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Longitudinal post-eruptive mandibular tooth movements of males and females

E. Watanabe[1,2], A. Demirjian[3] and P. Buschang[1]
[1]Department of Orthodontics & Center for Craniofacial Research and Diagnosis, Texas A&M University System—Baylor College of Dentistry, Dallas, TX, USA, [2]Department of Orthodontics, Nagasaki University School of Dentistry, Nagasaki, Japan and [3]Department of Stomatology, Faculté Medicine Dentaire, Université de Montreal, Québec, Canada

SUMMARY Unbiased estimates of post-eruptive eruption and migration of the mandibular teeth for large representative samples are presently unavailable. The purpose of this study was to evaluate pure tooth movements of untreated children and adolescents longitudinally. Lateral cephalograms of 214 French-Canadians, followed bi-annually between 8 and 15 years of age, were traced, and the positions of the mandibular permanent central incisors and first molars were digitized. Temporal changes in tooth position were evaluated relative to naturally stable mandibular reference structures, using the mandibular reference line for orientation. The statistical analyses included *t*-tests to assess gender differences and Pearson product-moment correlations to evaluate associations.

The results showed that the incisors proclined significantly more for males (6 degrees) than females (3 degrees). The incisor tips displayed early mesial movements that were countered by later distal movements. The incisor apex showed a consistent pattern of distal migration between 8 and 15 years. Mandibular arch length decreased over the 7-year observation period. Rates of mesial molar migration accelerated until 11 years of age and then decelerated. There was no significant change in the mandibular occlusal plane angle between 8 and 15 years of age. Incisor eruption showed the greatest rates during adolescence, attaining peaks at approximately 12 years for females and 14 years for males. The molars erupted approximately 5 mm between 8 and 15 years of age. The greatest gender differences occurred at the older ages, with males showing greater eruption potential than females.

It was concluded that the mandibular teeth show significant migration and eruption during childhood and adolescence, with gender differences in the amount, direction, and timing of movement.

Introduction

There is little longitudinal reference data available to guide dental professionals concerning tooth migration and eruption during childhood and adolescence. Such data would make it possible to better diagnose abnormal tooth movements (e.g. super eruption, impaction, ankylosis, eruptive failures, etc.), plan treatments (e.g. relative intrusion, extrusion, space maintenance, dental implants, etc.), and evaluate treatment effects (e.g. anchorage loss, extrusion, intrusion, etc.). Previous studies have traditionally evaluated tooth movements relative to skeletal reference structures that have been shown to model and remodel during growth.

Traditional views concerning migration are that the teeth tend to move mesially to close spaces created by the loss of teeth or tooth structure. This view has been supported by numerous extraction studies (Weber, 1969; Joondeph and Reidel, 1976; Stephens, 1983; Papandreas *et al.*, 1993), early tooth loss studies (Brauer, 1941; Northway *et al.*, 1984), normal tooth loss studies (Baume, 1950; Moorrees *et al.*, 1969), and investigations of inter-proximal tooth wear (Begg, 1954; Lysell, 1958). It suggests that, with the exception of early and late shifts associated with primate and leeway spaces, molars remain stable in contemporary populations showing little inter-proximal wear. It explains why arch depth remains stable between 8 and 12 years of age, decreases suddenly and dramatically when the deciduous molars are lost, and remains stable thereafter (Moorrees *et al.*, 1969; Moyers *et al.*, 1976). However, superimpositions on implants and stable reference structures indicate that movements of teeth, in addition to those associated with space closure, occur throughout growth (Björk and Skieller, 1972, 1977, 1983; Moyers *et al.*, 1976; McWhorter, 1992; Craig, 1995; Iseri and Solow, 1996). Similarly, the inclination of the central incisor, which remains stable relative to the mandibular plane (Riolo *et al.*, 1974), actually proclines relative to stable mandibular structures (Björk and Skieller, 1972; McWhorter, 1992; Craig, 1995).

Unless there is occlusal wear (Murphy, 1959; Manson, 1963), loss, or impaction of an antagonist (Compagnon and Woda, 1991), little or no eruption is thought to occur once the teeth have attained functional occlusion and prior to adolescence, the period of juvenile occlusal equilibrium (Steedle and Proffit, 1985; Darling and Levers, 1975). Eruption during adolescence has been associated with a growth spurt. Assuming that continued eruption is a compensatory mechanism for facial growth (Björk and Skieller, 1972), the rates of eruption should follow the general pattern of somatic growth. Riolo and co-workers (1974) showed that, relative to the mandibular plane, the molars and incisors erupt more or less regularly during childhood and adolescence. Actual eruptive patterns are confounded by substantial remodelling of the mandibular plane (Björk and Skieller, 1972, 1983). Although some data are available on tooth movements relative to stable reference structures during adolescence (Nielsen, 1989; Björk and Skieller, 1972; McWhorter, 1992), data on pre-adolescent eruption are limited to the maxilla (Iseri and Solow, 1996).

The purpose of this study was to evaluate post-eruptive movement of mandibular permanent incisors and first molars of untreated children and adolescents. It tests the hypotheses that (1) there are no gender differences in tooth migration or eruption, and (2) there are no relationships between tooth movements and incisor inclination, occlusal plane angulation, or arch depth.

Materials and methods

Samples

The data were derived from serial lateral cephalograms collected by the Human Growth Research Center, University of Montreal. They pertain to French-Canadian children, drawn from three school districts, representing the different socio-economic strata of the larger population (Demirjian *et al.*, 1971). The socio-economic status of families participating in the study showed no major bias compared with the general population (Baughan *et al.*, 1979). Within the districts, children were chosen at random from 107 schools, which were also chosen at random.

A mixed-longitudinal sample of 289 males and females 8–15 years of age was selected based on available and suitable serial records (Table 1). Of the 289 subjects, 28 per cent had complete longitudinal data (eight serial observations), and 75 per cent of the subjects had five or more longitudinal observations. All of the subjects were healthy with intact dentitions and had not previously received orthodontic treatment. In terms of dental occlusion 53 per cent of the subjects had Class I occlusions, 8 per cent were slightly Class II, and 37 per cent were either

Table 1 Number of subjects with serial data for the age interval indicated.

Age interval (years)	Males	Females	Total
8–10	60	63	123
9–11	59	54	113
10–12	108	101	209
11–13	111	103	214
12–14	110	100	210
13–15	110	80	190
8–15	52	39	91

Class II division 1 (29 per cent) or Class II division 2 (9 per cent).

Data collection and analysis

All cephalograms were traced and digitized by the same technician. The analyses described the eruption and migration of permanent mandibular teeth, including the tip and apex of the central incisor, and the mesial contact point of the first permanent molar. Technical reliability ranged between 97 and 99 per cent for the horizontal and vertical aspects of the three landmarks. Method errors ranged between 0.3 and 0.7 mm, with the apex showing the most error. The measurements were reduced to adjust for radiographic enlargement.

To describe tooth movements, each subject's serial radiographs were superimposed using natural mandibular reference structures (Björk and Skieller, 1983). The superimposition used orientated the radiographic tracing on: (1) the anterior contour or the chin; (2) the inner contour of the cortical plate at the lower border of the symphysis; (3) distinct trabecular structures in the symphysis; and (4) the contour of the mandibular canal. Reliability of the mandibular superimpositions ranged between 94 and 99 per cent (Buschang *et al.*, 1986).

The horizontal and vertical changes of each landmark were evaluated relative to the mandibular stable structure reference line, as described by Björk and Skieller (1983). Horizontal and vertical reference lines, drawn parallel and perpendicular with the mandibular plane of the first tracing, were transferred to subsequent tracings following superimpositioning and used for orientation (Figure 1). Positive changes of tooth position reflected superior and mesial movements; negative changes indicated inferior and distal movements. Changes in tooth position over 2-year intervals (e.g. 9–11, 10–12, etc.) were described as yearly rates (mm/year); absolute changes were reported between 8 and 15 years. Yearly rates of tooth movement were estimated at the mid-point of each age interval. The 2-year intervals were chosen to ensure a measurable effect that could be applied clinically. For comparisons of growth changes of less than 2 years, a constant rate of change must be assumed. For comparisons of yearly rates at the interval end-points, the average of the adjacent mid-point rates should be used.

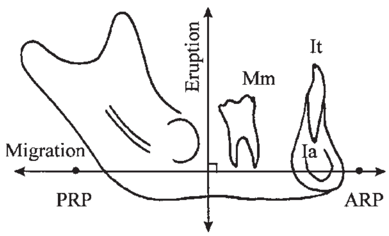

Figure 1 Cephalometric landmarks and reference lines: horizontal reference line connecting the anterior reference point (ARP) and posterior reference point (PRP), transferred after superimposition on stable anatomical structures. It, central incisor tip; Ia, central incisor apex; Mm, first molar mesial contact point.

Incisor inclination and occlusal plane angulation were computed relative to the horizontal reference line. Arch depth was computed as the linear distance between the incisor tip and mesial molar contact point. The curves describing tooth movements were drawn by connecting the average cumulated changes in the horizontal and vertical position of each landmark at each of the ages indicated.

Descriptive statistics

The skewness and kurtosis of each variable were normal. Independent *t*-tests were conducted to evaluate sexual dimorphism. Paired *t*-tests were used to evaluate differences between incisor and molar movements. Pearson product moment correlations were used to evaluate the relationships between mandibular tooth movements and changes of incisor inclination, occlusal plane angulation, and arch depth.

Results

Table 2 shows changes of incisor inclination, occlusal plane angulation, and mandibular arch depth between 8 and 15 years of age. Incisor proclination was approximately twice as great in males as in females (5.9 versus 3.3 degrees). The

Table 2 Changes of incisor inclination, occlusal plane angulation, and arch depth between 8 and 15 years of age.

	Males			Females			
	Mean	SD	SE	Mean	SD	SE	P-value
Incisor inclination (°)	5.87	4.12	0.61	3.25	6.06	0.98	0.027
Occlusal plane (°)	–0.15	4.20	0.69	1.28	3.65	0.82	0.205
Arch depth (mm)	–1.51	1.87	0.31	–1.60	0.96	0.23	0.797

Table 3 Annual rates of eruption and migration of the mandibular incisor tip between 8 and 15 years of age.[1]

Age interval (years)		Males			Females			
	Scale	Mean	SD	SE	Mean	SD	SE	P-value
Eruption								
8–10	mm/year	0.68	0.37	0.05	0.63	0.31	0.04	0.41
9–11	mm/year	0.58	0.33	0.04	0.43	0.27	0.04	0.01
10–12	mm/year	0.50	0.31	0.03	0.53	0.35	0.04	0.59
11–13	mm/year	0.64	0.41	0.04	0.56	0.31	0.03	0.01
12–14	mm/year	0.88	0.42	0.04	0.54	0.31	0.03	<0.01
13–15	mm/year	0.99	0.40	0.04	0.40	0.26	0.03	<0.01
8–15	mm	5.04	1.43	0.20	3.73	1.00	0.16	<0.01
Migration								
8–10	mm/year	0.16	0.53	0.07	0.21	0.46	0.06	0.56
9–11	mm/year	0.14	0.48	0.06	0.06	0.53	0.07	0.44
10–12	mm/year	0.18	0.48	0.05	–0.12	0.54	0.05	<0.01
11–13	mm/year	0.09	0.47	0.04	–0.31	0.51	0.05	<0.01
12–14	mm/year	–0.07	0.59	0.06	–0.23	0.62	0.06	0.05
13–15	mm/year	–0.31	0.57	0.05	–0.11	0.53	0.06	0.02
8–15	mm	0.33	1.89	0.26	–0.58	2.20	0.35	0.04

[1]Positive changes of tooth position reflect superior and mesial movements; negative changes indicate inferior and distal movements. Yearly rates of tooth movement were estimated at the mid-point of each age interval. For comparisons of yearly rates at the interval end-points, the average of the adjacent mid-point rates should be used.

occlusal plane showed no significant changes over the 7-year period. Arch depth decreased 1.5 mm in males and 1.6 mm in females.

The incisor tip erupted 3.7 and 5.0 mm for females and males, respectively, between 8 and 15 years of age (Table 3, Figure 2). Yearly rates of eruption decreased during childhood and were smallest at approximately 10 and 11 years of age for females (0.4 mm/year) and males (0.5 mm/year), respectively. Female rates of eruption increased during early adolescence, attained peak velocity (0.6 mm/year) at approximately 12 years of age, and then decelerated. Male eruption rates increased 0.5 mm between 11 and 14 years of age. Males showed significantly greater rates of eruption than females after 12 years of age.

Migration of the incisor tip between 8 and 15 years was not statistically significant because mesial movements during childhood were followed by distal movements during adolescence. With the exception of the changes between 12 and

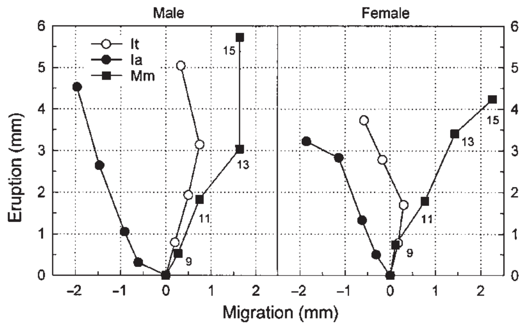

Figure 2 Cumulative eruption and migration paths of the mandibular incisor tip (It), apex (Ia), and molar mesial contact point (Mm), from 8 years of age to 9, 11, 13, and 15 years.

14 years for males, and between 9 and 11 years for females, the bi-annual changes were statistically significant. The transition from mesial to distal migration occurred at approximately 12.5 years for males and 10.5 years for females. Gender differences in migration were not significant before 11 years of age.

With the exception of the youngest ages, the incisor apex followed the same pattern of eruption as the incisor tip (Table 4, Figure 2). Between 8 and 10 years of age, the apex showed 0–0.3 mm/year of superior movement. Rates increased to approximately 0.4 mm/year between 9 and 11 years, after which time they closely followed the pattern previously described for the tip. Maximum rates of eruption were attained at approximately 14 and 12 years for males and females, respectively. Males showed significantly more eruption of the apex than females during the adolescent years.

The incisor apex showed a consistent pattern of distal migration between 8 and 15 years of age. Rates of distal movement were greatest between 8–10 and 11–13 years of age. Approximately 2 mm of distal movement occurred between 8 and 15 years of age. With the exception of the earliest (8–10) and latest (13–15) age groupings, there were no significant gender differences in migration.

The mandibular molar erupted 5.7 and 4.2 mm between 8 and 15 years of age for males and females, respectively (Table 5, Figure 2). For males, rates steadily increased from 0.6 mm/year

Table 4 Annual rates of eruption and migration of the mandibular incisor apex between 8 and 15 years of age.[1]

Age interval (years)	Scale	Males			Females			
		Mean	SD	SE	Mean	SD	SE	*P*-value
Eruption								
8–10	mm/year	–0.02	0.76	0.10	0.26	0.63	0.08	0.03
9–11	mm/year	0.36	0.77	0.10	0.44	0.61	0.08	0.57
10–12	mm/year	0.52	0.58	0.06	0.59	0.61	0.06	0.39
11–13	mm/year	0.63	0.70	0.07	0.60	0.52	0.05	0.74
12–14	mm/year	0.84	0.75	0.07	0.50	0.68	0.07	<0.01
13–15	mm/year	1.02	0.65	0.06	0.47	0.56	0.06	<0.01
8–15	mm	4.53	1.77	0.25	3.22	1.79	0.29	<0.01
Migration								
8–10	mm/year	–0.49	0.47	0.06	–0.28	0.40	0.05	0.01
9–11	mm/year	–0.19	0.41	0.06	–0.14	0.38	0.05	0.52
10–12	mm/year	–0.24	0.38	0.04	–0.22	0.40	0.04	0.71
11–13	mm/year	–0.27	0.44	0.04	–0.31	0.39	0.04	0.52
12–14	mm/year	–0.31	0.41	0.04	–0.26	0.41	0.04	0.43
13–15	mm/year	–0.27	0.45	0.04	–0.10	0.38	0.04	0.01
8–15	mm	–1.97	1.06	0.15	–1.86	1.28	0.21	0.67

[1]Positive changes of tooth position reflect superior and mesial movements; negative changes indicate inferior and distal movements. Yearly rates of tooth movement were estimated at the mid-point of each age interval. For comparisons of yearly rates at the interval end-points, the average of the adjacent mid-point rates should be used.

Table 5 Annual rates of eruption and migration of the mandibular molar mesial contact point between 8 and 15 years of age.[1]

Age interval (years)	Scale	Males			Females			
		Mean	SD	SE	Mean	SD	SE	P-value
Eruption								
8–10	mm/year	0.59	0.64	0.09	0.60	0.50	0.07	0.91
9–11	mm/year	0.67	0.56	0.08	0.44	0.54	0.08	0.05
10–12	mm/year	0.68	0.53	0.06	0.67	0.60	0.07	0.88
11–13	mm/year	0.72	0.55	0.06	0.73	0.64	0.08	0.85
12–14	mm/year	1.02	0.56	0.06	0.80	0.66	0.09	0.04
13–15	mm/year	1.18	0.47	0.05	0.62	0.47	0.08	<0.01
8–15	mm	5.73	1.73	0.28	4.24	1.65	0.37	<0.01
Migration								
8–10	mm/year	0.21	0.32	0.05	0.18	0.47	0.06	0.72
9–11	mm/year	0.25	0.50	0.07	0.35	0.46	0.07	0.32
10–12	mm/year	0.43	0.52	0.05	0.43	0.54	0.07	0.96
11–13	mm/year	0.38	0.57	0.06	0.28	0.44	0.06	0.27
12–14	mm/year	0.21	0.64	0.07	0.35	0.40	0.06	0.12
13–15	mm/year	0.05	0.45	0.05	0.26	0.45	0.07	0.02
8–15	mm	1.64	1.61	0.26	2.26	1.25	0.29	0.15

[1]Positive changes of tooth position reflect superior and mesial movements; negative changes indicate inferior and distal movements. Yearly rates of tooth movement were estimated at the mid-point of each age interval. For comparisons of yearly rates at the interval end-points, the average of the adjacent mid-point rates should be used.

Table 6 Correlations between tooth movements and changes in incisor inclination, occlusal plane angulation and arch depth between 8 and 15 years of age.

	Migration			Eruption		
	It	Ia	Mm	It	Ia	Mm
Incisor inclination	0.82**	NS	0.41**	NS	NS	NS
Occlusal plane	–0.47**	–0.34*	NS	NS	NS	–0.52**
Arch depth	0.53**	NS	–0.36**	NS	NS	NS

*$P < 0.05$; **$P < 0.01$.
It, central incisor tip; Ia, central incisor apex; Mm, first molar mesial contact point; NS, not significant.

between 8 and 10 years to 1.2 mm/year between 13–15 years of age. Rates of eruption for females decreased slightly during childhood, and then increased to 0.8 mm/year between 12–14 years of age, after which they again decreased. Overall, males showed significantly greater eruption (approximately 1.5 mm) than females, with the greatest differences occurring at the older ages.

The molars migrated mesially approximately 1.6–2.3 mm between 8 and 15 years of age. Rates increased from 0.2 mm/year between 8 and 10 years to 0.4 mm/year between 10–12 years, and then decreased. Rate decreases were greater for males than females, resulting in significantly less mesial migration for males between 13–15 years.

Pearson product-moment correlations showed that incisor proclination was related primarily with mesial movements of the incisor tip and secondarily with mesial molar movements (Table 6); partial correlations showed no significant correlation with molar migration once incisor movements had been controlled for. Changes in the occlusal plane angle were related to incisor migration and molar eruption; greater amounts of molar eruption and mesial incisor migration resulted in decreases in occlusal plane angulation. Incisor eruption was not related to occlusal plane changes. As expected, mandibular arch length decreases were related to distal incisor and mesial molar migration.

Discussion

This study goes beyond the existing literature by describing mixed-longitudinal changes based on large samples of boys and girls followed over an extended age span. Most importantly, it provides unbiased estimates of tooth movements based on stable mandibular reference structures. The results showed that the incisors proclined 3.2 degrees for females and 5.9 degrees for males between 8 and 15 years. Little or no change of incisal inclination relative to the mandible plane has been previously reported over similar time periods (Riolo *et al.*, 1974; Perera, 1987). The differences can be explained by the use of stable mandibular reference structures, rather than the mandibular plane, which remodels substantially between 8 and 15 years of age (Björk, 1968, 1969; Björk and Skieller, 1972, 1983). Implant studies have shown that mandibular plane remodelling depends largely on the individual's rotational patterns, with forward rotators showing apposition anteriorly and resorption posteriorly (Björk, 1955, 1963, 1968; Björk and Skieller 1972; Lavergne and Gasson, 1976). Spady *et al.* (1992) have shown that French-Canadians typically undergo approximately 5 degrees forward mandibular true rotation between 6 and 15 years of age, which is masked by the remodelling that occurs, suggesting little or no incisor proclination relative to the mandibular plane. Relative to mandibular implants, Björk and Skieller (1972) reported 1.5 degrees of incisor proclination for a smaller sample during adolescence, which was negatively correlated ($R = -0.7$) with true mandibular rotation. Since French-Canadians showed significantly greater forward rotation during childhood than adolescence (Spady *et al.*, 1992), greater proclination might also be expected during childhood than adolescence. Furthermore, the results show that the inclination changes were related with migration of the incisor tip only, indicating dentoalveolar compensation with changes in the soft tissue environment (Solow, 1980).

The incisor tip and apex showed distinctly different migration patterns. The incisor tip migrated mesially until the initiation of adolescence (Buschang *et al.*, 1988), 10 and 12 years of age for females and males, respectively, and then moved distally. In contrast, the incisor apex showed a consistent pattern of distal migration between 8 and 15 years. The distal migration of the apex closely follows symphyseal remodelling patterns. Buschang and co-workers (1992) showed that chin development between 7 and 15 years of age was primarily due to lingual drift of the upper symphysis, with the greatest apposition of bone occurring on the lingual symphyseal surface at the approximate location of the incisor apex. Masticatory forces during incision may be causing a clockwise moment of force, which is compensated for by bony deposition on the lingual symphyseal surface (Hylander, 1984). Resorption of the anterior alveolus as the mandibular incisor erupts has also been reported relative to mandibular implants (Baumrind *et al.*, 1992).

Arch depth decreased by 1.5–1.6 mm over the 7-year period, which compares well with previously reported changes (Moorrees *et al.*, 1969; Riolo *et al.*, 1974). Arch depths decreased somewhat less than reported by Moyers *et al.* (1976), which may be due to their measurement methodology or changes in their sample composition between 8 and 15 years of age. Changes in arch depth were related to both incisor and molar migration. Rates of mesial molar migration increased until 11 years of age and then decreased; the rate changes may be due to loss of the second deciduous molars, which normally occurs between 11 and 12 years of age (Riolo *et al.*, 1974; Demirjian and Levesque, 1980). Even though the incisors showed little or no average movement, changes in arch depth were more closely related to incisor than molar migration, suggesting that individual differences in arch length changes may be affected more by rotation and anterior soft tissues than occlusal development.

The mandibular occlusal plane showed no significant angular changes between 8 and 15 years, even though the molars erupted slightly (0.4–0.7 mm) more than the incisors. Over a similar time period, Riolo and co-workers (1974) showed that the incisors erupted 0.4–1.1 mm more than the molars relative to the mandibular plane, differences which can again be explained by mandibular remodelling. Furthermore, our results indicate that normal decreases in occlusal plane to cranial base angulation (Riolo *et al.*, 1974) are due to mandibular rotation rather than differential tooth eruption. They also support greater maxillary molar than incisor eruption (Riolo *et al.*, 1974; Nielsen, 1989; McWhorter, 1992; Craig, 1995). The correlations show that occlusal plane changes were related to molar eruption and, unexpectedly, incisor migration rather than eruption. In other words, individuals with the greatest decrease in the occlusal plane did not show the greatest incisor eruption, although they did show more mesial incisor movements.

Incisor and molar eruption followed the somatic pattern, with the greatest potential during adolescence and males having a greater potential than females. Both the incisor tip and apex showed an eruptive peak at 12 years for females and 14 years for males, which corresponds to the samples' peak mandibular growth (Buschang *et al.*, 1988). Greater amounts of vertical eruption during adolescence than childhood have been demonstrated previously (Riolo *et al.*, 1974). Sex differences in vertical eruption favouring males have also been previously shown (Riolo *et al.*, 1974; McWhorter, 1992).

The incisor tip showed significantly greater eruption than the apex during the earlier years (8–11), which was probably related to root development. The incisors tend to finish root development at approximately 9.6 years for males and 9.2 years for females (Dermirjian and Levesque, 1980). Riolo and co-workers (1974) also showed that the central incisor continues to increase its length until 9–10 years of age.

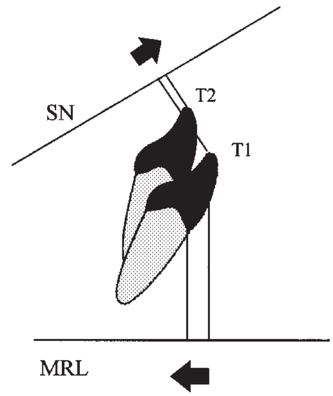

Figure 3 Effects of orientation on incisor proclination. Incisor tip migrated mesially relative to SN plane and distally relative to the mandibular reference line (MRL).

Finally, the orientation used to describe tooth movements must be considered when interpreting the results. Mandibular tooth movements have previously been orientated relative to the occlusal plane (Smith, 1980; Perera, 1987), the mandibular plane (Carlson, 1944; Riolo *et al.*, 1974; Feasby, 1981), and the Frankfort horizontal plane (McWhorter, 1992; Craig, 1995). The present study orientated movements relative to Björk's mandibular reference line, which parallels the mandibular plane. Had the anterior cranial base (sella–nasion) been used for orientation, more mesial migration of the molars and mesial, rather than distal, migration of the incisors might have been expected (Figure 3). The mandibular reference line was chosen because it is commonly used for superimposition, and it serves as an appropriate and stable orientation for tooth movements.

Address for correspondence

Peter H. Buschang
Department of Orthodontics and Center for Craniofacial Research and Diagnosis
Texas A&M University System—Baylor College of Dentistry
3302 Gaston Avenue
Dallas
TX 75243, USA

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