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Mandibular Morphological Changes According to Functional Occlusal Status: A Descriptive Radiomorphometric Study

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ABSTRACT

Objective: This study aimed to measure the gonial angle (GA) and the ramus height/condyle height (RH/CH) ratio in five groups defined according to the functional occlusal status of the mandibular molar teeth, using open-access panoramic radiography databases, and to establish descriptive reference values for these groups.

Methods: Digital panoramic radiographs from two open-access, fully anonymized databases (the Children's Dental Panoramic Radiographs Dataset for the pediatric group; the Tufts Dental Database for the adult groups) were evaluated retrospectively and cross-sectionally. Of 1093 radiographs screened, 214 individuals (428 mandibular regions) meeting the inclusion criteria were divided into five groups by the functional occlusal status of the mandibular first permanent molar: pre-functional pediatric (Group 1, n=31), functional pediatric (Group 2, n=36), adult functional (Group 3, n=40), partial molar loss (Group 4, n=73), and total edentulism (Group 5, n=34). GA and the RH/CH ratio were measured with ImageJ as magnification-independent parameters. Between-group comparisons used a linear mixed-effects model. Because the database and group effects were confounded, inferential evaluation was primarily restricted to groups within the same database.

Results: Measurement reliability was good at both intra- and inter-observer levels (all ICC > 0.80). GA was highest in the totally edentulous group (124.58° ± 7.03), which had a significantly higher GA than each of the other four groups ($p<0.001$ for all; eta-squared=0.168, large effect). Within the Tufts database, GA increased significantly from adult functional dentition toward partial molar loss ($p=0.010$) and total edentulism ($p<0.001$), the most pronounced increase being in total edentulism. Within the pediatric database, no significant difference was found between the pre-functional and functional groups (GA $p=0.227$; RH/CH $p=0.447$). The RH/CH ratio was less sensitive in distinguishing groups (epsilon-squared=0.035, small effect), with a significant difference only between partial molar loss and total edentulism ($p<0.001$).

Conclusion: The findings suggest that GA is sensitive to functional occlusal status from the partial tooth-loss stage onward, with the most pronounced widening in total edentulism; the contribution of molar function to the early developmental period appears limited. As the RH/CH ratio alone is weaker than GA in group discrimination, joint evaluation of the two parameters is recommended. Owing to the cross-sectional design, the absence of individual age and sex data, and the database–group confounding, the findings should be interpreted as descriptive rather than causal.

Keywords: Gonial angle, Panoramic radiography, Mandible, Pediatrics, Radiomorphometry.

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INTRODUCTION

The gonial angle (GA) is formed at the gonion by the intersection of tangents to the posterior border of the mandibular ramus and the lower border of the mandibular body, defining the inclination at the body–ramus transition (1, 2). The masseter and medial pterygoid attach here via a common tendinous band (3), so GA shape is largely determined by their functional load. Because bone continuously remodels under mechanical force (4), GA also serves as an indirect indicator of the mandible's functional history, with applications from orthodontic growth assessment to forensic age and sex estimation (5).

Panoramic radiography (orthopantomography) is the method most commonly used for measuring GA (6). Unlike lateral cephalograms, in which the right and left angles overlap and cannot be evaluated separately, panoramic radiography images both sides clearly and independently (7), making it preferred in both clinical diagnosis and morphometric research (5, 8).

GA changes markedly from birth to adulthood. Reported as approximately 135–150° at birth, it gradually narrows during growth (1), mainly because the ramus grows and becomes more vertically oriented faster than the body. With tooth eruption and the onset of masticatory function, the ramus-to-body ratio changes and the angle approaches adult values (9). Before functional occlusal contact is established, mandibular load is lower; the participation of teeth in functional contact and masticatory muscle development then bring the angle to its adult form. Thus GA differs between childhood/early permanent dentition and adulthood (9).

Aging and tooth loss alter mandibular morphology. GA reportedly widens with tooth loss, increasing gradually from dentate to partial and then total edentulism (5, 10). Edentulous individuals show significantly larger GA and lower RH and CH than dentate ones (8), so evaluating ramus and condyle dimensions alongside GA better reflects this change. This is attributed to reduced masticatory muscle function and alveolar bone resorption with aging, and GA is closely related to residual bone volume, cortical thickness, and edentulism duration (11). A prospective study found that extraction widened GA and that, with denture use, it slowly returned toward baseline (12).

Findings are inconsistent, however. Some studies report no significant GA difference between dentate and edentulous individuals or across edentulism levels (13, 14), while the age–GA correlation varies by population (15), likely because GA is simultaneously influenced by age, occlusal status, and imaging method.

The growth of open-access, anonymized panoramic databases now enables reproducible, broad morphometric studies. Yet existing literature generally examines GA only by adult dentate–edentulous categories or by ten-year age groups; studies addressing both developmental and aging stages according to mandibular molar occlusal status are limited.

This study measures GA and the ramus height/condyle height (RH/CH) ratio using open-access panoramic databases in five groups defined by mandibular molar functional occlusal status, from the pre-functional (pediatric) period to total edentulism, to establish descriptive reference values. Because pediatric and adult groups came from different databases, evaluation was primarily conducted within groups of the same life period (pre-functional and functional in development; functional dentition, partial molar loss, and total edentulism in aging). The aim is to document descriptive distributions rather than draw causal inferences about group differences.

METHODS

Data Sources and Ethical Statement

Digital panoramic radiographs from two different, publicly available and completely anonymized databases were used retrospectively. No personal data was included in either radiograph. Since the databases were publicly available and anonymized, separate ethics committee approval was not required. The license and terms of use of both databases were adhered to, and the data were used solely for scientific research purposes. The study was prepared based on the STROBE (Strengthening the Reporting of Observational Studies in Epidemiology) guidelines for reporting observational studies.

Radiograhs for the pediatric group were obtained from the "Children's Dental Panoramic Radiographs Dataset" database of individuals aged 2-13 years (16). Radiographs for adult

individuals were retrospectively obtained from the "Tufts Dental Database" database created by the Tufts University School of Dentistry (17).

Sample Selection and Study Pool

The sample was created by scanning all panoramic radiographs in the databases. For the pediatric group, a total of 93 radiographs were evaluated from the database. A total of 26 cases that did not meet the group criteria were excluded from the study. The remaining 67 radiographs were classified as Group 1 (n=31) and Group 2 (n=36) according to the functional occlusal status of the first permanent molars in the mandibular jaw.

For the adult group, all 1000 panoramic radiographs in the Tufts Dental Database were reviewed. After applying the exclusion criteria, the groups were classified as Group 3 (adult functional dentition, n=40), Group 4 (partial/functional molar loss, n=73), and Group 5 (total mandibular edentulism, n=34).

In our study, out of a total of 1093 panoramic radiographs reviewed, 214 cases (428 right-left mandibular regions) meeting the inclusion criteria were included. The flowchart of the case selection process is presented in Figure 1.

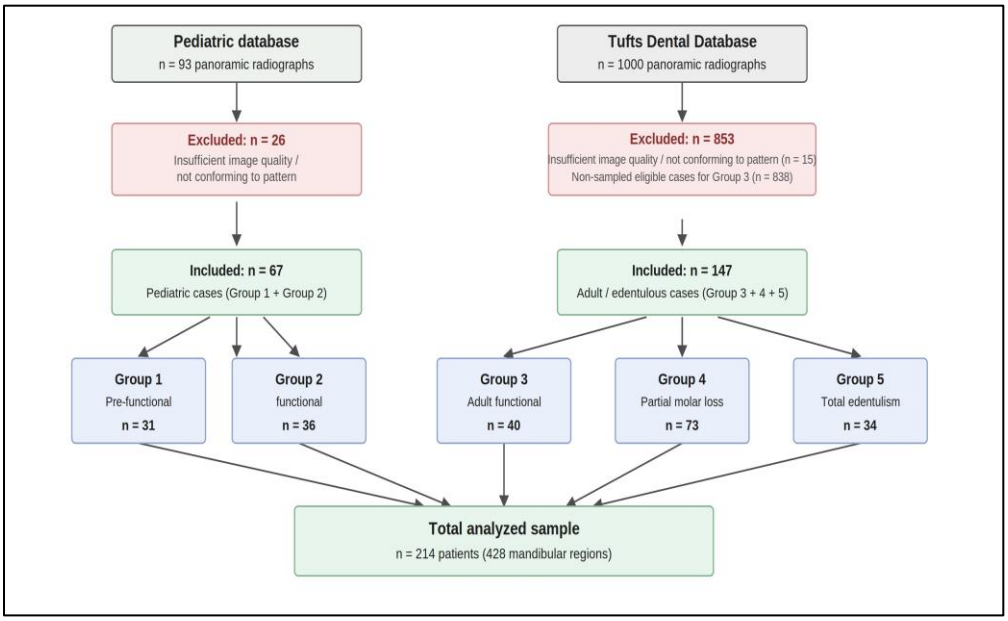

Figure 1. Flowchart of Case Selection (The Figure Was Created by The First Author)

Radiograph quality was assessed before measurement. A radiograph was deemed "insufficient for measurement" and excluded if it showed prominent ghost artifacts, marked occlusal-plane curvature or asymmetric magnification from positioning error, motion blur or poor sharpness that prevented tracing of the anatomical borders, or landmarks for GA and ramus/condyle measurement that were too ambiguous to mark reliably.

Inclusion criteria were radiograph quality sufficient for measurement, clear traceability of the anatomical borders, and unambiguous conformity to one of the five defined dentition/function patterns (Groups 1–5). Exclusion criteria were failure to conform to any defined pattern, borderline cases with classification ambiguity (e.g., a first permanent molar that had approached but not fully reached the occlusal plane), and cases whose inclusion would conflict with a group's definition (e.g., a case with a functional molar bilaterally was not assigned to Group 4). Radiographs of insufficient quality (as defined above) were also excluded.

The radiographs were divided into five groups according to the functional occlusal status of the mandibular molar teeth, based entirely on radiographic criteria. Because the open-access databases provided no individual age or sex data, these variables were used neither as inclusion/exclusion criteria nor for descriptive reporting. The pediatric database reported only a general age range (2–13 years) rather than per-patient ages; this is addressed in the limitations section.

Group 1 (Pediatric – Pre-functional): This group included panoramic radiographs of cases where the first permanent molar in the mandible was in the germ (tooth bud) stage or intraosseous development stage on both sides and had not yet approached the occlusal plane (n=31).

Group 2 (Pediatric – Functional): This group included panoramic radiographs of cases where the first permanent molar in the mandibular had reached the occlusal plane on both sides. For a tooth to be considered to have reached the occlusal plane, its occlusal surface had to be aligned with the occlusal level of the adjacent premolar/deciduous molar and in contact with the opposing maxillary molar tooth. Thus, each case had a total of two functional first molars, one on the right and one on the left (n=36).

Group 3 (Adult Functional): Included in this group were panoramic radiographs belonging to adult cases in which the permanent molar tooth was on the occlusal plane on both sides in the mandible and participated in functional occlusal contact (radiographic antagonist contact) with the opposing maxillary molar tooth (n=40).

Group 4 (Partial Molar Loss): Included in this group were adult individuals in whom the anterior teeth (incisor and/or canine teeth) in the mandible were preserved, but the mandibular molar teeth were physically absent. Cases that had a functional molar on both sides were excluded from this group (n=73).

Group 5 (Edentulous): Included in this group were individuals who were totally edentulous, having no teeth at all in the mandible. Whether the upper jaw (maxilla) was dentate or edentulous was not evaluated as an inclusion criterion for this group (n=34).

Radiomorphological Measurements and Standardization

All panoramic radiographs were analyzed using ImageJ software (v1.54, National Institutes of Health, Bethesda, MD, USA) (18), which is accepted as the international academic standard in digital image analysis. Since angular and proportional measurements are not affected by pixel size and resolution, calibration was not required on the radiographs. The measurement procedure was performed based on the following standard anatomical points and tangent lines, in a way that an external researcher could fully replicate.

Determination of anatomical points:

Point 1: The most prominent point on the posterior of the condylar process.
Point 2: The most prominent point on the posterior of the mandibular ramus, near the mandibular angle.
Point 3: The lowermost border point of the mandibular symphysis region.
Point 4: The most prominent point of the mandibular body near the mandibular angle.

Drawing of tangent lines:

Ramus tangent: The line descending from Point 1 to Point 2.
Body tangent: The line drawn from Point 3 to Point 4.

The internal angle formed by the intersection of these two lines at the mandibular corner was recorded in degrees.

In addition to GA, RH and CH were measured for the purpose of proportional evaluation of mandibular morphology. Because vertical magnification is high in panoramic radiography (7), the Habets method, which provides a proportional evaluation relatively independent of magnification, was used in order to limit the influence of magnification on the linear measurements (19,20). During measurement, Point 1 and Point 2 defined in the GA measurement were taken as reference. Line A, tangent to these two points, was drawn. Line B, perpendicular to Line A, was drawn from the uppermost point of the condyle. Line B intersected Line A at Point X. CH was defined as the distance between Point 1 and Point X along Line A. RH was defined as the distance between Point 1 and Point 2 (21, 22). All linear measurements were taken in pixels with ImageJ (Figure 2).

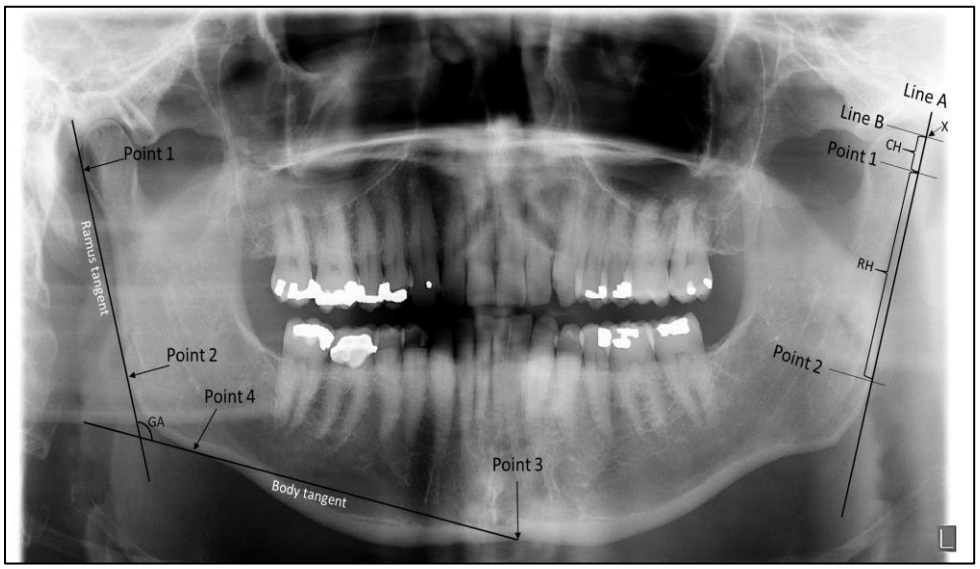

Figure 2. Schematic Illustration of the Radiomorphometric Measurements on a Panoramic Radiograph (The Figure Was Created by The First Author)

Sample Size and Sensitivity Analysis

Because no a priori sample size calculation was made in this study, a sensitivity analysis was preferred instead of a post-hoc power calculation in order to evaluate the effect size that the available sample could detect. In the analysis performed with G*Power (v3.1.9.7, University

of Kiel, Germany) (23), the minimum detectable effect size was calculated as approximately f=0.24 for α=0.05, 80% statistical power (1−β=0.80), five groups, and a total of 214 patients.

According to this result, it was seen that the study was of a nature capable of detecting, with sufficient power, true group differences at the medium level and above according to Cohen's criteria. This sensitivity analysis was based on the total sample of 214 patients under the assumption of equal group sizes. Because the actual group sizes were unbalanced (n=31, 36, 40, 73, and 34), the minimum detectable effect size is expected to be marginally larger than the value reported above; therefore, f=0.24 should be regarded as a lower bound rather than an exact threshold.

Measurement Reliability and Error Analysis

All measurements were performed on the entire sample by the primary observer (Researcher 1, anatomy specialist) and these measurements were used as the basis for the main statistical analyses.

For within-observer agreement, a subsample representing approximately 30% of the sample and distributed proportionally to group sizes was randomly generated (n=64). Researcher 1 re-measured this subsample two weeks later without access to the initial measurement values. For between-observer agreement, the same subsample was assessed by an independent second observer (Researcher 2, pediatric dentistry specialist) who was informed about the measurement protocol. The second observer independently marked anatomical points and recalculated the measurements based on these points.

Intra-observer and inter-observer agreement were evaluated separately for the GA and RH/CH measurements with the Intraclass Correlation Coefficient (ICC). ICC calculation was performed on the basis of a two-way mixed-effects model, absolute agreement, and the single-measures type, together with a 95% confidence interval (24). According to the Koo and Li (24) criteria, ICC values below 0.50 were interpreted as poor, 0.50–0.75 as moderate, 0.75–0.90 as good, and above 0.90 as excellent agreement.

In order for the measurements to be accepted as reliable, the threshold of ICC>0.75 (good) was adopted as the minimum criterion, and the running of the main analyses over the primary observer's full data set was made contingent on meeting this threshold.

Statistical Analysis

Analyses were performed in SPSS (v26.0, IBM Corp., Armonk, NY, USA). Because right and left measurements were obtained for each patient, the dependency between measurements from the same individual was accounted for throughout. Distributions were examined with the Shapiro–Wilk test and descriptive statistics.

Before the primary analysis, right–left GA symmetry was assessed with the paired t-test (Wilcoxon signed-rank test when parametric assumptions were not met). If significant asymmetry was found, side (right/left) was added to the model as a fixed effect; otherwise, right and left values entered the model as repeated measures of the same individual.

The primary analysis evaluated GA and RH/CH differences among the five groups with a linear mixed-effects model, with group as a fixed effect and patient as a random effect. Residual normality and homoscedasticity were checked with Q–Q and residual-versus-predicted plots. Pairwise between-group comparisons used Bonferroni correction.

As a sensitivity analysis, one-way analysis of variance was applied to each patient's right–left mean: One-Way ANOVA with Tukey HSD or Welch ANOVA with Games–Howell according to variance homogeneity, and the Kruskal–Wallis test with Dunn post-hoc (Bonferroni-corrected) when distributional assumptions were not met. Significance was set at $p<0.05$.

Effect sizes were eta-squared for ANOVA, epsilon-squared for Kruskal–Wallis, and Cohen's d (mean difference divided by pooled SD) for pairwise comparisons. Because database and group effects were confounded, within-database comparisons (Group 1 vs. Group 2 in the pediatric database; Groups 3 and 4 vs. Group 5 in the Tufts database) formed the primary inferential axis and were considered more reliable, whereas cross-database comparisons (e.g., Group 2 vs. Group 3) were interpreted only descriptively and with caution.

RESULTS

Of 1093 radiographs screened from two open-access databases, 214 patients (428 mandibular regions) met the inclusion and exclusion criteria and were divided into five groups according to the functional occlusal status of the mandibular first permanent molar. As noted, age and sex could not be reported because these data were absent from the databases.

Measurement Reliability

In a subgroup of ~30% of the sample (n=64 patients, 128 regions), all four ICCs fell within the good range (>0.75): for GA, intra-observer 0.811 (95% CI 0.70–0.88) and inter-observer 0.809 (0.72–0.87); for RH/CH, intra-observer 0.819 (0.75–0.87) and inter-observer 0.820 (0.75–0.87).

Right–Left Symmetry

Across the whole sample, GA showed no significant right–left difference (paired t-test, p=0.640), although group-level asymmetry was significant in Group 2 (p=0.008) and Group 4 (p=0.001) but not in Groups 1, 3, or 5. RH/CH showed no significant right–left difference either overall (p=0.509) or within any group (all p>0.19). Because of this partial GA asymmetry, side was added to the linear mixed-effects model as a fixed effect.

Descriptive Findings for GA and the RH/CH Ratio

Descriptive values are summarized in Table 1 and shown in Figure 3. GA was highest in Group 5 (124.58°). For RH/CH, the highest mean occurred in Group 4 (7.70) and the lowest in Group 5 (6.57).

Table 1. Descriptive Values of GA and the RH/CH Ratio by Group

Group	n (region)	GA, ° mean ± SD	GA median	RH/CH mean ± SD	RH/CH median
Group 1	62	118.72 ± 5.77	118.94	7.05 ± 1.55	7.04
Group 2	72	117.14 ± 5.67	117.38	7.51 ± 1.56	7.00
Group 3	80	115.11 ± 6.03	115.57	7.07 ± 1.84	6.55
Group 4	146	118.21 ± 7.87	118.48	7.70 ± 1.99	7.43
Group 5	68	124.58 ± 7.03	124.75	6.57 ± 1.88	6.25

GA: Gonial angle, RH/CH: ramus height/condyle height, SD: standard deviation. (n=428 mandibular regions; the corresponding patient numbers are 31, 36, 40, 73, and 34, respectively.)

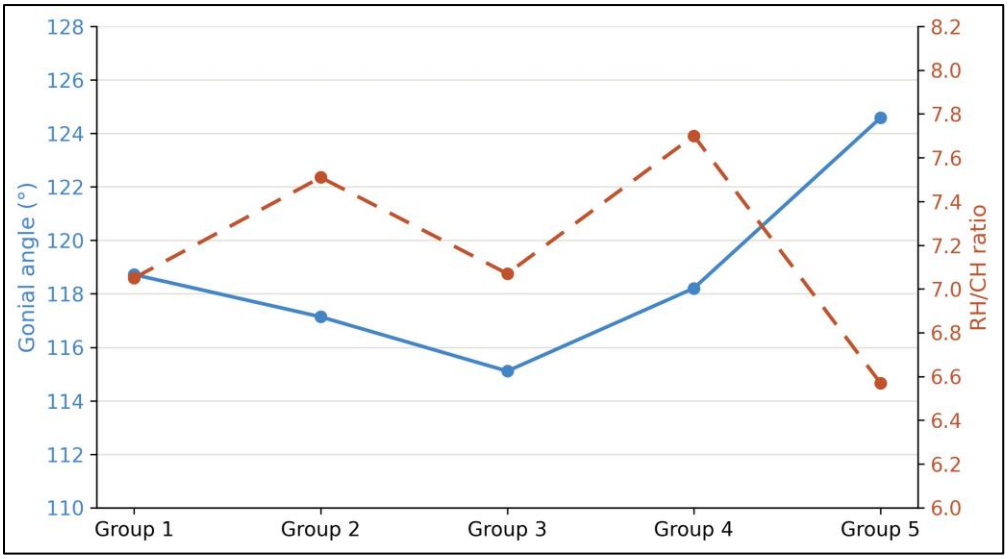

Figure 3. Change of GA and the RH/CH Ratio by Group

(The Figure Was Created by The First Author)

Between-Group Comparison on the Basis of GA

Variance homogeneity held (Levene F=1.90, p=0.113), so One-Way ANOVA with Tukey HSD was used in the sensitivity analysis. The group effect for GA was significant in the mixed model and confirmed by ANOVA on the per-patient right–left mean (F=10.58, p<0.001). In Bonferroni-corrected pairwise comparisons (Table 2), Group 5 had a significantly higher GA than each of the other four groups. The overall effect size was large (eta-squared=0.168), and Cohen's d for Group 5 versus the other groups ranged 0.87–1.50 (large).

Table 2. Bonferroni-Corrected Pairwise Group Comparisons For GA, Based on The Linear Mixed-Effects Model

Comparison	Mean difference, °	95% CI	p (Bonferroni)
Group 1 – Group 2	1.59	-1.63 ; 4.81	0.660
Group 1 – Group 3	3.61	0.46 ; 6.76	**0.015**
Group 1 – Group 4	0.51	-2.31 ; 3.33	0.988
Group 1 – Group 5	-5.86	-9.12 ; -2.59	**<0.001**
Group 2 – Group 3	2.02	-1.00 ; 5.04	0.355
Group 2 – Group 4	-1.08	-3.76 ; 1.60	0.805
Group 2 – Group 5	-7.45	-10.59 ; -4.3	**<0.001**

Comparison	Mean difference, °	95% CI	p (Bonferroni)
Table 2. (Continued)			
Group 3 – Group 4	-3.10	-5.69 ; -0.51	**0.010**
Group 3 – Group 5	-9.47	-12.54 ; -6.4	**<0.001**
Group 4 – Group 5	-6.37	-9.10 ; -3.64	**<0.001**

The effect size calculated for the general model (eta-squared = 0.168) was large according to Cohen's criteria. In the pairwise comparisons between Group 5 and the other four groups, Cohen's d values ranged between 0.87 and 1.50, and again showed a large effect size.

Between-Group Comparison on the Basis of the RH/CH Ratio

Because RH/CH deviated significantly from normality in all groups except Group 1 (Shapiro–Wilk p=0.294 for Group 1; p<0.02 otherwise, with right-skewed distributions in Groups 2–5), between-group comparisons used the Kruskal–Wallis test, which was significant (H=11.22, p=0.024). In the Dunn post-hoc test (Bonferroni-corrected), only Group 4 versus Group 5 was significant (p=0.027). In the mixed model, the group effect for RH/CH was significant only for Group 2 versus Group 5 (p=0.021) and Group 4 versus Group 5 (p<0.001) (Table 3). Mixed-model residuals deviated from normality (Shapiro–Wilk p=0.001), but skewness and kurtosis were slight (0.36 and 0.68) and mixed models are robust to moderate violations, so this was considered not to materially affect the results. The overall effect size was small (epsilon-squared=0.035); Cohen's d for Group 4 versus Group 5 was 0.61 (medium–large).

Table 3. Bonferroni-Corrected Pairwise Group Comparisons for The RH/CH Ratio, Based on The Linear Mixed-Effects Model

Comparison	Difference	95% CI	p (Bonferroni)
Group 1 – Group 2	-0.45	-1.32 ; 0.41	0.605
Group 1 – Group 3	-0.01	-0.86 ; 0.83	1.000
Group 1 – Group 4	-0.64	-1.40 ; 0.11	0.135
Group 1 – Group 5	0.48	-0.39 ; 1.36	0.553
Group 2 – Group 3	0.44	-0.37 ; 1.25	0.573
Group 2 – Group 4	-0.19	-0.91 ; 0.53	0.948

Comparison	Difference	95% CI	p (Bonferroni)
Table 3. (Continued)			
Group 2 – Group 5	0.94	0.09 ; 1.78	**0.021**
Group 3 – Group 4	-0.63	-1.32 ; 0.06	0.094
Group 3 – Group 5	0.50	-0.32 ; 1.32	0.462
Group 4 – Group 5	-1.13	-1.86 ; -0.40	**<0.001**

Comparisons Within the Same Database

Within the pediatric database, Group 1 and Group 2 did not differ in GA (t=1.22, p=0.227) or RH/CH (Mann–Whitney U=497, p=0.447). Within the Tufts database, Groups 3–5 differed significantly in both GA (F=17.52, p<0.001) and RH/CH (H=9.44, p=0.009), with sources detailed in Tables 2 and 3. Cross-database comparisons (e.g., Group 2 vs. Group 3) carried data-source confounding and were reported only descriptively, not for causal interpretation.

DISCUSSION

In this study, GA and the RH/CH ratio were compared among five groups defined according to the functional occlusal status of the mandibular molar teeth. GA was found to be significantly higher in total edentulism compared with the other four groups. In contrast, no significant difference was found between the pre-functional and functional pediatric groups within the same database. The RH/CH ratio, on the other hand, showed a much more limited sensitivity in group discrimination.

It has been reported that the loss of the molar teeth that participate in mastication in the mandible, in association with the decrease in the functional load at the mandibular corner region, leads to widening in the GA. Fouda (25), in a study on cone-beam computed tomography images, reported that GA was significantly larger in edentulous individuals compared with dentate individuals. Similarly, Huumonen (8) showed that GA was significantly wider on both sides in edentulous individuals compared with dentate individuals. Manja (26) reported that in the Bataknese population, partial tooth loss was

associated with an increase in GA. The GA elevation detected in the totally edentulous group in this study resembles the literature findings and is consistent with the sharp increase detected in total edentulism in the present study. This concordance supports the view that edentulism-related GA widening is a reproducible finding in different populations and with different imaging methods.

The complete loss of the occlusal relationship, by disrupting the balance of the stomatognathic system more markedly than partial loss, may trigger a strong remodeling in the mandible. Zheng (27), in their systematic review regarding the changes that edentulism gives rise to in the temporomandibular joint structure, reported that the complete loss of the occlusal relationship disrupts the balance of the stomatognathic system and may lead to morphological changes in the joint components. Within the pediatric database, no significant difference in GA was observed between the pre-functional and functional groups ($p=0.227$). Within the Tufts database, GA widened significantly with partial molar loss ($p=0.010$) and showed the most pronounced widening in total edentulism ($p<0.001$). This finding shows that GA's sensitivity to gradual tooth loss is moderate, whereas its sensitivity to complete functional loss (total edentulism) is high. This finding is consistent with findings showing that the effect of total and partial tooth loss on the mandibular bone is quantitatively different. Tallgren (28), in a 25-year longitudinal study, reported that mandibular bone loss in individuals using complete dentures was significantly greater compared with those using partial dentures. The association of partial molar loss and total edentulism with a significant increase in GA compared with the adult functional dentition state, and the largest change being observed in total edentulism, may be connected with the relationship between the magnitude of the functional/bone loss and GA widening. However, this interpretation needs to be evaluated carefully. Because age information was not available in the databases used, and because the edentulous population tends to be systematically older, it was not possible to distinguish the effect of aging from the effect of tooth loss. For this reason, it was not possible with the present design to distinguish how much of the GA widening observed in Group 5 was due to functional loss and how much to a mere age effect.

The functional relationship between the mandible and the occlusal plane of the teeth causes structural changes along the ramus and condyle (8, 29). Huumonen (8) reported that in

edentulous individuals RH and CH were significantly lower compared with dentate individuals, but that this decrease was more pronounced in RH. Öçal (22) also reported that the asymmetry indices calculated from CH and RH measured with the Habets method used in the present study did not show a statistically significant difference between dentate and totally edentulous patients. In the present study, on the other hand, the CH and RH obtained with the same measurement method were evaluated as the RH/CH ratio rather than as an asymmetry index. For this reason, the ratio results of the present study cannot be directly compared with literature findings that use absolute linear measurements. The RH/CH ratio ranged between 6.57 and 7.70 among the groups, and the overall Kruskal-Wallis test showed a statistically significant difference. However, in the post-hoc analysis this difference was significant only between the partial molar loss and total edentulism groups ($p<0.001$). No significant difference was found between the adult functional dentition and total edentulism groups. The absence of a significant difference in the dentate– edentulous comparison (Group 3 – Group 5) is consistent with the results reported by Öçal (22) and indicates that proportional evaluation based on the same measurement method may show limited sensitivity to dentate–dentate discrimination. In contrast, the significant difference found between partial molar loss and total edentulism is a comparison not reflected in the Öçal (22) study. The decrease in the ratio in total edentulism can be explained by the decrease in RH being more pronounced than the decrease in CH, and is consistent with the information reported by Huumonen (8). However, this interpretation can be evaluated not as a definite biological mechanism but as a hypothesis. Because the absolute linear measurements were not calibrated in the present study, the extent to which RH and CH changed could not be shown.

In the early mixed dentition period, mandibular growth proceeds together with the general skeletal growth and maturation process, independently of the functional contact of the teeth (9). For this reason, it is thought that the participation of the molar tooth in functional contact in this period does not significantly affect mandibular morphology. This view is consistent with the developmental course of GA, which is explained by the ramus growing and becoming more vertically oriented at a faster rate than the body from birth to adulthood. The absence of a significant difference between the pediatric pre-functional and pediatric

functional groups in terms of GA and the RH/CH ratio in the present study is consistent with this view and suggests that molar function makes a relatively limited contribution to the early developmental process.

Our findings showed that GA increased significantly together with both partial molar loss and total edentulism, and that the most pronounced widening was observed when all teeth were lost. Within the limits of the present sample, this observation suggests that GA may be sensitive to functional occlusal status even before complete tooth loss, with the most pronounced difference seen in the totally edentulous group. However, given the restricted sample size and the fact that only two morphometric parameters were evaluated, this finding should be regarded as descriptive and requires confirmation in larger, prospectively designed samples. The RH/CH ratio was weaker than GA in distinguishing the groups. For this reason, we think that the use of the RH/CH ratio together with GA in clinical evaluation would be a more reliable approach.

Limitations

This study was carried out retrospectively using panoramic radiographs obtained from publicly available databases. For this reason, clinical information regarding denture use, implant placement, duration of edentulism, and the cause of tooth loss in the adult groups was not available, and functional occlusion was evaluated only through radiographs. This limitation is particularly important for Group 5 (total edentulism), Because this group contained individuals with and without dentures, those with or without a denture in the opposing jaw, and individuals with different durations of edentulism. This situation suggests that Group 5 may have a more heterogeneous functional load profile than it appears. Further studies in which this information is available and in which groups based on denture use and opposing jaw status are included may better reveal the effect of the possible variability within Group 5. Accordingly, the reversal mechanism reported by Yanıkoğlu and Yılmaz (12), in which GA widened after extraction and then slowly returned toward baseline with denture use, could not be assessed in the present study owing to the absence of clinical records in the databases. The GA widening observed in Group 5 should therefore be interpreted independently of the duration and quality of denture use. Similarly, for Group 3, the

comparability of the 40 cases randomly selected from the 878-case pool with the general pool in terms of measurable characteristics could not be directly tested. Measurement data for the non-selected cases in the pool had not been recorded. Although computer-assisted randomized sampling was used to ensure that the selection was not systematically biased, this limitation can be remedied in future studies by recording baseline characteristics (for example, age or a pre-screening GA value). Because the pediatric and adult/dentate groups were obtained from different databases, there is a heterogeneity that may arise from radiograph equipment and population differences. The fact that the angular and proportional parameters are not affected by pixel size and magnification largely limits this situation. Because the databases used did not contain individual age and sex information of the patients, the known age- and sex-related variability of GA could not be controlled in this study. This means that there may be a separate effect of age on the differences observed in the between-group comparisons, and that this effect cannot be separated from the group effect.

This study is cross-sectional and descriptive in nature and does not aim to draw causal conclusions regarding the differences observed among the groups. Particularly the values observed in the pediatric groups may also be related to the growth and maturation process, which cannot be separated from the effect of the molar functional status. For this reason, the obtained values should be evaluated in the context of each group's own age and dentition stage. Despite these limitations, the study provides reference data to the literature by defining the GA and RH/CH ratio values for five groups extending from the pre-functional pediatric period to total edentulism.

CONCLUSION

This study presents descriptive radiomorphometric reference values for GA and the RH/CH ratio for different functional occlusal states extending from the pre-functional pediatric period to total mandibular edentulism. The findings suggest that, among these groups, GA is a more sensitive parameter than the RH/CH ratio in demonstrating mandibular morphological changes.

In the comparisons within the same database, GA increased gradually from adult functional dentition toward partial molar loss and total edentulism. Among the pediatric groups, on the

other hand, no significant difference was detected. Because the RH/CH ratio provided group discrimination only at a limited level, the use of this ratio together with GA in mandibular radiomorphometric evaluations may be recommended. Owing to the cross-sectional design of the study and the limitations of the databases, the findings should be interpreted not as causal but as descriptive reference data.

Ethics and Declarations

Ethics Committee Approval: This study was conducted using publicly available and fully anonymized panoramic radiography databases that contain no institutional identifiers, patient names, or sensitive personal data. As the datasets are open access and anonymized, ethics committee approval was not required. The license and terms of use of both databases were complied with, and the data were used solely for scientific research purposes.

Author Contributions: Conceptualization – AK; Design – AK; Supervision – AK; Materials – MFÖ, HZBG; Data Collection and/or Processing – AK, HZBG; Analysis and/or Interpretation – TA; Literature Review – MFÖ, TA; Writing – AK, HZBG, TA; Critical Review – TA. The contributions of authors to the study are indicated by the initials of their names and surnames in parentheses.

Artificial Intelligence Usage Statement: During the preparation of this manuscript, the authors used a generative AI tool (Claude, Anthropic) solely for language editing and for the technical preparation of tables and figures from the authors' own data. These tools were not used for the study's conception, design, data measurement, statistical analysis, or interpretation of the findings, all of which were carried out entirely by the authors. All authors reviewed and verified the content and take full responsibility for the scientific integrity, originality, and accuracy of the work.

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Accessibility of Data and Materials: The datasets analyzed in this study are openly available. The pediatric dataset (Children's Dental Panoramic Radiographs Dataset) is available at https://doi.org/10.6084/m9.figshare.21621705, and the adult/edentulous dataset (Tufts Dental Database) is available at https://tdd.ece.tufts.edu/.

Ethics Statement: It is hereby declared that scientific and ethical principles were followed during the preparation of this study, and all utilized works are cited in the references.

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