 2005). This is likely due to differences in the characteristics between the study sample, thus rendering impossible direct comparisons between these studies. Lindauer et al. (2005) reported flattening of the curvature in subjects during orthodontic bite opening treatment of patients with deep overbites. This differs from the malocclusion that was analysed in this study, which were malocclusions presenting with proclined incisors and excessive overjet. Hulsey (1970) compared photographs of smiling subjects post-orthodontic

Figure 4 Pre- and post-treatment change in the curvature of the smiling line.
treatment with photographs of smiling subjects with ‘normal occlusions’ and observed that orthodontic treatment resulted in the flattening of the smiling line. Similarly, direct comparisons with the study by Hulsey (1970) cannot be made as the original malocclusions of the treated subjects were not reported in his study.

Conversely, the results also suggest that there are limitations with preadjusted edgewise appliance therapy in modifying the curvature of the smiling line of malocclusions with the following presentations: 1. congruency between the pre-treatment AOP and FOP, and 2. normal inclination of the incisors. Therefore, if increasing the curvature of the smiling line is one of the treatment objectives in these malocclusions, treatment options other than that reported in this study should be reviewed. In the literature, depending on the complexity of the malocclusion, other investigators have recommended other options to increase the curvature of the smiling line. One of the options includes individualized vertical repositioning of the brackets (Sarver, 2001). By repositioning the brackets of the maxillary anterior teeth more cervically, the teeth will be repositioned more inferi orly with respect to the posterior teeth. This will orthodontically increase the inclination of the occlusal plane; whereas in more complex malocclusions, orthognathic maxillofacial surgery (Sarver, 2001) or posterior intrusion with vertical skeletal anchorage (Lai et al., 2008; Yao et al., 2008; Upadhyay et al., 2012) have been reported to increase the inclination of the occlusal plane more significantly.

Comparisons of soft tissue were not included in this study due to the variability in the presentation of the lower lip between individuals. The curvature of the lower lip is formed as the commissures of the left and right lip widen superior-laterally to reveal the maxillary anterior teeth during a smile. Variability in the lip curvature is thus brought about by differences in the amount of superior and lateral movement of the commissures between individuals. In addition, the amount of commissural change on smiles has also been shown to be affected by age and gender differences. Females have been found to have smiles with a wider change in intercommissural width than males and this tends to decrease with age in both genders (Chetan et al., 2013).

To facilitate the 3D analysis of treatment changes, pre- and post-treatment dental digital models have also previously been virtually superimposed onto the respective lateral cephalogram. This was achieved by matching the outline of the occlusal plane on the lateral cephalogram according to a best-fit method (Baumrind et al., 2003). Subsequent superimposition on reference anatomical structures of the pre- and post-treatment lateral cephalograms facilitated the superimposition of the models and 3D analysis of the change in teeth positions. In this study, in addition to using occlusal plane landmarks for anterior–posterior and vertical alignment, the median palatine raphe was also used as a reference for transverse alignment. As the median palatine raphe coincides with the mid-sagittal plane, alignment of the raphe with the lateral cephalogram allowed for the transverse horizontal alignment of the digital model. With the alignment and subsequent cephalometric superimposition, the pre- and post-treatment curvature of the smiling line could then be quantified from a frontal perspective.

Conclusions

The effect of fixed orthodontic appliance treatment in this sample of incisor class II division 1 malocclusions resulted in an overall increase in the curvature of the smiling line.

The change in the curvature of the smiling line in this study was found to be related more significantly to the magnitude of difference in the inclination between the pre-treatment AOP and FOP than to the change in the inclination of the maxillary incisors. The change in the maxillary intercanine width, however, did not influence the curvature significantly.

Conversely, the results also suggest that there are limitations with conventional preadjusted edgewise appliance therapy in modifying the curvature of the smiling line of malocclusions with congruency between the pre-treatment AOP and FOP, and maxillary incisors of average inclinations. Therefore, if increasing the curvature of the smiling line is one of the treatment objectives, treatment options other than that reported in this study should be reviewed.

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