

Post-treatment development of the curve of Spee

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SUMMARY The aim of this study was to investigate the post-treatment development of the curve of Spee (CS) and to predict its post-treatment stability on the basis of cephalometric parameters. Lateral cephalograms and study models of 135 subjects (50 males and 85 females) were taken before orthodontic treatment (T1; 12.0 ± 1.5 years), at the end of orthodontic treatment (T2; 14.6 ± 1.5 years), and at least 3 years out of retention (T3; 26.6 ± 5.0 years); the curve depth (CD), location of the deepest point (LDP) of the curve, and eight cephalometric parameters were assessed. The sample was divided into a treated and an untreated lower arch group. The upper arch was treated in all patients. The sample consisted of 25 per cent Class I, 73 per cent Class II, and 2 per cent Class-III-treated malocclusions.

The results showed that the post-treatment CD was frequently unstable and unexpected changes were relatively common. The LDP was displaced distally during T1–T2 and showed mesial relocation during T2–T3. Assessment of potential predictors of the post-treatment changes in CD and LDP using stepwise regression analysis showed that a deep curve at T2 was associated with a decrease of the CD during T2–T3. A combination of distal location of the LDP with proclination of the lower incisors at T2 and extraction treatment was associated with mesial relocation of the LDP during T2–T3. The results also suggest that an optimal CD of about 2.0 mm at T2 was associated with the least amount of post-treatment change.

Introduction

The curve of Spee (CS) is an important characteristic of the mandibular dental arch. An excessive CS is often seen in subjects with Class II malocclusions with deep overbites, and levelling of the curve with overbite reduction is hence a common treatment objective. Andrews (1972) advocated levelling the CS to a flat curve in order to facilitate construction of an optimal occlusion. He also suggested that a flat plane should be a treatment goal as a form of over-treatment. Levelling of the curve is associated with an increase of the arch circumference (Germane *et al.*, 1992); however, the amount of additional arch space required for levelling of the curve is not easily predictable. Proclination of the lower incisors has also been associated with levelling of the curve (AlQabandi *et al.*, 1999). However, Woods (1986) showed that incisor flaring may be primarily related to the mechanics of the levelling rather than to the difference in arch circumference. Reduction of the curve may also be achieved by intrusion of anterior teeth and/or tip-back of molars.

De Praeter *et al.* (2002) reported that levelling of the CS yielded more stable results compared with correction of incisor crowding and overbite. This finding was supported by Shannon and Nanda (2004) who reported that the CS was relatively stable after treatment. In contrast, Carcara *et al.* (2001) found that post-treatment development of the curve was unpredictable. According to that longitudinal study, curves that were not completely levelled after treatment had a higher incidence and magnitude of relapse. A number of investigations have shown a relationship

between the CS and craniofacial morphology (Braun and Schmidt, 1956; Orthlieb, 1997; Farella *et al.*, 2002). Although these studies did not address the relationship between the long-term post-treatment curve changes and the underlying craniofacial morphology, it is conceivable that the latter might influence post-treatment development of the CS. Further, no reliable information is currently available from the literature as to which shape of the curve leads to greater stability. Minimal long-term data exist on the stability of correction of the depth and shape of the CS and the factors influencing it. Therefore the aim of this retrospective longitudinal study was to assess the long-term development of the CS after orthodontic treatment and to evaluate a number of dental and skeletal parameters as potential predictors of its post-treatment stability.

Material and methods

Data collection

For this study 135 former orthodontic patients (50 males and 85 females) treated between 1971 and 1978 were selected on the basis of the availability of records with a minimum period of 3 years out of retention. Patients with craniofacial malformations and those who had undergone orthognathic surgery were excluded. The sample consisted of 25 per cent Class I, 73 per cent Class II, and 2 per cent Class-III-treated malocclusions. Subjectively, the main features of the original malocclusions such as dental

relationships, crossbites, and malposition of teeth were all corrected successfully. The upper arch was treated in all subjects. The lower arch was treated in 100 subjects and remained untreated in 35 subjects. In patients with treatment in both arches, 47 subjects underwent extraction of four premolars and 53 had non-extraction treatment in the lower arch. Study models and lateral cephalograms were obtained at pre-treatment (T1), end-of-treatment (T2), and post-retention (T3) stages. Further sample characteristics with regard to the subjects' ages and the time intervals between T1, T2, and T3 are detailed in Table 1.

Measurements on study models and cephalograms

Standardized photographs were made of the mandibular study models out of occlusion from the left and right sides with the buccal tooth surfaces aligned in the same plane. The photographs were taken in a plane perpendicular to the occlusal plane tangent to the buccal surface of the first molar and canine and centred on the first premolar. A ruler was included in all photographs to determine magnification. Fixed landmarks on the photographs were digitized using a Digi-Pad® digitizer (Super L Series®, GTCO Corporation, Columbia, Maryland, USA) and measurements were carried out as defined in Figure 1. For each model the left and right curve was measured. As no significant difference between the left and right side was found, the left and right curve depth (CD) and the location of the deepest point (LDP) of the curve were averaged to give one value per model. Lateral cephalograms were used to assess the dental and skeletal parameters listed in Table 2.

To assess the reliability of the measurements, a second set of photographs was made of 20 randomly selected study models, and the measurements were repeated. Cephalometric measurements were repeated on 33 randomly selected radiographs. Two different observers carried out the repeat measurements and the time period between the recordings was at least 6 weeks. Student's *t*-tests were performed to detect any systematic difference between the first and second recordings at the α level of $P < 0.01$ according to Houston (1983). No significant differences between the first and second recordings were found. Intraclass correlation coefficients for repeated measurements were calculated to test the inter-observer variability of the measurements which were above 0.90 for all measurements.

Data analysis

The sample was divided into treated (TLA) and untreated lower arch (ULA) groups and the post-treatment curve changes were evaluated and compared in both groups. Mean values and standard deviations of CD and LDP at T1, T2, and T3 were calculated for data presentation. Subsequently, the CD was defined as flat (<1 mm), normal (1–2 mm), or deep (>2 mm), and the changes in frequencies of the CD types at T1, T2, and T3 were calculated. The frequencies of post-treatment changes (T2–T3) of the CD types were studied, and distinction was made between relapse and spontaneous changes in relation to CD at T1. Post-treatment stability, which was defined as the absence of changes during T2–T3, was also registered. The different occurrence of modifications in the CS were tested by the χ^2 -test.

Repeated-measures analyses of variance (ANOVAs) were carried out to determine the changes of CD and LDP between the investigated time intervals in the TLA and ULA groups. In addition a paired *t*-test with a Bonferroni correction was performed to detect significant differences in time found by ANOVA. The factors gender and extraction in the lower arch were also included in the ANOVA to identify any significant interaction effects between groups and time intervals. Pearson correlation coefficients were calculated between the treatment changes and the post-treatment changes of CD and LDP in the TLA group. In the same group Pearson correlation coefficients were also calculated between overbite and CD and LDP at T1, T2, and T3 and during T1–T2 and T2–T3. Multiple linear stepwise regression analyses were performed in the TLA group to predict the changes of CD and LDP between T2 and T3 as dependent variables on the basis of the dental and skeletal parameters at T1 and T2 and extraction in the lower arch as the independent variables. All calculations were carried out using the SPSS 11.0 statistical program (SPSS Inc., Chicago, Illinois, USA).

Results

The descriptive statistics for CD and LDP and the statistically significant changes during T1–T2 and T2–T3 are summarized in Table 3. The frequencies of CD in the TLA and ULA groups at T1, T2, and T3 are presented in Figure 2a,b, respectively. For the 100 subjects in the TLA group CD

Table 1 Subjects' ages at pre-treatment (T1), end-of-treatment (T2), post-retention (T3), and duration of T1–T2 and T2–T3.

	Mean	SD	Minimum	Maximum	Range
T1	12.0	1.5	9.0	17.5	8.5
T2	14.6	1.5	10.5	20.5	10.1
T3	26.6	5.0	17.2	39.4	22.2
T1–T2	2.6	0.9	0.5	5.8	4.7
T2–T3	12.0	4.8	3.0	24.4	21.4

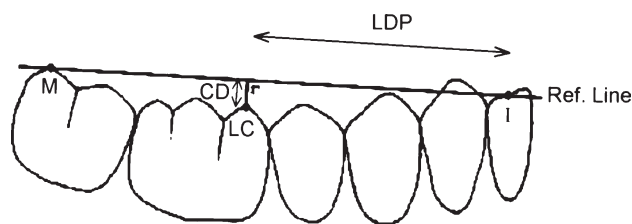


Figure 1 Study model landmarks, the reference line and measurements used in this study. M: distal cusp tip of the last lower molar; LC: lowest cusp tip in occlusion; I: mid-incisal edge of the lower lateral incisor; Ref. Line: reference line connecting points M and I. Curve depth (CD) measured in millimetres as the distance from point LC perpendicular to the Ref. Line. Location of the deepest point (LDP) measured as the distance between I and the intersection of LC perpendicular with Ref. Line expressed as percentage of the distance between M and I.

Table 2 Cephalometric measurements.

Parameters	Definition
Dental	
–I to NB (mm)	Distance from the incisal edge of the lower incisor to line NB
–I to NB (degrees)	Inclination of the axis of the lower incisor to line NB
Overjet	Horizontal distance between the incisal edges of the upper and lower incisors
Overbite	Vertical distance between the incisal edges of the upper and lower incisors
Skeletal	
ANB<	ANB angle
Wits	Wits appraisal
PPMP	Angle between the palatal plane and the mandibular plane (Schwarz, 1958)
LFH	Distance between anterior nasal spine and menton

remained stable in 52 subjects, relapsed in 29, and changed spontaneously to another curve type in 19 subjects. For the 35 subjects in the ULA group CD remained stable in 21 (60 per cent), relapsed in five (14 per cent), and changed spontaneously to another curve type in nine (26 per cent) subjects. The percentages of flat, normal, and deep curves as identified at T1, which either remained stable, relapsed, or changed spontaneously during T2–T3 in the TLA and ULA groups, are presented graphically in Figure 3a,b, respectively. There were, however, no significant differences in the occurrences of modifications in the CS, as revealed by the χ^2 -test.

In the TLA group repeated ANOVA showed significant differences between CD and LDP at T1, T2, and T3 (CD: $F(2,95) = 16.3$, $P < 0.01$; LDP: $F(2,128) = 18.3$, $P < 0.01$). In this group the differences in CD and LDP over time exhibited no significant interaction effects with gender or extractions in the lower arch. In the ULA group repeated ANOVA analyses showed only significant differences between LDP at T1, T2, and T3 ($F(2,32) = 6.6$, $P < 0.01$) and no significant differences between CD at

the various time intervals. In addition, no interaction effects between the changes of CD and LDP over time with gender were found in this group.

In the TLA group a significant correlation was found between the changes of CD during T1–T2 and those during T2–T3 ($r = -0.42$; $P < 0.01$) and LDP ($r = -0.41$; $P < 0.01$). A decrease of CD during T1–T2 was associated with an increase during T2–T3. Distal displacement of LDP during T1–T2 was related to its mesial relocation during T2–T3. In the TLA group, CD correlated positively ($r = 0.31$; $P < 0.01$) with the overbite at T1. At T2 and T3 no correlation was found between CD and overbite. The changes of overbite were positively correlated with the changes of CD during T1–T2 ($r = 0.43$; $P < 0.01$). There was no significant correlation between the changes of overbite and changes of CD during T2–T3. LDP and its changes showed no significant correlation with overbite.

Regression analysis revealed that only CD at T2 was a significant independent variable ($R^2 = 0.26$; $P < 0.01$) explaining 26 per cent of the total variance in the change of CD during T2–T3 in the TLA group. CD at T2 and the change of CD during T2–T3 in the TLA group is shown in Figure 4. In the scatter plot the intersection between the regression line and the zero post-treatment change line is located at CD at T2 of 1.9 mm. The difference of LDP during T2–T3 in the TLA group could be predicted by a combination of the variables LDP at T2, –I to NB at T2, and extraction in the lower arch ($R^2 = 0.47$; $P < 0.01$), together accounting for 47 per cent of the total variance of the dependent variable.

Discussion

The gender of the subjects had no significant effect on the variables assessed which confirms previous reports of the absence of sexual dimorphism in the CS in both treated (De Praeter *et al.*, 2002) and untreated (Braun and Schmidt, 1956; Ferrario *et al.*, 1997; Farella *et al.*, 2002; Shannon and Nanda, 2004) subjects.

In the ULA group only minimal changes of CD were revealed during and after orthodontic treatment, and it thus appears that treatment changes in the upper arch had little effect on CD in the lower arch. In contrast, in the TLA group CD showed relapse after levelling during treatment. However, the average changes were small and clinical relevance of such a relapse is therefore questionable. In addition, large standard deviations of the measurements indicate a large individual variation of CD. In general this observation parallels the findings of other studies that after levelling of the curve relapse may occur with a considerable degree of variation (De Praeter *et al.*, 2002; Baydas *et al.*, 2004; Shannon and Nanda, 2004).

In the TLA group the CD on average decreased 0.8 mm during treatment and increased 0.3 mm post-treatment, suggesting an average relapse of 37.5 per cent in this group

Table 3 Mean values and standard deviations of the curve depth (CD) and location of the deepest point (LDP) in the treated (TLA) and untreated (ULA) lower arch groups and the corresponding inferential statistics.

	Pre-treatment (T1)	End-of-treatment (T2)	Post-retention (T3)	Treatment period (T1–T2)	Post-treatment period (T2–T3)
TLA (<i>n</i> = 100)					
CD (mm)	2.1 (0.9)	1.3 (0.8)	1.6 (0.7)	−0.8 (1.3)*	0.3 (0.7)*
LDP (percentage)	58.9 (11.7)	67.4 (9.7)	63.3 (9.2)	8.4 (14.2)*	−4.1 (10.8)*
ULA (<i>n</i> = 35)					
CD (mm)	1.7 (0.8)	1.8 (0.7)	1.7 (0.7)	0.1 (0.9)	−0.2 (0.6)
LDP (percentage)	58.1 (12.7)	66.0 (6.0)	64.6 (8.3)	7.9 (13.0)*	−1.4 (6.7)

**P* < 0.025 (Bonferroni correction) significance of paired *t*-test.

during T2–T3. Carcara *et al.* (2001) studied long-term changes of the CS and reported 11.68 per cent relapse occurrence in completely levelled curves and 22.46 per cent in those not completely levelled during treatment. De Praeter *et al.* (2002) and Shannon and Nanda (2004) found that the CS was relatively stable after orthodontic treatment. In the present investigation 40–48 per cent of the total sample exhibited measurable post-treatment changes of CD, suggesting its instability after orthodontic treatment. Post-treatment stability appeared more frequent in the TLA group than in the ULA group, which, however, was not statistically significant. On the other hand, more post-treatment spontaneous changes of the CD were found in the ULA group compared with the TLA group. It would appear from these observations that if relatively large changes of the CD occur during treatment as seen in the TLA group, post-treatment relapse is greater and more frequent. If changes during treatment are small as seen in the ULA group, post-treatment spontaneous changes are most frequent. In the TLA and ULA subgroups with normal curves at T1 the smallest changes during treatment were observed; however, the largest spontaneous post-treatment changes occurred within these subgroups (27 and 31 per cent, respectively). The TLA subgroup of patients with a flat curve at T2 who originally had a normal curve showed a higher occurrence of relapse (60 per cent) than those who originally had a deep curve (53 per cent). In the TLA group originally deep curves exhibited more stability than originally flat or normal curves (58 per cent). In the ULA group originally normal curves showed more stability than originally flat or deep curves (69 per cent). In both groups originally flat curves showed the highest frequency of instability suggesting that treatment of flat CS might frequently lead to post-treatment instability of the CD. It appears, therefore, that more stability may be expected after relatively large changes during levelling of deep curves. When small changes occur during treatment in TLA and ULA patients, there is a tendency for less post-treatment stability and more spontaneous changes.

Measuring CD alone is considered insufficient and some means of characterization of the curve shape, such as for

instance its definition as a three-dimensional sphere by mathematical means has been suggested (Ferrario *et al.*, 1992). In the present study this was addressed by assessing the LDP of the curve as recommended by Koyama (1979) and Shannon and Nanda (2004), which was expressed as a percentage of the total curve length in order to counteract the confounding effects of curve lengthening caused by second molar eruption. Previously, Shannon and Nanda (2004) reported that the mesiobuccal cusp of the first mandibular molar was most commonly the LDP, whilst Koyama (1979) described its location in the second premolar area. The latter is in agreement with the present study in which, before treatment, the deepest point of the curve in 58–66 per cent of the cases was located, on average, near the antero-posterior midpoint of the curve. During treatment the LDP was displaced in a distal direction, and afterwards it returned slightly towards mesial. As there were minimal statistically insignificant differences between the TLA and ULA groups it would seem that similar changes of the LDP occurred during and after treatment with mechanotherapy in the upper arch and afterwards, irrespective of the presence of active treatment, in the lower arch.

Changes in dental dimensions and incisor position have been reported to occur after treatment with premolar extractions (Luppanapornlarp and Johnston, 1993; Shearn and Woods, 2000). This would imply that changes in the CS might also occur, as extractions could lead to deepening of the curve as the result of tilting of the teeth and movement of the deepest point towards the extraction site. However, Luppanapornlarp and Johnston (1993) and Shannon and Nanda (2004) found no significant difference between the CS in extraction and non-extraction cases. This finding is in agreement with the results of the present study as extraction had no significant effects on CD and LDP in the TLA group at any time point as shown by ANOVA.

In the TLA group the changes in CD and LDP during T2–T3 were negatively correlated with the changes during T1–T2. This suggests that the amount of relapse might be inversely related to the amount of change during treatment. This correlation can be explained to a large extent by the

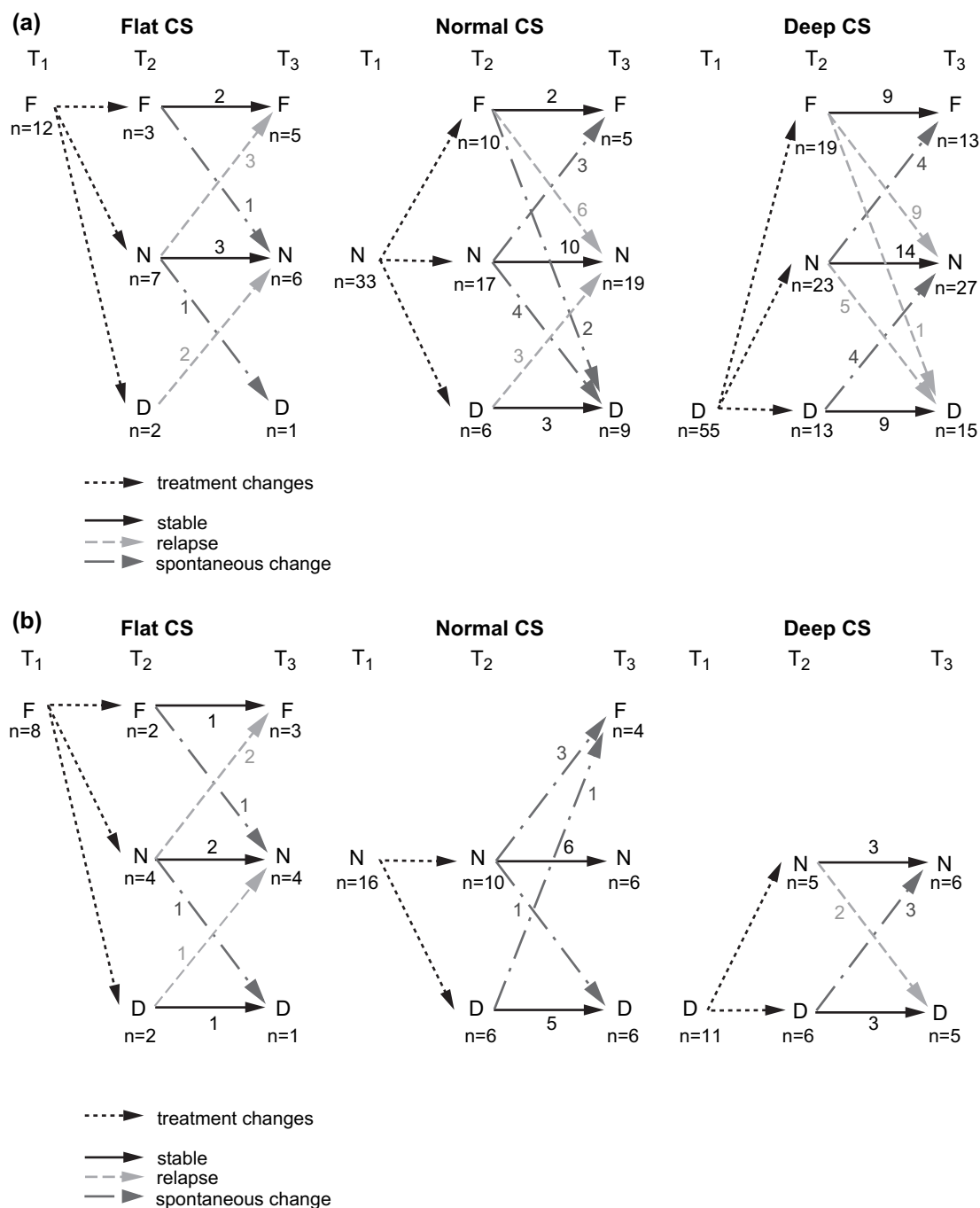


Figure 2 Follow-up of changes of flat (F), normal (N), and deep (D) curves of Spee as identified pre-treatment, and over the time course in (a) the treated and (b) untreated lower arch groups.

small amount of relapse in those cases originally showing a deep curve. The positive correlation between CD and overbite at T₁ may be an effect of the composition of the sample which comprised a majority of deep curves and large overbites. The positive correlation between CD and overbite during treatment may be a consequence of their coincidental correction. The absence of any relationship between overbite and CD after treatment suggests that these

parameters are independent. This also applies to the relationship between overbite and LDP of the CS.

In this study none of the assessed cephalometric parameters was of any significance in predicting post-treatment changes of CD in the TLA group. Only CD at the end of treatment explained 26 per cent of the total variance of CD during T₂–T₃ in the TLA group. A deep curve at the end of treatment was associated with a decrease of CD post-

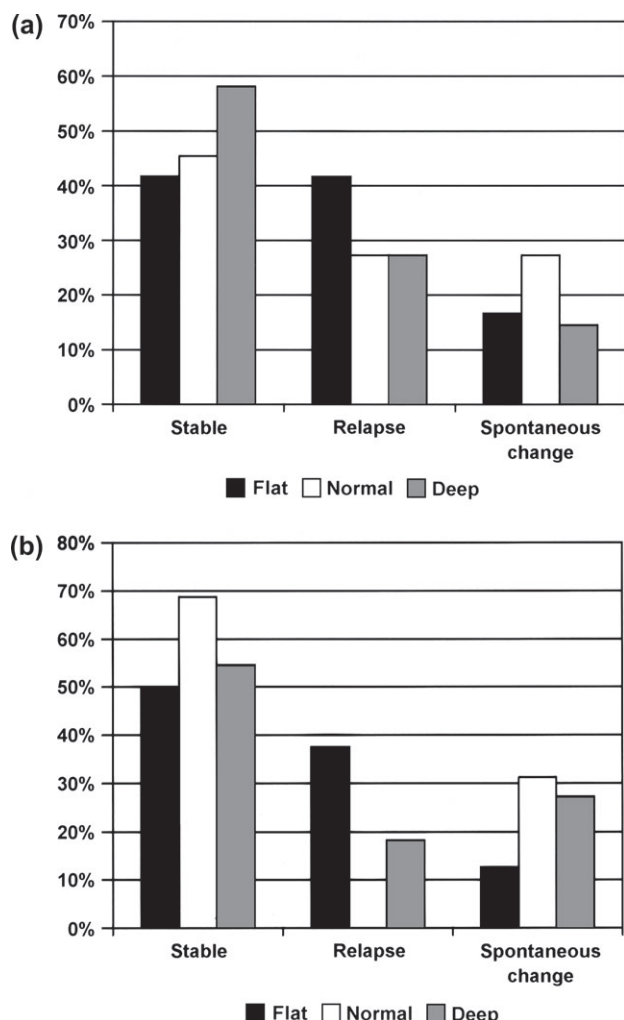


Figure 3 The percentages of flat, normal, and deep curves of Spee as identified pre-treatment, which remained stable, relapsed, or changed spontaneously during the post-treatment period (T2–T3) in (a) the treated and (b) untreated lower arch groups.

treatment. It seems that the post-treatment stability of CD depends in part on CD at the end of treatment and not on any dental or skeletal variables before or at the end of treatment. However, a large part of the variance in the post-treatment change in CD still remains unexplained by the variables used in this study. Other variables with potential influence on CD have been discussed in the literature. Baydas *et al.* (2004), studied the relationship between the CS and the position of the upper and lower incisors in patients before orthodontic treatment. The results showed that 22.6 per cent of the total variance of the curve could be explained largely by the overbite and to a smaller extent by the position of the lower incisors. Farella *et al.* (2002) found a relationship between the shape of the CS and the position of the mandibular condyle in relation to the occlusal plane, the position of the mandible with respect to the anterior cranial base, and the ratio between anterior and posterior face height. According to Osborn (1993), the CS

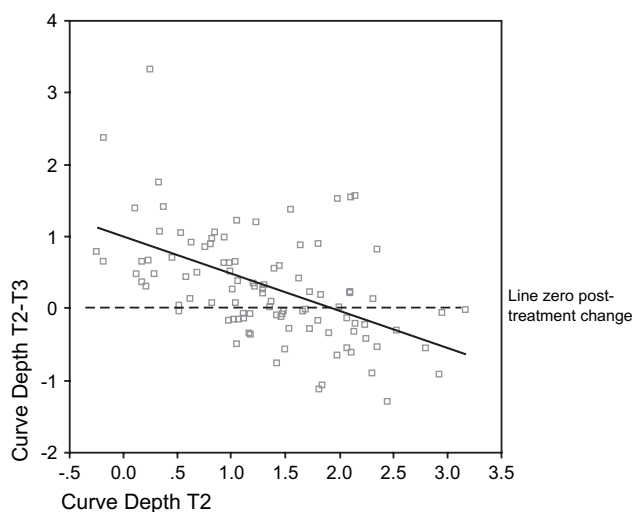


Figure 4 Scatter plot of the curve depth at the end of treatment (T2) and the change of curve depth during the post-treatment period (T2–T3) in the treated lower arch group.

has a biomechanical function as the increasing forward tilting of the posterior teeth in the vicinity of the masticatory muscles increases the crush–shear ratio exerted during mastication.

The intersection in the scatter plot between the regression line and the zero post-treatment change line (Figure 4) showed that the CD of 1.9 mm at the end of treatment was most stable afterwards. This would suggest that finishing treatment with a CD of 1.9 mm might result in higher stability. The existence of such an optimal CD of approximately 2 mm opposes levelling of the CS to a completely flat curve at the end of treatment in every case as suggested by Andrews (1972).

In the present investigation 47 per cent of the change of the LDP after treatment was explained by a combination of the variables LDP at the end of treatment, extraction in the lower arch, and position of the lower incisors at the end of treatment. More specifically, extraction treatment, more distal LDP of the curve, and proclination of the lower incisors at treatment end were associated with mesial post-treatment relocation of the deepest point. It seems that a relatively distal LDP of the curve and proclination of the lower incisors at the end of treatment is unfavourable for stability. Extractions in the lower arch also seem to affect long-term stability of the LDP.

Conclusions

The findings of the present study suggest that

1. Both the depth of the mandibular CS and the location of its deepest point after orthodontic treatment are frequently unstable and unexpected changes are relatively common.
2. Changing of flat curves during treatment leads most frequently to long-term instability of the CS.

3. More stability might be expected after relatively large levelling changes of deep curves during treatment, while there seems to be a tendency towards less stability and more spontaneous changes when treatment involves small changes.
4. The only predictor of the post-treatment CD change was the depth at the end of treatment; an end-of-treatment CD of approximately 2 mm seems to be associated with favourable long-term stability.
5. The predictors for the post-treatment change of the LDP were extractions in the lower arch, the LDP, and proclination of the lower incisors at the end of treatment.

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