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ORIGINAL ARTICLES

Variability of the craniofacial skeleton

III. Radiographic cephalometry of juvenile Macaca mulatta

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Although the rhesus monkey (*Macaca mulatta*) has been used in a great number of craniofacial studies, the normal variation in the craniofacial anatomy of this animal has received little attention.[1, 7] This article will report the results of a radiographic cephalometric study on a sample of juvenile *Macaca mulatta*, using a recently introduced analytical method.[3,12] The findings in this species will be compared to findings from similarly studied samples of young human children and adults.[14]

Material and methods

Twenty-three lateral cephalograms of juvenile *Macaca mulatta*, taken in the course of an extensive series of investigations,[1, 5, 6] were used for this study. The radiographs were taken of animals approximately 18 to 24 months of age, as determined by the emergence into occlusion of the first permanent molars.[2] The occlusion of all animals corresponded to Angle Class I; that is, there were no recognizable deviations from the so-called normal occlusion. The monkeys had not been subjected to any experiments prior to the time these films were obtained.

The original cephalograms were traced on 0.03 acetate sheets by one of us (K. K.). From the tracings, angular relationships between fourteen lines de-

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Table I. Means and variances of craniofacial angles in a sample of twenty-three Macaca mulatta

Lines	*ORB*	*SPHEN*	*INFRA*	*PAL*	*OCCL*	*AMC*
ORB		37.9	60.1	50.1	54.7	58.0
SPHEN	27.92		22.2	12.2	16.8	20.1
INFRA	20.04	25.65		10.0	5.4	2.1
PAL	32.92	33.56	23.88		4.6	7.9
OCCL	21.24	38.91	15.39	14.48		3.3
AMC	20.13	48.96	22.60	16.95	7.56	
MAND	31.10	46.90	23.20	20.48	14.17	11.74
PMC	23.02	22.43	26.34	32.46	21.88	32.84
RAMUS	22.26	48.66	32.20	34.91	29.92	26.11
COND	26.04	51.61	38.81	37.70	20.70	23.78
PTER	58.00	79.45	65.01	59.88	53.67	49.13
CLIVUS	26.97	46.63	48.15	57.87	58.88	53.18
PHAR	27.62	45.03	24.57	32.61	27.81	24.00
FOR	20.36	35.04	28.64	37.85	30.00	28.45

picting craniofacial structures were studied (Fig. 1). The lines selected for analysis corresponded to those used in our previous study,[14] with one exception: the posterior border of the mandibular condyle, which was used previously, proved to be difficult to determine and was replaced by a line bisecting the condylar process. It should be mentioned here that these two lines, which can be used to depict the orientation of the condyle, have practically identical directions in human subjects.

Only one set of thirteen angles was actually measured by one of us (H. V.), namely, that formed by the line representing the spheno-ethmoidal plane (SPHEN) with the other lines. The rest of the ninety-one angles were calculated on the basis of the measured set. The majority of the angles were read as opening facially/ventrally.[3, 14] Since it has been shown that the variability of angles depends partly on certain topographic aspects related to the arms of angles,[10] the lines on which the measurements were based were drawn or visualized as equidimensional as possible and were not extended to meet each other (Fig. 1).

The statistical treatment of the data consisted of calculating the mean and the variance for each angle. In comparing the means and variances within the present data and with the human data, t and F tests were used where appropriate.

Results and discussion

The results of the analysis in *Macaca mulatta* are presented in numerical form in Table I.

The present method is based on the idea that radiographic cephalometric analysis should utilize landmarks and lines based on truly anatomic structures as much and as closely as possible, even at the risk of losing some of the technical precision that has been characteristic of traditional cephalometric methods which have employed clearly definable but not necessarily biologically meaningful points. The intraobserver error in this method has been found to be not significant (at the 0.05 risk level) when tested by double determinations.[13]

monkeys

MAND	*PMC*	*RAMUS*	*COND*	*PTER*	*CLIVUS*	*PHAR*	*FOR*
56.6	106.2	138.5	111.0	120.7	3.2	30.8	60.2
18.7	68.3	100.6	73.0	82.8	145.3	172.9	22.3
3.5	46.1	78.5	50.8	60.6	123.1	150.7	0.1
6.5	56.2	88.5	119.1	109.3	46.9	19.2	10.2
1.9	51.5	83.8	123.7	113.9	51.5	23.8	5.5
1.4	131.8	99.4	127.0	117.2	54.8	27.1	2.2
	130.3	98.0	125.6	115.8	53.4	25.7	3.7
33.60		32.3	4.7	14.5	103.0	75.4	134.0
27.20	32.13		27.6	17.8	135.3	107.7	101.7
38.34	33.16	39.69		9.8	107.8	80.1	129.3
61.99	65.36	47.72	71.93		62.5	89.6	119.5
54.60	53.88	40.76	84.72	79.41		27.7	123.0
28.50	49.01	42.38	53.50	82.90	32.08		150.6
40.96	36.61	29.11	39.09	54.63	41.42	23.27	

An examination of the means reveals instances of parallelism and perpendicularism among the ninety-one angles. These are, of course, special phenomena from the geometric standpoint; since geometry, as such, is of no importance, they could be passed without notice. However, some of these instances seem to raise the question of a possible biologic significance. For example, the lines depicting the neurovascular canals of the jaws seem to be running parallel to each other anteriorly (INFRA/AMC) while the posterior end of the mandibular canal and the condylar process (PMC/COND) have the same orientation. These relationships may be more than mere coincidences.[9] Similar parallel relationships are also found in human samples, both in children and in adults,[14] as regards the posterior end of the mandibular canal and the condylar process, even in human fetal material.[4]

When the means of the juvenile monkeys are compared with the means of a juvenile human sample of nearly corresponding age,[14] no significant differences (at the 0.05 risk level) are found for the angles SPHEN/INFRA, INFRA/AMC, INFRA/MAND, PAL/PTER, OCCL/PMC, AMC/MAND, PMC/COND, RAMUS/PTER, RAMUS/PHAR, and CLIVUS/FOR. Some similarities can be expected to exist merely on a random basis in two sets of ninety-one angles. A few of the listed relationships have similar values, even in human adults: INFRA/AMC, INFRA/MAND, PAL/PTER, and CLIVUS/FOR. Does this, then, indicate a biologic basis for the geometric similarity? The question cannot be answered at the present time.

In order to facilitate comparison within and between samples as regards the variability of craniofacial relationships, the variances have been calculated. The total range of variances and the total sum of all variances are somewhat greater in the juvenile *Macaca mulatta* than in the previously studied human samples. The difference is small and could well be due to topographic factors[10] arising from the smaller dimensions of the monkey. The median and mode variance values are identical in all three samples. Variability of linear dimensions generally increases with age,[11] that is, with increasing size. It appears, however, that the total variability within the craniofacial complex in terms of angular relation-

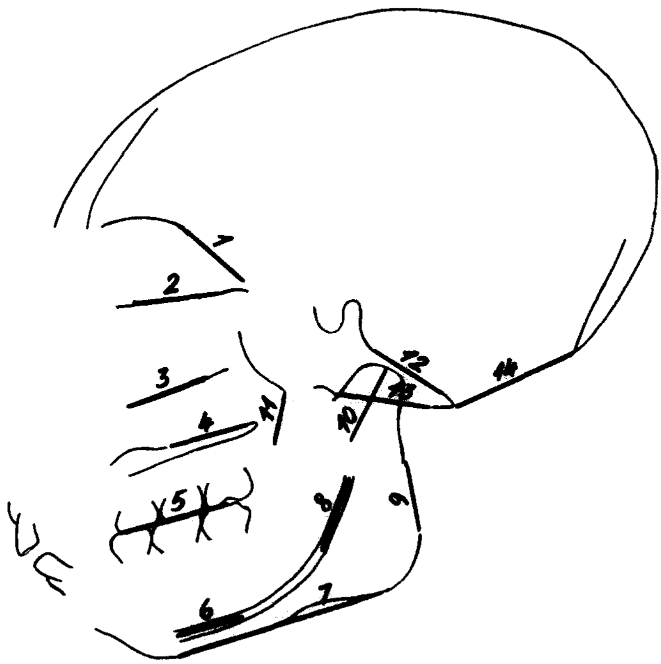

Fig. 1. The lines used in the cephalometric analysis of lateral radiograms of juvenile Macaca mulatta. **1,** Roof of the bony orbit, ORB. **2,** Spheno-ethmoidal plane, SPHEN. **3,** Infraorbital canal, INFRA. **4,** Posterior floor of the nasal cavity, PAL. **5,** Occlusal plane, OCCL. **6,** Anterior part of the mandibular canal, AMC. **7,** Tangent to the mandibular base, MAND. **8,** Posterior part of the mandibular canal, PMC. **9,** Tangent to the posterior border of the ramus, RAMUS. **10,** Bisector of the condylar process, COND. **11,** Tangent to the ventral surface of the pterygoid process, PTER. **12,** Cerebral surface of the clivus, CLIVUS. **13,** Pharyngeal surface of the clivus, PHAR. **14,** Foramen plane, basion-opisthion, FOR.

ships is unaffected by intra- and interspecies size differences. This may be one example of the "stability of overall pattern combined with variety of detail."[15]

It is understandable that if the number of variables chosen to represent homologous structures such as mammalian craniofacial skeletons is great, total variability figures (for example, the sums of variances) will not reveal intra- or interspecies differences. However, if the number of variables is small (the extreme case as regards angular relationships being two linear variables forming one angle), the chances of total variability figures being different are great indeed. As an example from our own data, the set of lines SPHEN, PAL, OCCL, PTER, and CLIVUS, which have markedly different variability rankings in *Macaca mulatta* and human children, was found to form a pattern of mutual angles that had significantly different ($P < 0.05$) sum total variances in these two species. In other words, the adaptive and compensating capacity of the parts was not evident because the choice of variables had fallen on too few and/or "wrong" parts of the whole complex, the skull.

Generally speaking, while well-chosen variables may be justifiably used to discriminate between structures at different stages of development or belonging to different species, a biologically unjustified discrimination effect may be obtained through unwise choice of variables.

It is not clear yet whether the kind of stability in the total pattern discussed above is maintained in grossly malformed structures, such as the more marked craniofacial malformations found in human beings. It may be postulated that if the shape of the structure is distorted to such an extent that the generally recognized genotypic boundaries are threatened, the principle of stability in the total variability pattern no longer fully applies. This problem needs further study.

The variability associated with individual lines and presumably with the structures they depict should also be considered. The majority of lines appear to be mainly involved in angular relationships of low variability: OCCL, ORB, AMC, INFRA, MAND, PAL, FOR, RAMUS, PMC, in ranking order on the basis of summed variances (the median variance in the total of ninety-one values is 32.92). On the other hand, the lines COND, CLIVUS, and PTER have rather high variances throughout. Part of the explanation for the differences between the lines in this respect may lie in the topographic aspects.[10] It is possible that the lines which are located in the geometric center of the complex have the lowest variability figures, primarily because of their central location. However, in all the samples so far studied, lines of low variability have also included lines located peripherally, and the opposite has been equally true. Thus, one may suspect that the inequities found may be, at least partly, due to differences in biologic variability. Or is it just a coincidence that the lines OCCL, PAL, and INFRA are lines of lowest variability also in both human children and adults, while the lines COND and PTER are lines of highest variability in the same samples?[14]

One may venture a biologic explanation for the relative invariability of some of these structures. For instance, the line INFRA represents not only the canal for the neurovascular bundle in the maxilla but also the floor of the bony orbit.[3] The line PAL is associated with the upper respiratory chamber. It is conceivable that both vision and respiration are functions important enough to warrant relative stable orientation in their positions within the craniofacial complex.

The key role of the occlusal region in the facial framework has been pointed out recently,[16] and our findings in both *Macaca mulatta* and human samples seem to support this notion. One intriguing discrepancy between the findings from the study just referred to and those from our own exists: In the first it was found that in human children the occlusal region was not oriented to the cranial base with "significant consistency."[16] As can be seen, our findings in the monkey are in agreement with this, but in the human samples, children and adults alike, the angular relationships between the occlusal plane and parts of the cranial base (OCCL/ORB, OCCL/SPHEN, OCCL/CLIVUS) had variances of low value. It should be noted that the lines employed in these studies were not quite identical.

The variance figures illuminate in an interesting way some of the structural features of the mandible. The variability of the occlusal plane (OCCL) to the anterior part of the mandibular canal (AMC) is significantly smaller ($P<0.01$)

than the variability of OCCL to the condyle (COND), the posterior part of the mandibular canal (PMC), and the ramus (RAMUS). It may be noticed, incidently, that the angle OCCL/AMC has the lowest variance of the ninety-one angles. The line AMC has significantly lower variability ($P<0.05$) with the occlusal plane than with the various parts of the mandible, except the mandibular base (MAND). When the associations of the condyle with the other parts of the mandible are examined, it appears that there is more variability in the relationship of the condyle to the ramus and the body than in its relation to the mandibular canal, though the variances are not statistically different at the 0.05 risk level.

The present data thus support our earlier findings from human samples[3, 14] regarding the relatively loose association between the body and the ascending ramus of the mandible. Although similar data have been presented previously,[8] the suggestion that the ramus-condyle part of the mandible, closely related to the pharynx,[3, 4] serves as an adjusting link between the masticatory jaw proper and the skull may deserve renewed emphasis. Our data may also partly fill the need to "more specifically characterize the mandible."[11]

In view of the limited sample, further analysis of the data does not seem warranted. While the figures presented in this article are an addition to the existing relatively meager data on the variability of the craniofacial skeleton of *Macaca mulatta*, it is hoped that they are also of more general relevance and interest for students of craniofacial biology.

Summary

The variability of the craniofacial skeleton of the juvenile *Macaca mulatta* was studied from lateral radiographic cephalograms of twenty-three animals, using a previously described method based on fourteen lines depicting certain anatomic features.

The findings, when compared to corresponding human data, revealed that a number of angular relationships are similar in this monkey and in human children and adults. The same is true regarding the variability of individual lines. These similarities suggest that biologic similarities exist in the cranio-facial skeletal architecture in these species. Specifically, the findings in the *Macaca mulatta* were in agreement with previous findings in human children and adults as regards the parallelism between the anterior parts of the neuro-vascular canals of the upper and lower jaws and the apparently adaptive role of the ramus and the condyle.

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