Age-Associated Changes of the Mandibular Foramen Position in Anteroposterior Dimension and of the Mandibular Angle in Dry Human Mandibles

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ABSTRACT

The effect of age on the anteroposterior (A-P) position of the mandibular foramen (MF) and on the size of the gonial angle (GA) was evaluated in this study. From an Israeli Bedouin population, 121 dry mandibles with primary (36), mixed (26), and permanent dentitions (59) were analyzed. The A-P position of the MF perpendicular to the posterior border of the ramus was measured with a digital caliper. A mandibulometer was used to evaluate the GA. The MF distance from the posterior border of the ramus increased significantly with age by 66% from primary (7.75 mm) to permanent (12.9 mm; $P < 0.001$). Similarly, the MF distance from the posterior border of the ramus relative to the total ramus width in A-P dimension increased significantly (21.4%) with altered dentitions from primary (0.28) to late permanent dentition (0.34; $P < 0.001$). The GA decreased significantly with age from $140.17^\circ \pm 5.9^\circ$ (primary dentition) to $123.61^\circ \pm 6.9^\circ$ (late permanent dentition; $P < 0.001$). The anterior movement of the MF and the decreased size of the GA that occurred with changing dentition were related to growth process. The MF moves anteriorly, and the GA decreases with age. Anat Rec, 294:1319–1325, 2011. © 2011 Wiley-Liss, Inc.

Key words: gonial angle; children; mandibular block; scalp; horizontal

The most routinely used procedure for anesthetizing mandibular molars is the inferior alveolar nerve block (mandibular block), with a success rate of only 63%–87% (Kaufman et al., 1984; Childers et al., 1996). To increase the effectiveness of the mandibular block, the local anesthetic solution should be injected as close as possible to the mandibular foramen (MF). It is agreed that the MF moves superiorly with age. At 4–5 years, the MF is located under the occlusal plane; at 6 years, it is located at the level of the occlusal plane or slightly above; and it moves superiorly above the occlusal plane by 13 years (Lampshire, 1947; Shiere, 1950; Olsen, 1956; O'mullane,

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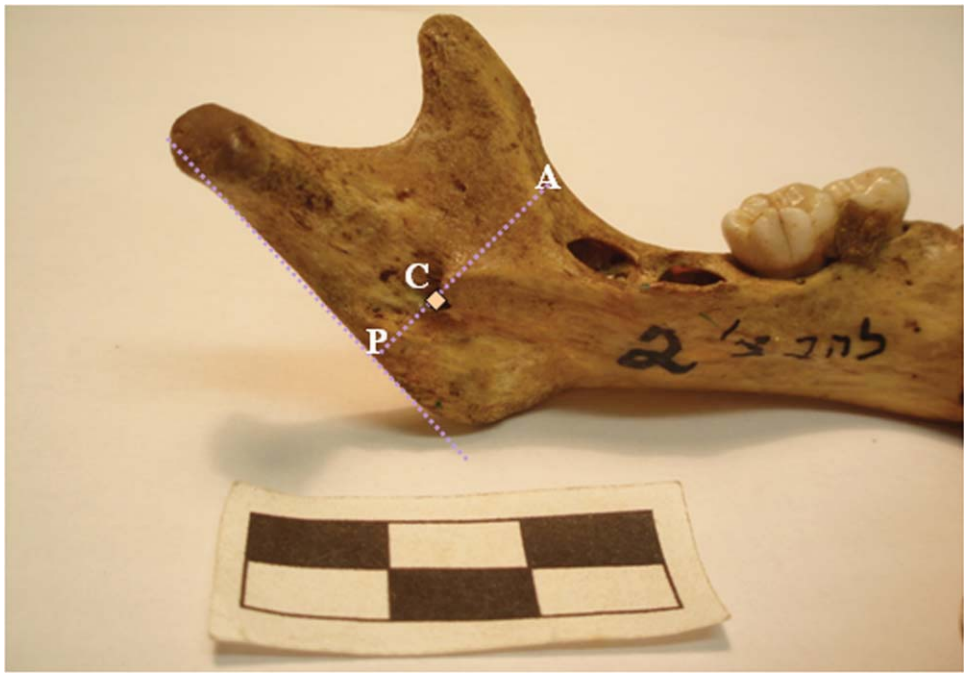


Fig. 1. A drawing demonstrating the determination of the position of the mandibular foramen (MF) at anterior-posterior (A-P) dimension. The position of the MF was determined by drawing a perpendicular line from the MF to the tangent of the posterior border of the ramus (AP line). The mid A-P dimension of the MF on the AP line was determined as point C.

1971; Benham, 1976; McDonald et al., 2004; Kanno et al., 2005; Pinkham et al., 2005). However, researchers disagree the exact location of the MF in the anteroposterior (A-P) dimension. Approximately one-half of the adult studies show that the MF is located posterior to the mid-line of the ramus (Hayward et al., 1977; Hetson et al., 1988; da Fontoura et al., 2002; Fujimura et al., 2006) and at the mid-line of the ramus in the other half (Sweet, 1943; Monheim, 1969; Weiss, 1972; Ricketts, 1975; Nicholson, 1985). In contrast, there is no available information regarding the positional changes of the MF in the A-P dimension in growing children. McDonald et al. (2004) recommend the injection of the mandibular block more posteriorly in children than in adults. Pinkham et al. (2005) mentions that the MF is located at the mid-line of the ramus and alters with age, but this alteration is not described. Evaluation of the altered MF location in the A-P dimension with age has been found in only three studies. In one (Benham, 1976), cephalometric radiographs revealed that in Americans the percent dept of the MF from the anterior to posterior on the ramus is not altered significantly with age. Harrison (1948) concluded from measurements of several anatomic landmarks in developing and adults' mandibles that it is a mistake to rely on any technique for an inferior alveolar injection that depends on fixed measurements for obtaining either the correct insertion point or the depth to which the needle is to pass in order to reach the sulcus. In contrast, Tsai (2004, 2002) concluded that in the Taiwanese population, the MF moves anteriorly with age concomitantly with the decreasing size of the gonial angle (GA) and hypothesized that the change in the MF position with age results from bone apposition in the posterior border of the ramus, and the decrease in the GA results from functional forces exerted from the masseter and medial pterygoid muscles. Anatomic structures evaluated with cephalometric or panoramic radiographs have been found to be inaccurate (Tronje et al., 1981; McDavid et al., 1985; Tronje et al., 1985; Kaffe et al., 1994). Harrison (1948) described neither how the posterior border was determined nor how the total A-P width of the rami was measured. Only the distance of the lingula from the internal oblique line was measured but not from the anterior border of the ramus.

The objectives of this study, which was conducted in Israel, were to determine the location of the MF in A-P dimension in primary, mixed, and permanent dentitions in dry mandibles and to correlate these changes to the size of the GA.

METHODS

The study included 121 dry mandibles from Israeli Bedouins that were obtained from the collection of the Department of Anatomy, Faculty of Medicine, Tel Aviv University. This population was considered to represent the general mean of a modern human population (Rosenberg et al., 1983). Mandibles included 36 with primary dentition (stage 1), 26 with mixed dentition (stage 2), 21 with early permanent dentition (only second permanent molars erupted, stage 3), and 38 with late permanent dentition (permanent third molars erupted, stage 4). Mandibles with extensive attrition or without permanent third molars were excluded. No information was available regarding the sex of the studied population. Because of the great amount of error in attempting sex

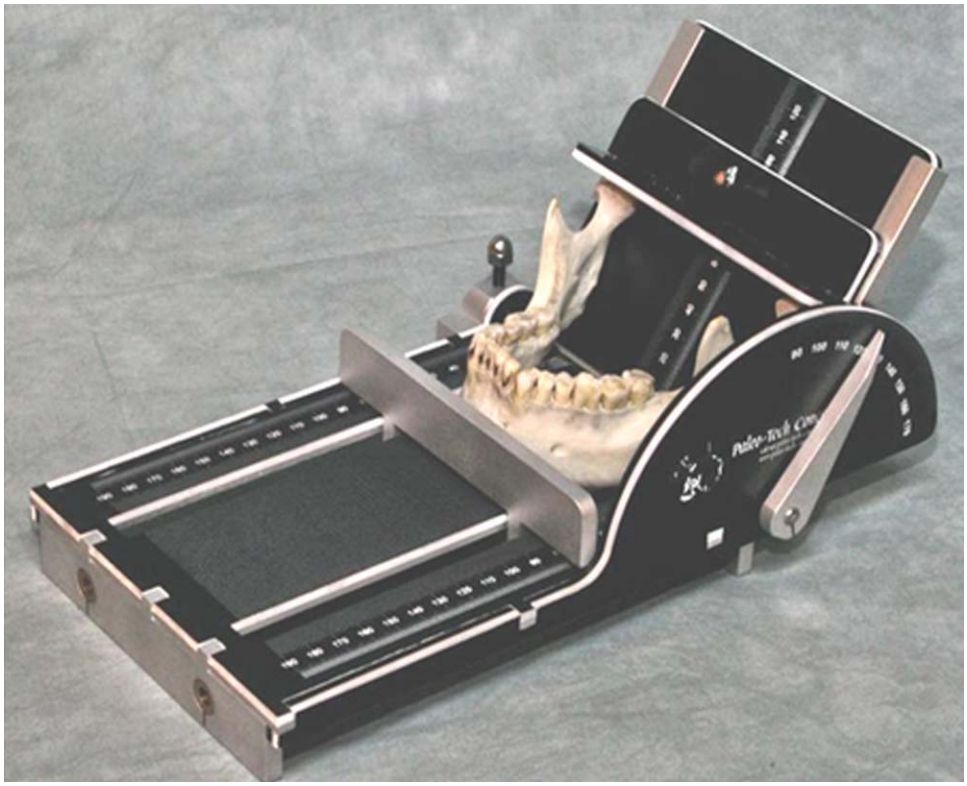


Fig. 2. Paleo-Tech Mandibulometer.

TABLE 1. Dimensions of various measurements in the anterioposterior aspect of the ramus according to different developmental stages of the dentition (in mm)

		AP (mm)[a]		AC (mm)[b]		PC (mm)[c]		MF (mm)[d]		PC- (MF /2)[c,d]	
Stage of dent	N	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
1	36	22.48	2.06	14.73	1.25	7.74	1.32	2.97	0.62	6.26	1.31
2	26	28.23	2.54	17.73	1.75	10.49	1.56	3.59	0.59	8.69	1.70
3	21	30.18	2.93	18.88	1.90	11.30	1.66	3.76	0.65	9.41	1.69
4	38	32.01	2.67	19.15	1.94	12.86	1.70	4.16	0.82	10.77	1.65
ANOVA		$P < 0.001$		$P < 0.001$		$P < 0.001$		$P < 0.001$		$P < 0.001$	
Tukey		$4 \neq 3 \neq 2 \neq 1$		4, $3 \neq 2 \neq 1$		$4 \neq 3,2 \neq 1$		2,3,4 $\neq$ 1 and 3,4 $\neq$ 2,		$4 \neq 3,2 \neq 1$	

[a]AP, Anterior posterior width of the ramus.
[b]AC, Anterior border to mid mandibular foramen width.
[c]PC, Posterior border to mid mandibular foramen width.
[d]MF, Anterior posterior width of the mandibular foramen.

determination, it was decided not to differentiate the skulls by sex (Weiss, 1972). No signs of hypoplasia or other developmental defects related to stress during development were noticed in the studied sample.

The A-P position of the MF on the ramus was determined by drawing a perpendicular line from the MF to the tangent of the posterior border of the ramus (AP line) as described by Fujimura et al. (2006). The distance of the foramen from the posterior (P) and anterior (A) border was measured on the left side of the mandible using a digital caliper (Mitutoyo America, Aurora, IL; level of accuracy = 0.01 mm; Fig. 1). The A-P diameter of the MF on this perpendicular line was also determined. The mid-A-P dimension of the MF on the AP line was determined as point C. To describe the location of the MF in A-P position at different stages of development, the A-P dimension was divided to equal four A-P quarters. The most anterior was the first A-P quarter and the most posterior was the forth A-P quarter. All measurements were taken on the left side of the mandibles (Bass, 1987). Additional measurements included: the distance of the posterior edge of the ramus from the posterior border of the MF (distance between posterior edge to mid MF width minus half anterior-posterior width of the MF (PC-[MF/2], posterior distance), and the relation of the posterior distance to the total width of

TABLE 2. Size of the gonial angle and relation between the posterior ramus and the total anteroposterior dimension of the ramus according to different developmental stages of the dentition

Stage of Dentition	N	(PC-[MF/2])/AP[a]		PC/AP[a]		Size of GA[b]	
		Mean	SD	Mean	SD	Mean	SD
1	36	0.2768	0.0434	0.3431	0.0378	140.16	5.94
2	26	0.3066	0.0424	0.3711	0.0383	128.69	6.47
3	21	0.3111	0.0883	0.3737	0.0339	128.23	6.14
4	38	0.3363	0.0074	0.4016	0.0391	123.60	6.91
ANOVA		$P < 0.001$		$P < 0.001$		$P < 0.001$	
Tukey		2,3,4≠1 and 4≠2		1≠2, 3≠4		1≠2, 3≠4	

[a]PC, Posterior border to mid mandibular foramen width; AP, Anterior posterior width of the ramus; MF, Anterior posterior width of the mandibular foramen.
[b]GA, Gonial angle.

TABLE 3. Pearson correlation tests

	GA[a]	{PC-(MF/2)}/AP[b]	PC/AP[b]
GA		$r = -0.485$ $P < 0.001$	$r = -0.514$ $P < 0.001$
{PC-(MF/2)}/AP	$r = -0.485$ $P < 0.001$		$r = -0.966$ $P < 0.001$
PC/AP	$r = -0.514$ $P < 0.001$	$r = -0.966$ $P < 0.001$	

[a]GA, Gonial angle.
[b]PC, Posterior border to mid mandibular foramen width; MF, Anterior posterior width of the mandibular foramen; AP, Anterior posterior width of the ramus.

the ramus (PC/AP and [PC-(MF/2] divided by AP). To evaluate the distribution of the satellite foramina of the mandible on the ramus, the ramus was divided into four quadrants: superior-anterior, superior-posterior, inferior-anterior, and inferior-posterior. This was determined by drawing a perpendicular line at the mid AP line. In addition, to evaluate the alteration in the anterior-posterior position of the MF with age, the AP distance was divided equally to four quarters anterior-posteriorly. A Paleo-Tech Mandibulometer (Crystal Lake, IL) was used to evaluate the GA. The mandible was placed on the mandibulometer where the condyle, the base of the mandible, and a point on the ramus were in contact with the device (Fig. 2).

Intraexaminer Reliability

In 10 mandibles, all parameters were measured twice in a 2-month interval to determine intraexaminer reliability (LT).

Statistical Analysis

Differences between measurement variables (in the group and between groups) were calculated by one-way ANOVA. Tukey's method for multiple comparisons was performed to determine the difference between groups. Intraclass correlation coefficient was performed to determine the intrarater variability. The correlation between the relative position of the MF and the size of the GA was analyzed for all the mandibles and also was analyzed separately for each of the four different stages of dental development.

RESULTS

Mandibular Growth in A-P Dimension

The size of the ramus (AP), the posterior (PC) and anterior (AC) ramus, and the MF significantly increased in A-P dimension concomitantly with the dental development ($P < 0.001$; Table 1). A-P dimension of the ramus was increased by 42% ($P < 0.001$), the posterior by 66.2% ($P < 0.001$), the anterior by 30% ($P < 0.001$), and the A-P diameter of the MF by 40.1% ($P < 0.001$). However, the timing of the growth spurts of the A-P rami relative to changing dentition was not identical. For example, the A-P dimension of the ramus increased significantly in all four stages of dental development (stages 1–4). The growth spurts of the AC of the ramus occurred at stages 1–3 and the PC between stages 1 and 2 and between stages 3 and 4.

Growth of the PC of the Ramus in A-P Dimension

The distance of the MF from the posterior border of the ramus (PC) increased significantly by 66.2% with age, from 7.74 mm in primary dentition to 12.86 mm in late permanent dentition ($P < 0.001$; Table 2, Fig. 1). This finding was similar when the anterior border of the posterior ramus was determined as the mid-point of the MF (PC-[MF/2]) or at the posterior border of the MF (PC). Moreover, the posterior ramus increased significantly relative to the total width of the ramus (PC/AP) from 0.34 in primary dentition to 0.40 in late permanent dentition ($P < 0.001$). The growth spurts of the posterior ramus mainly occurred between stages 1 and 2 and between stages 3 and 4.

Altered Location and MF Size with Growth

The size of the MF increased by 40% with changing dentition from 2.97 ± 0.62 mm in primary dentition to 4.16 ± 0.82 mm in late permanent dentition ($P < 0.001$; Table 1). The distance of the posterior border of the MF from the posterior border of the ramus increased with age from 6.26 mm in primary dentition to 10.77 mm in late permanent dentition ($P < 0.001$). As dentition developed, the MF moved anteriorly. As a result, the posterior border of the MF was located at the posterior half of the third quarter in anterior-posterior dimension in children with primary dentition and at the anterior half of the third quarter (A-P) in adults (permanent dentition). A

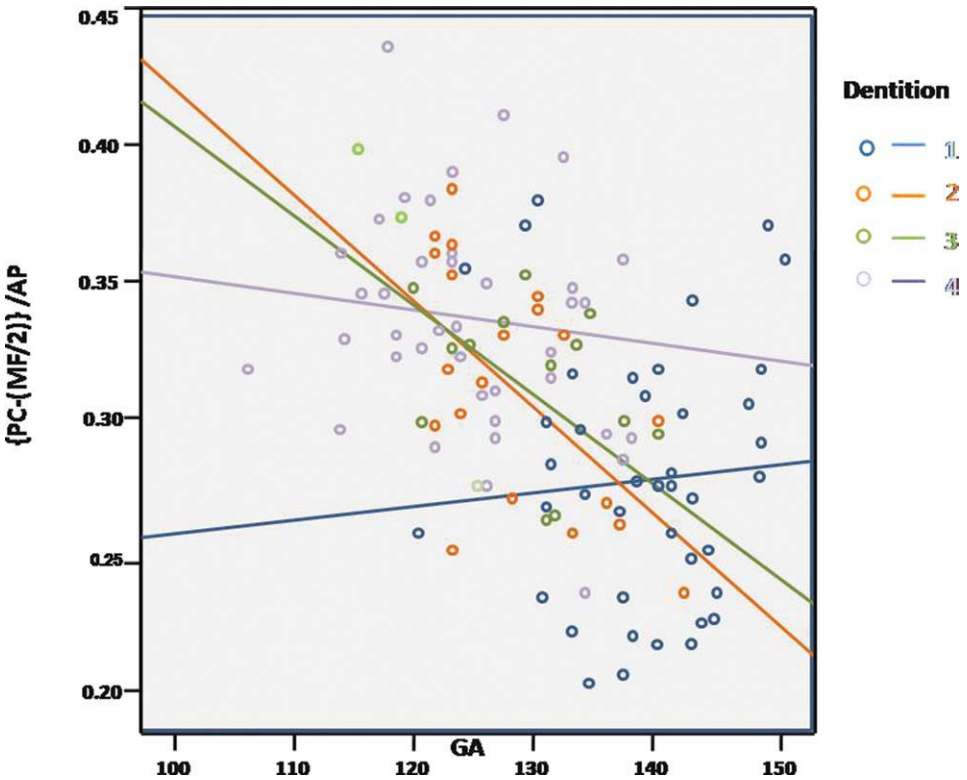


Fig. 3. Correlation between the anterior movement of the mandibular foramen (MF) and the decrease in the gonial angle in each dentition stage.

TABLE 4. Intrarater variability

Parameter	Intraclass correlation	95% confidence Interval	
		Low border	High border
AP	1.000	0.998	1.000
PC	0.999	0.995	1.000
AC	0.995	0.981	0.999
MF	0.994	0.975	0.998
GA	0.995	0.981	0.999

number of satellite foramina increased with age from an average of 2.5 in primary dentition to 3.3 in mixed and 3.4 in permanent dentitions and were located at the anterior-superior quadrant (45%–51%), the superior-posterior quadrant (21%–24%), the inferior-posterior quadrant (22%–27%), and the inferior-anterior quadrant (only 1%–6%) of the ramus.

Effect of Growth on the Size of the GA

The GA decreased significantly by 11.8% with changing dentition from 140.16° ± 5.94° in primary dentition to 123.6° ± 6.91° in late permanent dentition (stage 4, $P < 0.001$; Table 3). Similar to the growth spurts of the posterior ramus relative to the total A-P dimension of the ramus, the main decrease occurred between the primary and mixed dentitions (stages 1 and 2) and between the early permanent to late permanent dentitions (stages 3 and 4, $P < 0.001$). The decrease in the size of the GA was negatively correlated to the increase dimension of the posterior ramus ($r = -0.49$; $P < 0.001$) and to the increase in the relation between the posterior ramus and the total A-P dimension of the ramus ($r = -0.51$; $P < 0.001$). To further verify whether the decrease occurs with changing dentition due to the change in the location of the MF or to the growth, Pearson's correlation analysis was performed between the two variables (anterior movement of the MF and the decrease in the GA). A significant correlation was found between anterior movement of the MF and the decrease in the GA only during stages 2 ($r = -0.573$; $P = 0.002$) and 3 ($r = -0.530$; $P = 0.013$) of the dentitions in which there was the highest growth spurt but not during stages 1 ($r = 0.069$; $P = 0.691$) and 4 ($r = -0.110$; $P = 0.511$) of the dentitions in which there was no growth spurt (Fig. 3).

Intraexaminer reliability

The range of the intraclass correlation coefficient was 0.994–1.00, and the range of the 95% confidence interval was 0.975–1.00 for all the various measurements (Table 4).

DISCUSSION

It is essential for the practitioner to know the precise location of the MF on the ramus to achieve effective mandibular block anesthesia in children and in adults. As bone remodeling changes the MF position over

ontology, the optimal location for administrating mandibular block anesthesia should vary by the growth stages.

In this study, the posterior border of the MF was located at the posterior half of the third quarter (A-P) in children and at the anterior half of the third quarter (A-P) in adults. The MF location in adults was in accordance with anatomic and radiographic studies, which conclude that the MF is located posteriorly to the mid-line (Hayward et al., 1977; Hetson et al., 1988; da Fontoura et al., 2002; Fujimura et al., 2006). However, these results contradict others who found that in adults the MF in A-P dimension is located at the mid-point of the ramus (Sweet, 1943; Monheim, 1969; Weiss, 1972; Ricketts, 1975; Nicholson, 1985).

Till now, only three studies have been found in English, where the changing position of the MF in A-P dimension occurring with age has been evaluated. In two of these studies, cephalometric (Benham, 1976) and panoramic (Harrison, 1948) radiographs were used, which may not be precise and may be influenced by technical factors (Tronje et al., 1981; McDavid et al., 1985; Tronje et al., 1985; Kaffe et al., 1994). Harrison (1948) measured 51 developing mandibles from the Odontological Museum of the Royal College of Surgeons of England, in which 15 were of children with primary dentition (up to 6 years), 29 mixed dentition (6–13 years), and seven adults. The distance was measured between the center of the lingula from the posterior border of the ramus and from the internal oblique line. The posterior ramus increased with age from 9 mm in 2-year-old children to about 16 mm in adolescence and adults. The relation between the posterior ramus to the total A-P dimension of the ramus (measured from posterior ramus to the internal oblique line) was constant during primary and mixed dentition but increased by $\sim$ 7% (0.4995–0.535) from mixed to permanent dentition. From the study, it could be concluded that the MF position moved slightly anteriorly with age but only after adulthood.

In this study, the increase in the posterior ramus was from 7.74 mm in the primary dentition to 12.86 mm in the permanent dentition, and the increase relation between the posterior ramus to the total A-P width of the ramus was 17% from primary to late permanent dentition. The increase in the posterior ramus in A-P dimension occurred in two main growth spurts, between primary and mixed dentitions and between early permanent and late permanent dentitions. Differences between the former and this study may be attributed to different anatomic landmarks measured. For example, in the present study the posterior ramus was measured from the center of the MF and not from the center of the lingual (Harrison, 1948). Harrison (1948) describe neither how the posterior border was determined nor how the total A-P width of the ramus was measured. Other differences may be attributed to differential accuracy of measurement instruments (Harrison's study was conducted before 1948), as well as to different populations (the origin of Harrison's studied population was not clear). Nevertheless, the results of both the studies are similar but not identical. Similarly, the present results are also in accordance but not identical with Tsai (2004) who studied the MF position from deciduous to early permanent dentition on 311 panoramic radiographs of Taiwanese children. It was concluded that through all stages, the MF is located at the posterior half of the ramus and moves anteriorly by 1.5 mm from deciduous to permanent dentition.

Movement of the MF to a more anterior position can be explained by the fact that the mandibular growth of the ramus in an A-P direction is mainly by bone apposition on the posterior border and bone remodeling in the anterior border. In the present study, the posterior ramus increased by mean of 5.12 mm (mean of 7.74 $\pm$ 1.32 mm at stage 1 to mean of 12.86 $\pm$ 1.70 mm at stage 4) with age. It is noteworthy that if the total width of the ramus increased by 9.53 mm (from 22.48 mm in primary dentition to 32.01 mm in late permanent dentition) and all growth of the ramus occurred only in the posterior aspect, the width of the posterior ramus should have been 17.27 mm (7.74 $\pm$ 9.53 mm). This does not take into account that without any increase in A-P dimension during development, all of the bone remodeling resorption that occurred in the anterior border should have been compensated by growth in the posterior border to retain the same A-P dimension, a fact that should increase the width of the posterior ramus. However, the posterior ramus increased by a dimnesion of only 5.12 mm and not by 9.53 mm, which is the total increase width of the ramus from stage 1 to 4. When considering the compensation of the posterior growth to the remodeling that occurred in the anterior border, it is concluded that the MF moved with age posteriorly, at least to the same extent as the size of its anterior movement to compensate the remodeling in the anterior border and the growth in the posterior border. It is noteworthy that the growth of the mandible continues until the end of height growth. This can explain the continuous movement of the MF during the late permanent dentition at 18–21 years when the permanent mandibular third molars erupt.

The results of the present study are in contrast to Benham who studied cephalometric radiographs of 60 children and adults in different age groups (5, 7, 9, 11 years, and adults; Benham, 1976). No statistical difference was found in the percentage depth of the MF on the ramus between any of the age groups. The conflicting results between the study of Benham and this study may be attributed to the fact that in the latter study dry mandibles were used and not cephalometric radiographs and from the different anatomic landmarks measured. Moreover, these conflicting results may indicate a large degree of variability in the size of the mandibles and in the distance of the MF from the anterior border of the ramus. Accordingly, when placing a hypodermic needle to administer an injection, the precise distance cannot be established. These findings are in agreement with observations found in an anesthesiology textbook (Monheim, 1969). The question still remains: Is it better to inject more posteriorly or more anteriorly if you do not know where to ideally inject? There is no clear answer from the data. However, as the hillock of the lingula is located just anteriorly to the MF (Kanno et al., 2005), it could be speculated that injecting the anesthetic solution anteriorly to the apogee of the lingula will lead the solution anteriorly far from the foramen. However, if injected more posteriorly, the solution will probably penetrate into the foramen by the concavity located immediately above the entrance to the MF. Nevertheless, this is an area that needs further investigation.

In the present study, the growth spurts of the anterior ramus occurred between all stages of dentitions (1, 2, 3, and 4). In contrast, the posterior ramus had two growth

spurts: between stages 1 and 2 and between stages 3 and 4. In contrast, Tsai (2004) found only one growth spurt in the posterior ramus, which occurred after the permanent mandibular second molars erupted.

Gonial Angle

The GA decreased significantly with age and negatively correlated with the distance between the MF and each mandibular border, which is in accordance with other studies (Bremer, 1952; Hetson et al., 1988; Tsai, 2002). Hetson et al. (1988) made 12 measurements from 317 hemisected dried human mandibles. These results would have indicated that a more obtuse GA represents expanded growth potential of the mandible, while a less obtuse GA indicates lower growth potential of this bone. Nevertheless, the decrease in the GA with changing dentition significantly correlated with the movement of the MF only during stages 2 and 3 of developing dentition in which the main growth occurred, and not during stages 1 and 4 in which there was only insignificant growth. Therefore, in the general population, the size of the GA cannot predict the location of the MF in A-P dimension. This is in contrast to Hetson et al. (1988) and Tsai (2002) who concluded that the GA and the narrowest A-P width of the ramus most accurately predicted the MF position.

In the present study, all measurements were taken on the left side of the mandible, which is in accordance with others (Bremer, 1952; Hayward et al., 1977; Bass, 1987) who found that the location of the MF in AP dimension was the same on both sides and that measuring one side is sufficient to obtain reliable results.

CONCLUSIONS

The MF is located in the third quarter of the ramus in A-P dimension and moves anteriorly with age by 5.2 mm (from 7.75 mm in the primary dentition to 12.86 mm in late permanent dentition). The GA decreases with age independently to the anterior movement of the MF, which occurs with age. These changes occur during the growth spurts at stages 2 and 3 of dentition development. Most satellite foramina are located at the anterior superior quadrant of the ramus and rarely at the anterior inferior quadrant.

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