Original Article

Measurements of Mandibular Length: A Comparison of Articulare vs Condylion

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Abstract: This study examines the validity of articulare for mandibular length measurements by exposing 3 lateral cephalograms on each of 60 consecutive patients. The radiographs were exposed with the patient in a closed-mouth position in habitual occlusion, a closed-mouth position with the patient in centric relation, and in an open-mouth position. The linear distances (mm) of articulare (Ar) to pogonion (Pog), Ar to gonion (Go), and Go to Pog were measured on the 2 closed-mouth cephalograms and compared with each other as well as the linear distances of condyle (Co) to Pog, Co to Go, and Go to Pog measured from the open-mouth cephalogram on each individual. Product-moment correlation coefficients were used to measure the linear associations among the mandibular measurements from the 3 techniques. Repeated measures analyses of variance were also fit to estimate the correlations between the 3 measurements adjusted for age and sex. The results of this study show that measurements taken from both closed-mouthed techniques agreed extremely well (intraclass correlation coefficient = 0.99). In addition, measurements from both closed-mouth techniques highly agreed with the corresponding measurements taken with the open-mouth technique (intraclass correlation coefficient = 0.94). This data suggests that measurements taken from Ar correlate very well with measurements taken from Co and that this correlation is not dependent on whether the patient is positioned in habitual occlusion or centric relation. (*Angle Orthod* 2001;71:210–215.)

Key Words: Open-bite cephalogram; Condylion; Articulare; Leaf gauge; J-point; Mandibular growth; Functional appliances

INTRODUCTION

Mandibular length is often defined as the linear distance between the Co (the most superior point on the head of the condyle[1]) and the pogonion (Pog), gnathion, or menton—the most anterior, anterior-inferior, and inferior points on the chin, respectively.[2] The use of Co for determining mandibular length is technically difficult because Co is often obscured in the standard closed-mouth lateral cephalogram by superimposition of cranial base and middle cranial fossa structures.[3] Several researchers have shown that Co cannot be accurately and consistently located on the closed-mouth lateral cephalogram.[4,5] A method that increases the reliability of accurately locating Co is the open-mouth lateral cephalogram.[5,6] Retrospective studies are unable to adequately localize Co because open-mouth lateral cephalograms are rarely used in conventional orthodontic diagnosis and treatment. Most studies have used articulare (Ar)[7–12] as a substitute for Co. Ar is defined as the point of intersection of the images of the posterior border of the ramal process of the mandible and the inferior border of the basilar part of the occipital bone.[13] In 1947, Bjork[14] introduced the term *articulare*. The constructed Ar is routinely taught as landmark point for determining mandibular growth. Determining the validity of Ar for the measurement of mandibular length would be of tremendous value in evaluating studies of mandibular growth and growth modification.

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MATERIALS AND METHODS

Experimental design

This study involved patients of any age, sex, or malocclusion for inclusion criteria. Exclusion criteria consisted only of pregnant women and patients with a history of temporomandibular dysfunction. Three lateral cephalograms were taken on each individual: (1) a closed-mouth lateral cephalogram was exposed in habitual occlusion, (2) A closed-mouth lateral cephalogram was exposed in centric relation by using the leaf gauge technique as described by Williamson et al,[15] and (3) an open-mouth lateral cephalogram was exposed after we instructed the patient to open ''as wide as possible without pain.''

The following quality controls were introduced during the collection of the lateral cephalograms to ensure consistency in radiographic technique and patient positioning. All lateral cephalograms were exposed and developed by the same X-ray technician. All radiographs were exposed on the same day with the same cephalometer. A single orthodontic practitioner took all closed-mouth lateral cephalograms in centric relation. The mandible was traced on acetate tracing paper (3M Unitek, Monrovia, Calif.) by using a mechanical pencil with a 0.5-mm lead. For consistency and to minimize the effect of magnification errors, the left mandibular body and ramus were traced on each cephalogram, whereas the left Co was traced only on the open-mouth cephalogram. The anterior Co was traced by following the left body of the mandible posteriorly. The left Co was defined as the most anterior and in focus.

Ar, Pog, and gonion (Go) were identified on the closed-mouth habitual occlusion (CM-HO) and closed-mouth centric relation (CM-CR) mandibular tracings. Co was identified instead of Ar on the open mouth (OM) mandibular tracings. Pog and Go were also identified on the OM mandibular tracing. Four linear measurements were made on each of the above mandibular tracings. The linear distances on the CM-HO and CM-CR tracings from Ar to Pog, Ar to Go, Go to Pog, and the maximum distance of Ar to the anterior contour of mandibular symphysis were measured. Co was substituted for Ar on the OM mandibular tracing. Measurements were made with a millimeter gauge approximated to the nearest 0.5 mm. A total of 12 measurements were made for each participant in the study.

To determine intra-examiner repeatability, the cephalograms of 15 randomly selected participants were retraced and remeasured by the same orthodontic resident with a 2-week interval between the first and second tracing and measurement sessions. To determine interexaminer repeatability, a second blinded orthodontist traced the cephalograms of 15 randomly selected participants.

Statistical analysis

The sample size of 60 patients was chosen because a 95% lower confidence bound for a univariate correlation coefficient would be within 0.2 of the correlation estimate if the correlation were moderate (around 0.5) and within 0.1 of the correlation estimate if the correlation were substantial (around 0.8). Plots were used to assess whether the techniques are associated in a nonlinear manner. Agreement between the techniques was assessed by using mixed-effect analysis of variance (ANOVA) models. The ANOVA models provided comparisons between techniques, with age and sex included in the models as covariates. The models also allowed for computation of intraclass correlation coefficients (ICCs) to measure the agreement between the techniques. Intraexaminer and interexaminer repeatability were examined by using paired *t*-tests to compare means and ICCs to assess agreement within and between examiners. Within-sample measurement errors were computed by using the repeatability data, which can be used to represent the measurement error within an examiner and between examiners.[16]

TABLE 1. Intraclass Correlation Coefficients (ICCs) Between Measurements for the 3 Cephalometric Techniques[a,b]

Variable	CR and HO	CR and Open	HO and Open
Go-Pog	.93	.94	.90
Ar-Pog or CO-Pog	.99	.94	.93
Ar-max or Co-max	.99	.94	.93
Ar-Go or Co-Go	.94	.63	.64

[a] Methods show strong agreement (ICC > 0.9) except for those measurement in bold.

[b] CR indicates centric relation; HO, habitual occlusion; Open, open mouth; Go, gonion; Pog, pogonion; Ar, articulare; and Co, condylion.

RESULTS

Agreement between measurement techniques

Table 1 depicts the ICCs for each measurement among the 3 cephalometric techniques. As Table 1 shows, measurements of mandibular body length (Go to Pog) and measurements of overall mandibular length (Ar/Co-Pog and Ar/Co-max) highly agree (ICC = 0.90–0.99) among all 3 cephalometric techniques.

Measures of ramal height (Ar/Co-Go) highly agree between the 2 closed-mouth techniques but were only moderately correlated between the closed-mouth techniques and the open-mouth technique (ICC = 0.63–0.64). One would expect that measurements of the mandibular body would strongly agree between cephalometric techniques. These data clearly indicate that measurements of overall mandibular length taken from Ar with either a centric relation or habitual occlusion closed-mouth cephalogram are valid for measurements of overall mandibular length. On the other hand, the use of Ar for measurement of ramus length is not warranted.

Comparison of the 3 cephalometric techniques

Table 2 compares the 3 cephalometric techniques. The presence or absence of the leaf gauge technique did not significantly affect the Go-Pog measurement ($P = .37$). The use of the leaf gauge significantly affected the different measures of overall mandibular length (Ar-Pog, $P = .0079$; Ar-max, $P = .0060$), whereas the measure of ramal height (Ar-Go) was not significantly affected ($P = .78$).

TABLE 2. Comparison of Measurements Between Leaf Gauge (LG), Habitual Occlusion (HO), and Open Mount (OM) Cephalograms

Landmark[a]	Variable	n	Mean	SD	SE	Min	Max	P Value
Go-Pog	Leaf gauge	60	79.6	5.6	0.7	68.0	90.0	
	Habitual occlusion	60	79.8	5.4	0.7	68.5	92.0	
	Open mouth	60	79.0	5.4	0.7	69.0	89.0	
	Leaf—habitual	60	−0.2	1.9	0.2	−9.5	3.5	.37
	Leaf—open	60	0.6	1.8	0.2	−3.5	5.5	.0127
	Habitual—open	60	0.8	2.3	0.3	−3.0	12.0	.0085
Ar-Pog or Co-Pog	Leaf gauge	60	113.2	7.6	1.0	94.0	132.0	
	Habitual occlusion	60	113.5	7.7	1.0	95.0	132.0	
	Open mouth	60	120.4	8.3	1.1	101.0	142.0	
	Leaf—habitual	60	−0.4	1.0	0.1	−4.0	1.5	.0079
	Leaf—open	60	−7.2	2.6	0.3	−13.0	−2.0	.0001
	Habitual—open	60	−6.9	2.8	0.4	−13.0	0.0	.0001
Ar-Max or Co-Max	Leaf gauge	60	113.3	7.6	1.0	94.0	132.0	
	Habitual occlusion	60	113.6	7.7	1.0	95.0	132.0	
	Open mouth	60	120.7	8.3	1.1	101.0	142.0	
	Leaf—habitual	60	−0.4	1.0	0.1	−4.0	2.0	.0060
	Leaf—open	60	−7.4	2.6	0.3	−13.0	−2.0	.0001
	Habitual—open	60	−7.1	2.8	0.4	−13.0	0.0	.0001
Ar-Go or Co-Go	Leaf gauge	60	47.0	6.2	0.8	35.0	63.0	
	Habitual occlusion	60	46.9	5.9	0.8	33.0	61.0	
	Open mouth	60	60.2	7.8	1.0	35.5	82.0	
	Leaf—habitual	60	0.1	2.1	0.3	−5.0	9.0	.78
	Leaf—open	60	−13.2	5.9	0.8	−22.0	21.5	.0001
	Habitual—open	60	−13.3	5.6	0.7	−23.5	18.5	.0001

[a] Ar indicates articulare; Co, condylion; Pog, pogonion; and Go, gonion.

TABLE 3. Intraexaminer and Interexaminer repeatability[a]

Technique	Length	Within-examiner Measurement Error, mm	Intraexaminer ICC	Between-examiner Measurement Error, mm	Interexaminer ICC
Centric relation	Ar-Go	1.56	0.96	1.49	0.93
	Go-Pog	1.72	0.92	1.81	0.88
	Ar-Pog	0.53	0.99	1.22	0.97
	Ar-Max	0.50	0.99	0.58	0.99
Habitual occulsion	Ar-Go	0.82	0.99	1.40	0.92
	Go-Pog	0.72	0.99	1.38	0.93
	Ar-Pog	0.66	0.99	1.13	0.97
	Ar-Max	0.68	0.99	0.41	0.99
Open mouth	Co-Go	1.58	0.97	1.65	0.89
	Go-Pog	0.91	0.98	1.00	0.96
	Co-Pog	0.54	0.99	2.25	0.91
	Co-Max	0.53	0.99	1.39	0.97

[a] ICC indicates intraclass correlation coefficient; Ar, articulare; Go, gonion; Co, condylion; and Pog, pogonion.

It is important to note, however, that the difference of the means was only 0.3 mm for both Ar-Pog and Ar-max. Therefore, although statistically significant, it is probably not clinically significant when the 0.5-mm within-sample measurement error is taken into consideration (see Table 3). Thus, the use of the leaf gauge technique does not appear to be a critical factor for ensuring the validity of mandibular measurements taken from Ar.

Repeatability of measurements

The measurements showed excellent intraexaminer repeatability. As Table 3 shows, intraexaminer ICCs were very high (ICC = 0.92–0.99). A statistically significant (P = .0224) difference between the first and second measurements was noted only for Ar-max in the leaf gauge cephalogram. However, the mean difference between the 2 measurements was only 0.4 mm. Although statistically significant, a 0.4-mm mean difference is probably not clinically significant because it is less than the 0.5-mm within-sample measurement error for Ar-max in the LG cephalogram (Table 3).

The measurements also demonstrated very good interexaminer repeatability. Table 3 depicts high interexaminer ICCs (ICC = 0.88–0.99). It can be appreciated that although interexaminer ICCs were high, they are somewhat lower than intraexaminer ICCs. This reflects a systematic and significant ($P < .01$) difference between the 2 examiners in the measurement of Ar/Co-Pog for all 3 techniques. It can also be appreciated in Table 3 that the between-examiner measurement error is higher than within-examiner measurement error for all measurements except the Ar-max in the habitual occlusion cephalogram.

DISCUSSION

One would expect that measurements of the mandibular body would highly correlate between cephalometric techniques. These data clearly indicate that measurements of overall mandibular length taken from articulare with either a centric relation or habitual occlusion closed-mouth cephalogram are valid for measurements of overall mandibular length. However, the use of Ar for measurement of ramus length does not seem warranted. The geometry of the mandible is very much like a triangle with the hypotenuse of Ar-Pog/Max or Co-Pog/Max. The combined horizontal and vertical differences between Ar and Co seem to be linearly correlated, whereas the strictly vertical differences are not.

Comparison of correlation results with previous studies of Ar

Controversy surrounds Ar's validity. Aelbers and Dermaut[3] stated that a change in the amount and direction of growth does not necessarily create the same positional change of Ar. Stickel and Pancherz[17] noted that the posture of the mandible might also affect the position of Ar as with anterior, posterior, and lateral forced bites and dual bites. Thus, if Co position is altered during orthodontic treatment, the distance between Ar and Pog, for example, could change without any actual alteration in mandibular length. Nelson et al[18] further asserted that ''articulare should not be used'' in studies of mandibular growth. Intuitively, their arguments make sense: the position of Ar can change with mandibular position, and these changes in position may not correspond to the actual direction and magnitude of mandibular growth. However, intuition is not equivalent to evidence.

As noted in the literature review, only 4 studies have examined Ar. Stickel and Pancherz[17] looked at mean differences between measurements taken from Co/Ar-Pog. They found a mean difference of 6.3 mm (SD = 2.6 mm), which did not change over an interval of 3.5 years. This study found a comparable mean difference of 7 mm between Co/Ar-Pog, although the standard deviation was greater (8.3 mm). However, this study did not examine the change in mean differences over time.

Love et al[19] and Foley and Mamandras[20] found reasonably high correlations between Co-Pog and Ar-Pog (r = 0.84 and 0.75, respectively). Unfortunately, these studies examined narrow population parameters in age and sex. This study looked at a wide variety of ages and both sexes. As noted in Table 1, extremely high agreement was found in all measures of overall mandibular length and length of the mandibular body (ICC = 0.90–0.99). The correlation was much weaker, however, for measurements of ramal height between closed- and open-mouth techniques (ICC = 0.63–0.65).

Finally, the study by Hägg and Attstrom[21] found that mean measurements of overall mandibular growth (Co/Ar-Pog) were not significantly different over a 6-year period. This agrees with our results of a very high agreement (ICC = 0.93–0.94) between closed-mouth cephalometric measures of Ar-Pog and open-mouth measures of Co-Pog. Thus, on the basis of our cross-sectional data, Ar can be used as a substitute for Co in measurements of overall mandibular length, but not for measurements of ramal height.

Comparison of measurement error with previous studies

A number of studies have examined the amount of error associated with landmark identification and measurement error.[4,21] In addition, several noted that the major source of error in measurements from cephalograms is landmark identification.[3,22] Savara et al[22] determined that landmark location variability is about 5 times that caused by measurement. Baumrind and Frantz[23] found that Pog estimation error was 1.06 ± 0.36 mm, whereas estimation error of Go was 3.48 ± 1.12 mm. Forsberg and Odenrick[24] estimate the error of Co identification to be 0.69 mm. Several studies also show that the estimation error of Co is significantly decreased with the use of an open-mouth cephalogram.[4] Unfortunately, no studies were found that examined the estimation error of Ar.

This study did not examine the error associated with individual landmarks. However, the within-examiner measurement error for the various measures of mandibular length ranged from 0.5 to 1.72 mm (Table 3). Between-examiner measurement error ranged from 0.41 to 2.25 mm (Table 3). These results are consistent with the findings of Savara et al.[22] They found a within-sample error of 0.72 mm for Co-Go, 1.34 mm for Go-Pog, and 0.42 mm for Co-Pog. They also found the between-sample measurement error to be 2.22 mm for Co-Go, 1.34 mm for Go-Pog, and 2.07 mm for Con-Pog. These data suggest that the measurement error for this study is comparable with that found previously. The results should be viewed with caution for individual growth changes that use Ar as a reference point. Group comparisons using the substituted Ar for Co would seem more appropriate.

Cephalometry and detection of mandibular growth

This study has shown that intrameasurement error can range from 0.50 to 1.72 mm for the various measures of mandibular cephalometric dimensions (Table 3). Given this range of error associated with landmark identification, can it be reasonable to detect small changes in mandibular length by using lateral cephalometry? Baumrind and Frantz[23] state that the observed difference as a result of therapy should be at least twice the standard deviation of the estimating error. In the normal individual, the mandible grows 1–2 mm/y.[23] With functional appliances, we are trying to detect an additional 1–2 mm/y.[12] Given that landmark identification error is in the range of 1–2 mm, errors in landmark identification do not meet Baumrind and Frantz' criteria. Thus, it is difficult to distinguish between a biological response to functional appliances and a measurement error. Large HO-CR discrepancies, as in a posturing Sunday-bite, may reflect measurement differences between Ar and Co.

A refinement in describing mandibular growth that uses other than the defined Co is needed. A new landmark should be established describing the superior-posterior landmark point for determining linear mandibular growth. It is suggested by convention that the landmark be called *J-point* after the 2000 Jarabak Awardee, James J. Baldwin.

Two options exist to correct this problem: find a way to decrease measurement error in cephalometry, or consider an alternative method to cephalometry. It seems unlikely that the measurement error of cephalometry can be significantly reduced. However, recent advances in computer tomography scans and magnetic resonance imaging (MRI) technologies provide alternative method for imaging the Co and the temporomandibular joint complex. Some studies have already been published that look at mandibular growth by using MRI techniques.[25] The future of mandibular growth research will be using the third dimension.

CONCLUSIONS

The major aim of this study was to establish the validity of using Ar as a measure of mandibular length. In addition, we wished to determine whether this validity was influenced by 2 mandibular positioning techniques. The results of this study were decisive. Measurements with Ar strongly agree (ICC = 0.93–0.94) and, therefore, are a good proxy measurement for Co when measuring overall mandibular length (Ar-Pog/Max). However, Ar is not a good substitute for Co when measuring ramus height (ICC = 0.63–0.65). Cephalometric technique did not influence the validity of using Ar for measuring overall mandibular length. The measurements showed (Table 3) excellent intra- and inter-examiner repeatability. An analysis of the measurement error suggests that detection of small amounts of mandibular length change associated with functional appliances would be difficult to distinguish from measurement error.

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