Variations in corpus and ramus measurements based on gonial angles in adult complete dentate mandibles

Ken Hiratsuka [a, 1], **Shigeo Osato** [a, 2]

[a] *Former Department of Oral Anatomy, The Nippon Dental University, School of Dentistry at Tokyo, 1-9-20 Fujimi, Chiyoda-ku, Tokyo 102-8159, Japan*

[1] *Hiratsuka Dental Clinic, #101, 1-16-8, Honcho, Toda, Saitama, 335-0023, Japan*

[2] *dento-Oral Science Institute, #2F Fukuoka 3rd Bldg, 1-4-7, Iidabashi, Chiyoda-ku, Tokyo, 102- 0072, Japan*

SUMMARY

This study aimed to reveal differences in the mandibular corpus and ramus measurements, volume (VOM), and gross weight of the mandible (GWOM) between the low and high gonial angles (L-GA and H-GA, respectively) in adult mandibles, and to evaluate the correlations between GAs and the measurement variables. Twenty-nine dried adult human complete dentate mandibles (L-GA ≤ 120°: 13 mandibles; H-GA: 125° ≥ GA: 16 mandibles) were measured using a lateral radiograph image-processing system, digital Vernier calipers, and an electric balance. The total length of the mandible (TLOM), corpus length (mental foramen–gonion [MeF'-Go'], mental foramen–mandibular foramen [MeF'-MaF'], and mandibular foramen–gonion [MaF'-Go']), inter-ramus (bicondylar, bicoronion, and bigonion) widths (BiCoW, BiCorW, and BiGoW), GA width (GAW), condylar perpendicular height (CPH), the VOM, and GWOM were measured. Data were assessed using the exact binomial test, Mann–Whitney U test and Pearson's correlation coefficient test. The MeF'-Go' and MaF'-Go', three inter-ramus widths, GAW, CPH, VOM, and GWOM in the L-GA group were significantly larger than those in the H-GA group. Significant negative correlations were found between GA size and multiple variables other than TLOM and BiCorW. Therefore, GA size was closely related to the enlarged morphometric dimensions of both the GA and the mandibular ramus in the posterior region of the mandibular corpus, as well as the volume and weight of the mandible, but it was not related to TLOM. These results indicate that the evaluation of GA size is useful for strategic dental treatment.

Key words: Forensic anthropology – Gonial angle – Lateral mandibular radiograph – Mandibular measurement – Mandibular volume and weight

INTRODUCTION

Over a person's lifetime, each area of the maxillofacial complex undergoes numerous changes. The morphological variations of the gonial angle (GA) depend on tooth growth (Larrazabal-Moron

Corresponding author:
Shigeo Osato. dento-Oral Science Institute, #2F Fukuoka 3rd Bldg, 1-4-7, Iidabashi, Chiyoda-ku, Tokyo, 102-0072, Japan. E-mail: osato-s@giga.ocn.ne.jp

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and Sanchis-Gimeno, 2018), aging (Leversha et al., 2016; Larrazabal-Moron and Sanchis-Gimeno, 2018), loss of teeth (Xie and Ainamo, 2004), presence or absence of dentures, and period of denture installation (Yanikoglu and Yilmaz, 2008).

The size of GA of the mandible is larger in women than in men (Huumonen et al., 2010; Joo et al., 2013; Fouda et al., 2019) and is more obtuse in edentulous patients than in dentulous patients (Xie and Ainamo, 2004; Huumonen et al., 2010; Joo et al., 2013). GA size is closely related to the functions of the masseter and internal pterygoid muscles, and is also affected by occlusal force (Kiliaridis et al., 1995; Sondang et al., 2003; Miwa et al., 2019). Notably, dentate patients with a small GA have well-developed masseter muscles. In addition, patients with a small GA have large mandibular cortical widths below the mandibular mental foramen (MeF) (Osato et al., 2012). Recently, the correlation of GA size with the prevalence of impacted lower third molars (Barone et al., 2021), frequency of mandibular and dental implant appliance fractures (Dhara et al., 2019; Murakami et al., 2020), and apnea syndrome severity (Gurgel et al., 2022) have been reported.

Many studies on GA size have been performed using lateral cephaloradiography (Sondang et al., 2003), dental panoramic radiography (DPR), and anatomohistological examination (Kingsmill and Boyde, 1998). Furthermore, a three-dimensional morphometric study using cone-beam computed tomography (CBCT) has been reported (Fouda et al., 2019). However, an electronic literature search did not find any studies on morphological changes in the body and mandibular ramus of the complete adult dentate mandible based on GA size. Therefore, this study was designed to identify areas in which morphological differences between the low and high GA groups (L-GA and H-GA, respectively) occur.

The purpose of this study was to investigate the GA-related morphometric differences in the mandibular corpus and ramus, bone weight, and the density of the adult complete dentate mandibles, as well as to evaluate correlations between the GA size and measurement variables.

MATERIALS AND METHODS

Twenty-nine dried adult human complete dentate mandibles that met the selection criteria for this investigation were used. The mandibles were selected and separated from several adult skull specimens of Indian origin. Indian adult specimens were used, because it was difficult to find Japanese specimens that met similar selection criteria. The upper and lower dentitions of these skull specimens had normal eruption of 32 permanent teeth, and normal dentition and occlusion. The skulls were collected in and around Kolkata from the early 1970s to the late 1980s, and were imported legitimately from India for academic research and education. As the identity of the specimens were not known; sex and age were estimated using forensic anthropological methods: sex, according to Krogman and Iscan (1986) and Singh et al. (2015), and age, according to Gazge et al. (2018). The GAs of these mandibular specimens were measured using a mandibulometer (GPM Anthropological Instruments, Zurich, Switzerland) and categorized into two groups: the L-GA group, where GA ≤ 120° (n = 13 mandibles), and the H-GA group, where GA ≥ 125° (n = 16 mandibles).

X-ray imaging and measurement methods

Lateral radiography

Two intra-oral X-ray films (DF-50 occlusal size, Kodak, Rochester, NY, USA) were used as a single sheet film. The two films were placed closely together and were attached with mending tape on the reverse side. After the X-ray film was temporarily adhered to a vertical plate, it was fixed so that the inside of the mandible was in contact with the film surface. Lateral radiography was performed on the right and left sides of the mandibles using a portable dental X-ray device (CK6105, Asahi Roentgen, Kyoto, Japan) with a tube voltage, tube current, and an exposure time of 65 kVp, 1.2–2.7s, and 10 mA, respectively. The focal film distance was 1 m. The X-ray films were processed using an automatic developing device (Max-Rhein, NIX, Tokyo, Japan).

The X-ray film image was converted to a JPG format using a scanner (GT-9800F, EPSON, Tokyo, Japan). The image was pasted into Microsoft Office PowerPoint (Microsoft Corp, Redmond, WA, USA) on a Macintosh PC. Reference points and lines were drawn on the digital radiographs, which were then saved in TIFF format. The image was then transferred to a Windows PC.

The mandibular corpus length (horizontal distances from the mental foramen to gonion, MeF'-Go'; from the mental foramen to the mandibular foramen, MeF'-MaF'; and from the mandibular foramen to the gonion, MaF'-Go'), GA width (GAW), and condylar perpendicular height (CPH) were measured on TIFF images using Image-Pro Plus software (NIPPON ROPER, Tokyo, Japan) on a Windows PC (Fig. 1).

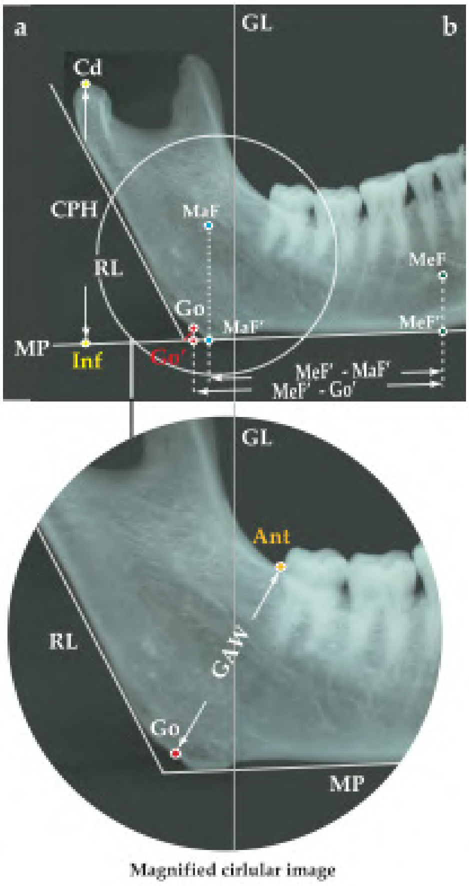

Fig. 1.- Lateral radiograph imaging and linear measurements of the adult human complete dentate mandible. Abbreviation: GL, gray line: border line of films **a** and **b**; MP, mandibular plane: the tangential line tied between the two most projected points on the mandibular inferior border; RL, ramus line: the tangential line connecting the two most projected points in the posterior margin of the ramus; MeF, mental foramen: the point at the middle of the lower border of the mental foramen; MaF, mandibular foramen: the point at the middle of the lower border of the mandibular foramen; Go, gonion: the point where the bisector of the angle formed by the mandibular plane and ramus line intersects the contour of the angle of the mandible; Cd, Condylion: the most superior point of the condyle of the mandible; Inf: the point where the perpendicular line passing through the Cd intersects the MP; MeF': the point where the perpendicular line passing through the MeF intersects the MP; MaF': the point where the perpendicular line passing through the MaF intersects the MP; Go': the point where the perpendicular line passing through the Go intersects the MP; CPH, condylar perpendicular height: the perpendicular distance from the Cd to the Inf; MaF'-MeF', the distance from MaF' to MeF'; MaF'-Go', the distance from MaF' to Go'; GAW, gonial angle width; the distance between the point where the bisector of the GA intersects the anterior margin of the ramus (Ant) and the Go. Measured in mm.

Compared to lateral cephalometric radiography, this method produces clearer and more reproducible projection images without overlap of left and right images. The horizontal distortion is smaller than that in the digital dental panoramic radiography (DPR), and metrology can be accurately measured. Moreover, it is a small and easy-to-carry device that is cost-effective compared to large and costly counterparts. Furthermore, the MeF, mandibular foramen (MaF), condylion (Cd, the most superior point of the condyle of the mandible), and the gonion (Go), which were used as anatomical landmarks, can be precisely positioned, and the measurement error of the distance between two points is very small.

Dental panoramic radiography

After fixing the dried mandible on a plastic structure, digital DPRs were taken on the chin rest of the X-ray equipment (Veraview epoc 3Df, MORITA, Kyoto, Japan) with the mandibular plane set at approximately 25°. The image was saved as a JPG file (Fig. 2).

Digital caliper measurements

The total length of the mandible (TLOM) and the inter-ramus widths (bicondylar width, BiCoW; bicoronion width, BiCorW; bimandibular foramen width, BiMaFW; and bigonion width, BiGoW) were measured by using digital Vernier calipers with 1/100 mm precision (CD-20AX, MITSUTOYO, Kawasaki, Japan) (Fig. 3).

Mandibular volume and weight measurements

The volume of the mandible (VOM; g/cm^3) was measured by hanging the mandible on a hook

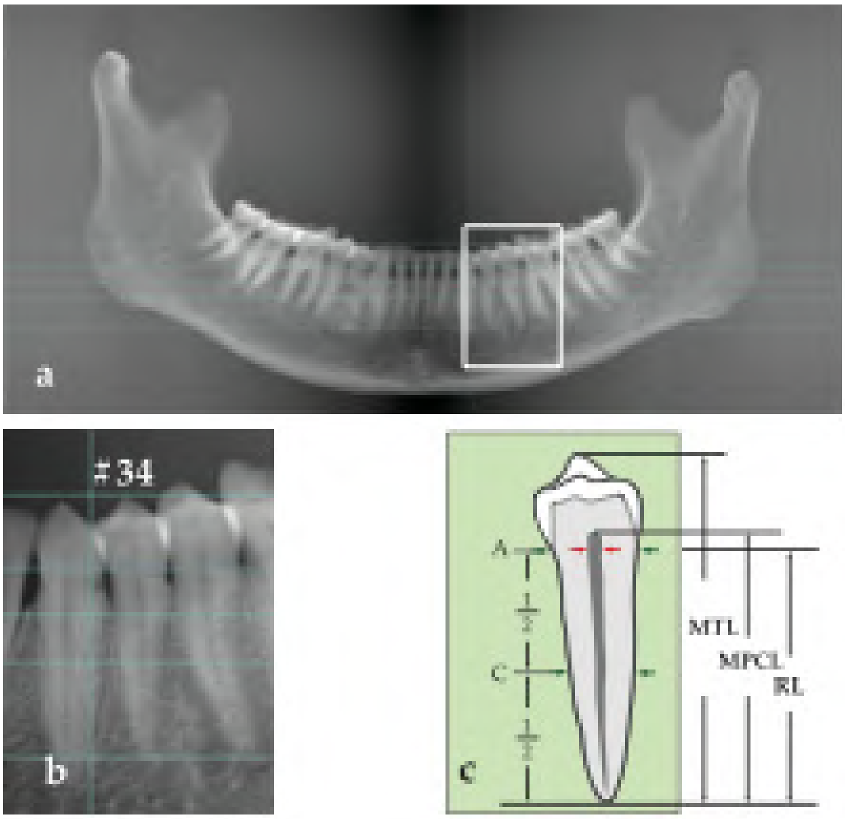

Fig. 2.- Measurement of tooth number #34 for the age estimation. **a:** A digital dental panoramic radiographic (digital DPR) image of mandible with a low gonial angle (L-GA; GA ≤ 120°). **b:** Enlarged view of #34 measured using DPR image and Photoshop's measurement tool. **c:** Drawing of tooth measurement (#34) and line measurement locations. MTL: Maximum tooth length; MPCL: Maximum pulp chamber length; RL: Root length on mesial surface. **d:** Multiple regression equations of Gazge et al. (2018) according to Kvaal's method (1995). Age = (81.1 × X1) + (180 × X2) – (69.6 × X4) – (1.7 × X3) + (3.7 × X5) – 36.6 [X1 = PW_A/RW_A, X2 = MPCL/MTL, X3 = RL, X4 = MPCL/RL, X5 = RW_C]. A: Root and pulp width (RW_A and PW_A, green and red arrows) at the cement-enamel junction (CEJ); C: Root width (RW_C, green arrow) at the midpoint between the root apex and level A.

of a digital hanging weight scale (SANKO, Tokyo, Japan) in a 15-cm square plastic case filled with water. The VOM was obtained by subtracting the value at the time of mandibular immersion from the gross weight of the mandible (GWOM). GWOM was measured using an electronic balance (ED-200, Shimadzu Corp, Kyoto, Japan).

Sex and age estimation

Sex was tentatively determined by observing the degree of development of the neurocranium and facial skeleton according to Krogman and Iscan (1986). Subsequently, sex was determined according to the criteria of Singh et al. (2015) for Indian mandibular evaluation using measurement parameters (BiCoW, male > 110 mm and female ≤ 110 mm; BiGoW, male ≥ 91 mm and female < 91 mm), and morphological parameters: the symphysis menti angle shape (square in males, and rounded in females), gonion flaring (everted in males, and inverted in females), muscular markings (more prominent in males, and less prominent in females) (Mobin and Vathsalya, 2018; Kanwar et al., 2021).

In this study, after the above thresholds were set, metric variables (BiCoW and BiGoW) were converted into nominal variables. Estimates for males and females were determined by sex, with at least three of the five geometrical characteristics. As a result of estimation, the sex of the 29 mandibles were 17 male and 12 female, with no significant difference in sex distribution (P = 0.2291).

Figure 2 shows the linear measurement sites for age estimation. The length and width of FDI #34 teeth and pulp chambers were measured using digital DPR images (in JPG format) and Photoshop (Adobe, Lehi, UT, USA) on a Mac PC. The measurement was performed by enlarging the image to 200–300%.

Age estimation was performed according to Gazge et al. (2018) concerning the methods of

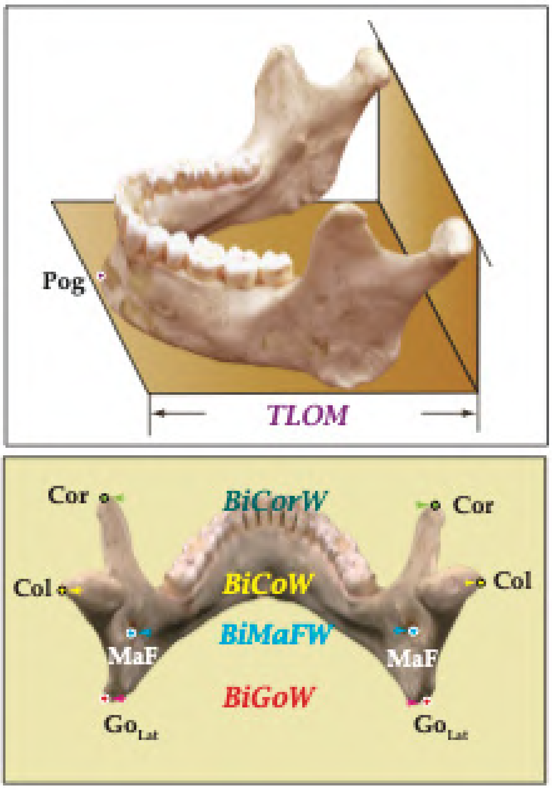

Fig. 3.- Measurements of the length and inter-ramus width of the complete dentate mandible using digital Vernier calipers. This photograph excluded a hand-fabricated mandibular fixation device (K.H.) and X-ray film. Abbreviations: TLOM, the total length of the mandibles: the distance from Pog to the posterior margin of the condylar of the mandible; Col, Condylion lateralis: the most lateral pole of the condyle of the mandible; Cor, Coronion: the tip of the coronoid processes of the mandible; MaF, mandibular foramen: point at the middle of the lower border of the mandibular foramen; Go_{Lat}, gonion: the lowest posterior and most lateral point of the angle of the mandible; Pog, pogonion: the most forward- projecting point on the anterior surface of the chin.

Gustafson (1950), Kvaal et al. (1995) and Cameriere et al. (2012). That is, the age evaluation was performed from the multiple regression equation of tooth #34 using the six-site measurements, which are considered optimal for age estimation. The 29 mandibles were estimated to be between 37 and 54 years. The mean age based on sex was 46.47 ± 4.27 years (37–54 years) for males and 46.43 ± 3.60 years (38-50 years) for females, and there was no significant difference between the sexes (P = 0. 9294).

Reproducibility of measurement and morphological evaluation

Five lateral radiograph images and five mandibular specimens were randomly selected, and linear measurements (MeF'-Go', MeF'-MaF', CPH) on the images and actual measurements (BiCoW, BiGoM, BiCorW, BiMaFW) with digital Vernier calipers were performed by a research assistant (T.S.) with more than 10 years of experience. The measurement reliability was evaluated from the intraclass correlation coefficient (ICC; 1, 1). The ICC (1, 1) for lateral radiographic imaging and digital caliper measurements of the mandibles was 0.99 and 0.99, respectively. Reliability results approximated studies with other Indian populations (Mobin and Vathsalya, 2018; Kanwar et al., 2021).

Sex was determined by two dentists (K.H. and S.O.) for the five geometrical features described above, after 12 mandibles were selected at random, and inter-rater reproducibility was evaluated from Cohen's kappa (κ) coefficient. The κ coefficient was 0.83. This result was comparable to that of another study (Mello-Gentil and Souza-Mello, 2022).

For age estimation, 12 digital DPR images were randomly selected. Two dentists (K.H. and S.O.) measured the six locations for #34 on the digital DPR images, and inter-rater reliability was confirmed from the ICC (2, 1). The ICC (2, 1) for #34 on digital DPR images was 0.99. The result was similar to results of other studies (Mobin and Vathsalya, 2018; Kanwar et al., 2021).

Statistical analysis

The average values of the right and left parameters were used for the linear measurement of mandibular corpus length (MeF'-Go', MeF'-MaF', MaF'-Go') and GAW. The linear and actual measured values obtained from the lateral radiograph images and dried mandibles were inputted into a Microsoft Excel Spread-sheet. The significant differences in the distribution of mandibular specimens between L-GA and H-GA groups and between males and females were evaluated with the exact binomial test, respectively. Similarly, the Mann-Whitney U test was used to analyze significant differences in the mean age between the two GA groups and between both sexes. The significance of the correlation between GA and each variable was determined using Pearson's correlation test. Statistical analyses were performed using Stat View 4.02 (Abacus, Berkeley, CA USA), open free js-STAR XR+ software, and the Microsoft Excel analysis tool.

RESULTS

Table 1 shows the mean values and standard deviations for the mandibular morphometric, VOM, and GWOM parameters in the L-GA and H-GA groups. There was no significant difference between the distribution of the number of mandibular specimens (13 vs. 16) and mean age in the L-GA and H-GA groups (P = 0.3555 and P = 0.2635, respectively). The GA was 12.14° and was significantly smaller in the L-GA group than that in the H-GA group (P < 0.01). When comparing the mean values of the parameters for mandibular corpus lengths, the MeF'-Go' and MaF'-Go' in the L-GA group were significantly larger, by 7.02 mm and 3.82 mm, respectively, than those in the H-GA group (P < 0.01). Similarly, the parameters for BiCoW, BiCorW, and BiMaFW were significantly larger in the L-GA group than those in the H-GA group by 4.03 mm, 2.96 mm, and 2.57 mm, respectively (all P < 0.05). BiGoW, GAW, CPH, and VOM were also significantly larger in the L-GA group than that in the H-GA group by 5.08 mm, 7.48 mm, 8.84 mm, and 9.62 cm^3, respectively (all P < 0.01). VOM and GWOM were significantly greater in the L-GA group than that in the H-GA group by 9.62 cm^3 and 13.02 g (P < 0.05 and P < 0.01, respectively). No significant differences in the parameters TLOM and MeF'-MaF' were observed between the groups.

Table 2 shows the correlations between the GA and each variable, and their statistical significance. Significant negative correlations were observed between the GA and mandibular corpus length variables (MeF'-Go' and MaF'-Go': r = -0.63 and r = -0.65, respectively).

Furthermore, significant moderate negative correlations of the GA with the BiCoW, BiGoW, VOM, and GWOM were observed (r = -0.40 and r = -0.44, r = -0.53, and r = -0.44, respectively) (all P < 0.05). Significant strong negative correlations of the GA with the GAW (r = - 0.79) and CPH (r = -0.61) were observed (both P < 0.01). In contrast, no significant correlations of the GA with the TLOM, MeF'-MaF, BiCorW, and BiMaFW were observed.

DISCUSSION

To achieve the objectives of this study, we analyzed the relationship between GA and morphometric changes in the mandible by examining adult mandibles with 32 fully erupted teeth, a normal dental arch, and a normal occlusion. The mandibular specimens used in this study were categorized into the L-GA (GA ≤ 120°) and H-GA (GA ≥ 125°) groups, and comparisons were subsequently made between the two groups. It revealed that the three-dimensional morphology of the posterior mandibular corpus and ramus, as well as the mandibular volume and weight, was greater in the L-GA group than in the H-GA group. Based on the estimated age range (37–59 years) of the mandibles investigated and analyzed, these morphological changes are considered to be the effects of mastication and bite force in daily life during aging, rather than heredity, growth and development, time in which they lived or geographical influences.

The present study was one of a series of investigations on the differences in mandibular structure between the two GA groups. No statistically significant difference was observed in the number and mean ages between the 13 L-GA group (mean: 47.51 years) and the 16 H-GA group (mean: 45.43 years). Thus, the sample numbers and the mean ages were similar.

Table 1. Comparison of morphometric, bone volume, weight, and density measurements between L-GA and H-GA groups of the mandible.

Parameters		L-GA (n = 13) [#]		H-GA (n = 16) [#]				*P-value*
		mean ± SD	**(95%CI)**	**mean ± SD**	**(95%CI)**	**Differences**	**%**	
Age, yr	Age	47.51 ± 5.83	(36.53, 58.49)	45.43 ± 3.60	(38.59, 52.27)	2.08	4.38	0.2635
Gonial angle, degree								
	GA	115.73 ± 2.41	(111.19, 120.27)	127.88 ± 2.00	(124.07, 131.68)	-12.14	-10.49	**<0.0001****
Mandibular length, mm								
	TLOM	101.23 ± 5.71	(90.47, 111.99)	101.03 ± 5.82	(89.98, 112.08)	0.20	0.20	0.8953
Mandibular corpus length, mm								
	MeF'-Go'	62.74 ± 3.29	(56.55, 68.93)	55.72 ± 3.74	(48.61, 62.82)	7.02	11.19	**0.0001****
	MeF'-MaF'	56.41 ± 3.88	(49.10, 63.72)	54.79 ± 3.68	(47.81, 61.76)	1.62	2.87	0.2452
	MaF'-Go'	6.41 ± 2.07	(2.52, 10.31)	2.60 ± 1.32	(0.08, 5.11)	3.82	59.50	**<0.0001****
Inter-ramus width, mm								
	BiCoW	113.81 ± 4.33	(105.65, 121.97)	109.78 ± 3.90	(102.37, 117.19)	4.03	3.54	**0.0159***
	BiCorW	94.73 ± 3.76	(87.65, 101.82)	91.77 ± 3.71	(84.73, 98.82)	2.96	3.12	**0.0353***
	BiMaFW	79.39 ± 2.48	(74.71, 84.07)	76.82 ± 3.97	(69.28, 84.35)	2.57	3.24	0.0226*
	BiGoW	96.29 ± 4.37	(85.50, 106.16)	91.21 ± 4.03	(83.56, 98.86)	5.08	5.28	**0.0075****
Width of the angle, mm								
	GAW	39.70 ± 1.85	(36.22, 43.17)	32.22 ± 3.06	(26.40, 38.03)	7.48	18.85	**<0.0001****
Ramus height, mm								
	CPH	60.61 ± 3.77	(53.52, 67.70)	51.77 ± 6.50	(39.44, 64.10)	8.84	14.59	**0.0006****
Bone volume, cm^3								
	VOM	56.23 ± 7.78	(41.58, 70.88)	46.61 ± 7.3	(32.71, 60.52)	9.62	17.11	**0.0044****
Bone weight, g								
	GWOM	90.64 ± 13.33	(65.54, 115.74)	77.62 ± 11.17	(56.42, 98.82)	13.02	14.36	**0.0124***

L-GA and H-GA, low and high gonial angles; SD, standard deviation; CI, confidential interval; Significance: Exact binomial test and Mann-Whitney U test, $*P < 0.05$ and $**P < 0.01$ (bold text). Abbreviations: TLOM, the total length of the mandible; MeF'-Go', the distance from the mental foramen to the gonion on the mandibular plane (MP); MeF'-MaF', the distance from the mental foramen to the mandibular foramen on the MP; MaF'-Go', the distance from the mandibular foramen to the gonion on the MP; BiCoW, bicondylar width (Col-Col); BiCorW, bicoronoid width (Cor-Cor); BiMaFW (MaF-MaF), bimandibular foramen width; BiGoW, bigonion width (GoLat-GoLat); GAW, gonial angle width (Go-Ant); CPH, condylar perpendicular height: the perpendicular distance from the Cd to the Inf; VOM, the volume of the mandible; GWOM, gross weight of the mandible (See reference Figs. 1 and 3).
#: Testing significance using exact binomial test for distribution of number of L-GA (13) and H-GA group mandibles (16) ($P = 0.3555$).

In addition, no abnormalities were observed in the teeth and periodontal tissues in the mandibles, suggesting that they belonged to a population group with similar social activities, sociocultural levels, regions, habit, customs, and economics. Consequently, it was not necessary to adjust the results.

Cho et al. (2014) classified face configurations into brachyfacial and mesofacial groups, with a GA threshold of 120°. In this study, a gap of 5° was set to distinguish the L-GA and H-GA groups clearly (Osato et al., 2012). The result showed a significant difference (12.14°) in the mean GA between the groups ($P < 0.01$). Compared to the H-GA group, the L-GA group showed a significantly larger MeF'-Go', MaF'-Go', GAW, inter-ramus widths, CPH, VOM, and GWOM. Changes in the GA had a significant negative correlation with multiple variables, but did not correlate with TLOM and BiCroW.

Table 2. Pearson's correlation analysis between the gonial angles (GA) and **v**ariables of the mandible, as well as statistical assessments (n = 29).

Variables		r	P-value
Age, yr			
	Age	-0.235	0.2218
Mandibular length, mm			
	TLOM	0.113	0.5603
Mandibular corpus length, mm			
	MeF'-Go'	-0.626	**0.0003****
	MeF'-MaF'	-0.127	0.5121
	MaF'-Go'	-0.651	**0.0001****
Inter-ramus width, mm			
	BiCoW	-0.400	**0.0313***
	BiCorW	-0.296	0.1196
	BiMaFW	-0.267	0.1616
	BiGoW	-0.436	**0.018***
Width of the angle, mm			
	GAW	-0.791	**<0.0001****
Ramus height, mm			
	CPH	-0.611	**0.0004****
Bone volume, cm^3			
	VOM	-0.531	**0.0026****
Bone weight, g			
	GWOM	-0.439	**0.0171***

r: Pearson's correlation coefficients; Significance: Pearson's correlation test, $*P < 0.05$, $**P < 0.01$ (bold text). Abbreviations: TLOM, the total length of the mandible; MeF'-Go', the distance from the mental foramen to the gonion on the mandibular plane (MP); MeF'-MaF', the distance from the mental foramen to the mandibular foramen on the MP; MaF'-Go', the distance from the mandibular foramen to the gonion on the MP; BiCoW, bicondylar width (Col-Col); BiCorW, bicoronoid width (Cor-Cor); BiMaFW, bimandibular foramen width (MaF-MaF); BiGoW, bigonion width (Go_{Lat}-Go_{Lat}); GAW, gonial angle width (Go-Ant); CPH, condylar perpendicular height (Cd-Int); VOM, the volume of the mandible; GWOM, gross weight of the mandible.

Corpus and ramus dimensions of the mandible

The biomechanical load of mastication affects mandibular morphology (Mays, 2015). Occlusal force strongly depends on the relative size of jaw-closing muscles and is associated with mandibular morphological changes (Custodio et al., 2011). The GA in a mandible with multiple teeth was significantly smaller, while the mandibular ramus was larger, than that in a mandible with few teeth. Furthermore, the mandibular length of mandibles with few teeth was larger than that of mandibles with multiple teeth (Vinter et al., 1997). It has also been suggested that functional hyperactivity of the masticatory system may affect bony structures through increased stress (Kiliaridis et al., 1995).

This study revealed that the complete dentate mandibular corpus lengths (MeF'-Go' and MaF'-Go') in the L-GA group were significantly larger than those in the H-GA group. On the other hand, there was no significant difference in dimensions from the MeF' to the MaF' with the central corpus area in the L-GA group as compared to the H-GA group, indicating that this region was less susceptible to occlusal force. This interesting finding indicates that the influence of occlusal forces on the midcorpus is small.

Adult patients with a sharp GA, as compared to those with an obtuse GA, have a flaring Go and a significantly larger BiGoW (Hong et al., 2009). A reduced masticatory function is associated with decreased BiCoW and BiGoW (Rando et al., 2014). Based on these reports, it is considered that the occlusal force of the L-GA group was strongly applied to the lower (BiGoW), middle (BiMaFW), and upper (BiCoW and BiCorW) areas of the inter-ramus, which consequently expanded laterally.

A study on the relationship between the ramus width of the mandible around the MaF and GA size revealed that the ramus width in adult dentate patients was larger in the L-GA group than in the H-GA group (Ogawa et al., 2012). The ramus width measured using CBCT was 2.0 mm larger in the L-GA group (118.5°) than in the H-GA group (128.6°) in a previous study (Barone et al., 2021). Strong sexual dimorphism was also observed in these ramus widths (Leversha et al., 2016; Mehta et al., 2020). In this study, the GAW around the GA was also significantly greater in the L-GA group (by 7.48 mm [18.85%]) than in the H-GA group (Table 1). Thus, it is indicated that individuals with narrow GA may have increased masticatory muscle activity, greater occlusal force, and vigorous bone addition in a wide area from the Go to the retromolar triangle of the anterior margin of the mandibular ramus.

According to previous lateral cephalogram analyses regarding the ramus height of the mandible, patients with a small GA had a short face with a shorter anterior (distance between nasion and menton, N-Me), and vertically larger posterior (sella to gonion, S-Go) facial heights, and a larger facial height ratio (S-Go/N-Me) (Karlsen, 1997). CBCT analysis also showed that the ramus height of a small GA was higher than that of a large GA (Barone et al., 2021). Furthermore, ramus height was higher in dentate patients than in completely edentulous patients (Okşayan et al., 2014) and was also higher in men than in women (Lopez-Capp et al., 2018). This investigation showed that the CPH was 8.84 mm (14.59%), which was significantly larger in the L-GA group than in the H-GA group (Table 1). Therefore, the skeletal facial configuration of individuals with a L-GA may involve a large posterior facial height (Tsai, 2000). Although it is clear from previous reports that masticatory muscle function and occlusal force are closely related to the difference in GAW and the mandibular ramus widths value between the two GA groups, it is necessary to investigate the relationship between GA and bite force in the same subject.

Mandibular volume and weight

There have been few reports on the volume of completely dentate mandibles. Based on the analysis using MRI, it has been reported that the volume of the mandible increased by 6,530 mm^3 (18.6%) during the growth period (age 7-13 years) (Maeda, 2018). Additionally, an investigation of maxillofacial morphology and mandibular volume used lateral cephalometry and CBCT, respectively. The mean volume of mandibles was 63.23 cm^3 in males and 53.92 cm^3 in females. No significant differences were observed in mandibular volumes among cases with Angle classes I, II, and III maxillofacial morphology. On the other hand, an inverse relationship between the mandibular plane angle (MPA) and mandibular volume was observed, and the hypodivergent (short face height, MPA: < 23°) group was larger than the hyperdivergent (long face height, MPA: > 30°) group (Nakawaki et al., 2016).

In this study, the Archimedes method was used to determine volume, revealing that the volume in the L-GA group (56.23 cm^3) was significantly larger (by 9.62 cm^3, 17.11%) than that in the H-GA group (46.61 cm^3), indicating that the decrease in GA size affected not only an increase in three-dimensional dimensions, but also in mandibular volume (Table 1). This change is thought to be the effect of bone remodeling associated with increased masticatory muscle function and occlusal force. The results of this study supported those of Nakawaki et al. (2016) mentioned above.

From a conventional report on the weight of the mandible, in patients with developed masticatory muscles, the mandibular weight was greater while the GA was smaller than in those with less muscle mass (Jensen and Palling, 1954). On the other hand, no studies have reported on the relationship between mandibular angle and mandibular weight. It has been reported that the mandibular weight and morphology in Indians are divided into three types, and the heavy and large group (30.0%) was most common in males, while the light and small group (12.5%) was most common in females. Bone weights were not described in that paper (Mobin and Vathsalya, 2018). The GWOM of dried, completely dentate adult mandibles in the L-GA group (90.64 g) was significantly heavier than that of the H-GA group (77.62 g), by 13.02 g (14.36%), in this study (Table 1). Therefore, it was conceivable that a decrease in GA size was associated with an increase in mandibular morphometric dimensions.

Correlations between GA and measured variables

In correlations between GA and craniofacial radiomorphometry, increasing GA changes the facial features from a brachyofacial to a dolicofacial pattern (Custodio et al., 2011). It is associated with a decreased ramus width and posterior ramus notch depth (Ogawa et al., 2012). Moreover, a smaller GA is associated with maximum occlusal force from the second premolars and first molars (Miwa et al., 2019). Notably, a reduced GA size is associated with a higher incidence of impacted lower third molars (Barone et al., 2021). GA also has a negative correlation with the growth of permanent teeth (Ashkenazi et al., 2011; Larrazabal-Moron et al., 2018), and positive correlations with tooth loss and aging (Vinter et al., 1997; Xie and Ainamo, 2004; Joo et al., 2013; Okşayan et al., 2014). In this study, the GA negatively and significantly contributed to bone apposition with bone remodeling of the posterior mandibular area, MeF'-Go' and MaF'-Go'. Thus, changes in the GA size were considered to be closely associated with remodeling of the posterior region of the corpus length, while maintaining TLOM and corpus length from MeF' to MaF'.

Regarding the association between the dimensions of the right and left mandibular ramus and masticatory function, a previous study reported that BiGoW in patients with a small GA was positively correlated with masseter muscle volume (r = 0.37) (Hong et al., 2009), and that the occlusal force was strong (Kiliaridis et al., 1995; Sondang et al., 2003; Miwa et al., 2019). Generally, the BiGoW decreases with aging (Leversha et al., 2016). This study revealed negative moderate linear relationships between the GA size and the inter-ramus width variables of BiCoW and BiGoW (r = - 0.40 and r = -0.43, respectively) (Table 2), suggesting that occlusal force and mandibular bone morphology are related. Specifically, it was indicated that, when the masticatory muscle activity and occlusal force increased, the GA decreased, and the inter-ramus width spread laterally.

In a digital DPR analysis, the ramus width around the mandibular foramen was closely associated with a decreased GA, and an increase in GA contributed to reduced ramus width on lateral radiograph imaging (Ogawa et al., 2012; Cho et al., 2014). It was found that GA size had a significantly strong negative linear relationship with GAW (r = -0.79). In addition, the GA size strongly affected the MaF region, including the gonion process and anterior margin of the retromolar triangle, through bone apposition. Similar reports on the negative association between GA size and ramus width (BiGoW; r = -0.44) have been reported using CBCT analysis (Kronseder et al., 2020). The activities of the jaw-closing muscles and increased occlusal force are closely associated with enlargement of the GAW.

The ramus height generally decreases with age (Leversha et al., 2016). GA size showed significant negative correlations with the coronoid and ramus heights of the mandible (Huumonen et al., 2010; Joo et al., 2013). Therefore, as the occlusal force increases, the posterior facial height gradually increases, while GA size decreases (Sondang et al., 2003). This investigation observed a significantly negative moderate linear relationship between the GA and CPH (r = -0.61), which was similar to the previously reported results (Huumonen et al., 2010; Joo et al., 2013). The occlusal force of patients with a small GA is strong (Kiliaridis et al., 1995; Miwa et al., 2019), and contributes to bone apposition around the GA. In addition, a 10-year follow-up study also reported that the fracture risk of abutments in implant treatment was higher in male patients with a GA size less than 120° on digital DPR images (Murakami et al., 2020). These results indicate that careful consideration should be given to the strong occlusal force of patients with a GA ≤ 120° when designing and fabricating a prosthesis and that the evaluation of the GA is an important checkpoint for reducing oral rehabilitation risk (Osato et al., 2012). Further investigation into the relationship between the complications of implant-supported prosthetic treatment and GA size is warranted.

The volume of the mandibles increased in proportion to body weight in Norwegian schoolchildren (Maeda, 2018). In addition, a cephalometric investigation on the association between maxillofacial morphology (ANB, SNB, or MPA) and mandibular bone volume in patients with skeletal malocclusion reported that a significant weak linear relationship was found between GA and mandibular bone volume (Katayama et al., 2014). On the other hand, a significant correlation (r = 0.44) was observed with the length index (condylion to gonion; Cd-Go) (Katayama et al., 2014).

From this result, significant negative moderate correlations (r = -0.53 and r = -0.44) were observed between GA size with mandibular volume and weight, indicating that the two variables were closely related to the GA in adult mandibles.

Hence, these results suggest that the mandibular morphology (external trait) in a wide range from the mandibular posterior corpus to the mandibular ramus, centered on the attachment of the mouth-closing muscle, and the mandibular volume increased; the stimulus caused by mastication was also active. These may be associated with increased bone strength (endomorphic bone quality and bone mass) through bone remodeling.

CONCLUSIONS

In this study, morphometric measurements of sex- and age-estimated completely dentate mandibles of Indian revealed that the MeF'-Go' and MaF'-Go' of the posterior corpus, the inter-ramus widths, GAW, CPH, VOM and GWOM were significantly larger in the L-GA group compared to the H-GA group. GA size had a negative linear relationship with those variables, whereas no significant association found in TLOM and BiCorW. Hence, the results could reveal that the L-GA group compared to the H-GA group occurred in vigorous bone apposition in the three-dimensional directions around the Go and also had larger VOM and GWOM without changing the TLOM. These results suggest that the evaluation of GA size is helpful in the field of prospective dental medicine. Future studies should focus on the relationship between GA size and mandibular morphometry and occlusal forces in a large population of dentate and edentate individuals.

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The authors declare no conflicts of interest associated with this article.

INFORMED CONSENT

The authors declare that informed consent was not required.

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