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RELATIONSHIPS BETWEEN MANDIBULAR JOINT SIZE AND CRANIOFACIAL SIZE IN HUMAN GROUPS

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Summary—Substantial evidence attests to the capability of the joint to undergo morphological alteration in response to biomechanical forces transmitted to it during function. Measurements expressing the size of mandibular condyles and fossae were obtained from skulls representative of a broad spectrum of subsistence practices and tooth use. Craniofacial dimensions were measured for some groups. Considerable differences in joint size were noted between groups roughly consistent with known or presumed intensity of masticatory stress. Size was largest in the hunter-gatherers, intermediate in aboriginal horticulturalists and smallest in 20th century American caucasoids and 17th century British. In each group, male joint size was absolutely larger than females. With the exception of condylar breadth, male joint dimensions were not relatively larger than female when corrected for differences in craniofacial size. In contrast, same-sex comparisons of Eskimo and American caucasoid means adjusted for differences in craniofacial size showed joint size in Eskimos to be significantly larger, both absolutely and relatively. Eskimo females had relatively larger joints than American caucasoid males. Thus, intergroup differences in joint size persist even when differences in craniofacial size are taken into account. Although the influence of genetic factors cannot be excluded, differences in the nature or intensity of tooth use during growth may account, at least in part, for the observed differences in joint size.

INTRODUCTION

Because of the complexities of articulation and movement introduced by its morphology and its connections to the dentition, the human mandibular joint (MJ) is a focal point for discussion and debate. There is increasing evidence that some force is transmitted to the human joint during function. Long suspected on the basis of histological studies (Sicher, 1952; Rees, 1954; Moffett *et al.*, 1964; Scheman, Milstoc and Rubin, 1974) and biomechanical analyses (Barbenel, 1969, 1972; Hylander, 1975; Smith, 1978), *in-vivo* measurements of bone strain in the subcondylar region of the lower jaw of macaque monkeys (Hylander, 1979) confirm forces at the macaque MJ to be of considerable magnitude during mastication and incisal biting.

Although the possible effects of functionally-induced stresses on joint morphology are not well understood, orofunctional factors may influence the growth of the MJ. Experimental investigations of growing monkeys and other laboratory animals have shown that the joint, far from being an independent or intrinsic growth centre, is a site of compensatory or adaptive growth which can occur in response to disturbances in occlusion that alter the biomechanical environment of the joint (Stöckli and Willert, 1971; McNamara, 1972; Petrovic, Stutzmann and Oudet, 1975; Simon, 1977; McNamara and Carlson, 1979) or to alterations in masticatory muscle orientation and utilization that takes place during normal craniofacial growth (Carlson, McNamara and Jaul, 1978). Although such changes have been investigated experimentally only in (sub-adult) animals, examination of human skulls (Mongini, 1972; Seward, 1976; Wedel, Carlsson and Sagne 1978; Granados, 1979; Hinton, 1981a,b) and human cadaveral material (Moffett *et al.*, 1964; Oberg, Carlsson and Fajers, 1971) suggest that joint contours may continue to change in response to tooth attrition or tooth loss throughout life.

However, growth in size of the joint appears to cease, at least in the condyle, by the late teens or early twenties (Rushton, 1944; Moffett, 1966; Scott and Symons, 1974; Wright and Moffett, 1974), by which time the condylar cartilage has been almost entirely replaced by bone. Presumably a similar timing is true of the temporal joint component, although considerably less information is available concerning the duration and nature of its growth (Hinton, 1981a). Although information is sparse concerning the adaptability of joint size during growth, a number of experimental studies have demonstrated larger condylar dimensions in rats fed a diet of coarse consistency when compared with controls fed a diet requiring little strenuous mastication (Watt and Williams, 1951; Barber, Green and Cox, 1963; Moore, 1965; Beecher and Corruccini, 1981). As there are great differences among human groups in diet and the magnitude of forces which are routinely applied to the dentition (cf. Molnar, 1972), it could be supposed that relative levels of orofunctional stress might be reflected in differential size of the human joint. Although no systematic comparisons have been made, the available data suggest that intergroup differences in joint size may indeed exist. The largest condylar dimensions are in fossil hominids (Wolpoff, 1975; Smith, 1976; White, 1977), but there are indications of appreciable variability among living human groups also (Wallace, 1927; Dingwall and Young, 1933; Weidenreich, 1936). For the temporal joint component, considerable differences in size among extant human groups have been documented, the largest dimensions being in hunting and gathering peoples (Moffett, 1968; Oberg, Carlsson and Fajers, 1971). The size of the temporal component may be secondary to that of the condyle (Hinton and Carlson, 1979) but the two joint components are probably closely linked during development (Kazanjian, 1939), resulting in congruence between the condyle and mandibular fossa (Van Zile, 1954; Lindblom, 1976). Thus, the size of both structures is probably related to severity of orofunctional stimuli, although condylar size presumably provides the more direct estimate of adaptational response to biomechanical forces.

There are, however, indications that joint size is correlated to some extent with the overall size of the cranium and face (Demirjian, 1967; Wedel *et al.*, 1978). Accordingly, analysis of intergroup differences in joint size must take into consideration the possibility that the differences that exist may represent disparities in craniofacial size among the groups studied. My aim was to evaluate quantitatively intergroup differences in MJ size and to examine the relationship of joint size dimensions to selected parameters of craniofacial size.

MATERIALS AND METHODS

The mandibular fossa and condyle were measured in human skulls encompassing a broad range of subsistence practices and, presumably, tooth use. The skulls (Table 1) ranged from hunter-gatherers of the aboriginal New World (Eskimos, Ohio Woodland and Tennessee Archaic samples) to food producers of both the New and Old World (Southwestern Pueblo and Tennessee Mississippian samples; British Anglo-Saxons) to 17th and early 20th century samples from England and the United States. All were over 18 years of age, as assessed by known or assigned chronological ages, or by status of third molar eruption or closure of the spheno-occipital synchondrosis. Sex determinations were made, postcranially in most cases, by workers at the institutions listed in Table 1. Condylar breath was defined as the maximum distance between the most medial and most lateral points on the articular surface. Condylar length was defined as the maximum anterior–posterior distance on the articular surface near its midpoint. Area of the condylar articular surface was calculated as the product of condylar breadth and condylar length. Size of the temporal joint component in basal view was assessed by the following 3 measurements (Hinton and Carlson, 1979): (1) postglenoid process (PGP) to articular tubercle (AT) distance; (2) postglenoid process (PGP) to temporal spine (TS) (the junction of the squamosal suture and the tympanosquamosal fissure) distance; (3) temporal spine (TS) to articular tubercle (AT) distance. Size of the mandibular fossa was estimated as the area of the joint triangle defined by these measurements. In order to assess the influence of overall craniofacial size on MJ size, selected cranial dimensions were measured: maximum cranial length, maximum cranial breadth, bizygomatic breadth, bicondylar breadth, cranial height and upper facial height.

Two groups, Eskimo and American caucasoid, were selected for analysis, based on the extremes of joint size, craniofacial size and tooth use which they represent and on the large number of specimens in the groups. The 6 cranial dimensions measured in those groups sampled were subjected to a principal-components analysis; an individual's score for the first principal component, which accounted for 53.8 per cent of the total variance, was taken as an indication of overall craniofacial size. Differences in relative joint size between the two groups (that is, comparative joint size when craniofacial size is taken into account) were then investigated using analysis of co-variance to test for group differences between means adjusted for the co-variate (score on the first principal component).

Table 1. Sizes, dates and location of human skeletal samples

Sample	*n*	Dates	Location
Eskimo	195	Late 18th–early 20th century; 12th century	Smithsonian Institution; Arizona State University
Ohio Woodland	129	AD 800–1100	Kent State University
Tennessee Indians, Archaic period	106	6000–500 BC	University of Tennessee
Tennessee Indians, Mississippian period	118	AD 1300–1550	University of Tennessee
Pueblo Indians, Southwestern U.S.	248	AD 1280–1600	Arizona State Museum; Arizona State University
Anglo-Saxons	102	AD 650–950	British Museum (Natural History), London
American caucasoid	162	Early 20th century	Smithsonian Institution Cleveland Museum of Natural History
17th Century British	61	17th Century	Duckworth Laboratory Cambridge University

For further information concerning the samples, see Hinton (1981b,c).

RESULTS

Differences in absolute joint size

Mean joint dimensions (Tables 2 and 3) in the North American aboriginal samples are in virtually every instance larger than the corresponding values in 20th century caucasoids or in the British. This disparity is least pronounced in comparisons with pre-Medieval Anglo-Saxons. The difference in joint size between aboriginal and American caucasoid or 17th century British is most marked, on a relative basis, for condylar length. The female means in certain of the aboriginal groups (most notably, the hunter-gatherers) are equal to or greater than the male means in the American caucasoid and British for a number of measurements. The means among the aboriginal groups display a distinct size hierarchy, with hunter-gatherers (Eskimos, Ohio Woodland and Tennessee Archaic Indians) having appreciably larger joints than groups depending partly or completely on horticulture (Tennessee Indians, Mississippian period; Pueblo Indians from Southwestern United States).

Differences in joint size relative to craniofacial size

In virtually every instance, Eskimo joint dimensions, adjusted for differences in overall craniofacial size, were significantly ($p < 0.001$) larger than those in American caucasoids (Table 4). Selected depictions of these data (Figs 1–4) illustrate the magnitude of intergroup differences, which were especially pronounced for condylar length. By contrast, similar comparisons of relative joint size between males and females within groups (Table 5, Figs 1–4) demonstrate much less clear-cut differences. For a number of dimensions, females are as large or larger (significantly so in some cases) than males when means are standardized for overall craniofacial size. The main exception was for condylar breadth, in which males were significantly larger. Comparison of adjusted mean values for Eskimo females and American caucasoid males (Table 4, Figs 1–4) demonstrates that Eskimo females were significantly larger in every instance, with the exception of condylar breadth.

DISCUSSION

The data demonstrate considerable variation in size of the MJ among recent and aboriginal human groups. Furthermore, differences in mean values between

Table 2. Comparative MJ dimensions in North American aboriginal, American caucasoid and British samples: males

Sample		Condylar length	Condylar breadth	Condylar area	PGP–TS	PGP–AT	TS–AT	Mandibular fossa area
Eskimo	Mean	10.3	21.8	226.8	18.4	18.7	27.1	171.1
	SD	1.1	1.6	31.1	1.7	1.9	1.7	23.1
	n	104	100	100	109	109	109	109
Ohio Indians, Woodland	Mean	8.6	21.5	184.4	20.3	17.5	27.0	176.7
	SD	0.9	1.6	27.9	1.8	1.4	1.7	20.6
	n	38	33	33	64	65	64	64
Tennessee Indians, Archaic	Mean	9.1	21.5	200.9	20.0	17.2	27.0	170.9
	SD	0.9	1.8	27.7	1.7	1.6	1.6	22.3
	n	49	31	31	60	60	61	60
Tennessee Indians, Mississippian	Mean	8.3	20.2	166.6	18.7	16.8	25.4	156.1
	SD	0.8	1.8	27.9	1.8	1.4	1.9	17.8
	n	49	41	41	64	62	62	62
Pueblo Indians, Southwest U.S.	Mean	9.2	19.6	181.9	18.5	17.1	25.4	158.9
	SD	1.0	2.1	32.3	2.3	1.7	1.7	20.3
	n	96	90	90	109	108	107	105
Anglo-Saxons	Mean	8.2	21.5	176.4	17.6	17.7	25.8	154.4
	SD	1.1	1.6	29.3	1.7	1.8	1.6	19.3
	n	47	41	41	53	53	53	53
American caucasoid	Mean	7.8	20.3	159.4	17.5	17.3	24.8	149.2
	SD	1.1	1.8	28.2	1.8	1.7	1.8	19.0
	n	102	101	101	105	105	105	105
17th Century British	Mean	7.6	19.8	149.7	17.3	16.2	24.1	139.5
	SD	0.8	1.6	22.9	1.4	1.5	1.6	18.4
	n	49	47	47	37	37	37	37

All means are in millimeters, except for condylar area and mandibular fossa area which are in square millimeters.

One way analysis of variance showing that Eskimo means are significantly ($p < 0.001$) greater than those of other groups in nearly every instance; significant differences between other hunter-gatherer, horticultural and more recent groups are present for all dimensions studied. In general, and particularly for condyl and mandibular fossa differences among group means correspond to subsistence patterns: hunter-gatherers comprise a cluster, not significantly different from each other but significantly different from horticulturalists, which form a cluster significantly different from the British and American caucasoid groups.

Table 3. Comparative MJ dimensions in North American aboriginal, American caucasoid and British samples: females

Sample		Condylar length	Condylar breadth	Condylar area	PGP–TS	PGP–AT	TS–AT	Mandibular fossa area
Eskimo	Mean	9.3	19.4	181.5	17.5	18.4	25.4	160.0
	SD	1.1	1.7	30.8	1.9	1.7	1.9	22.3
	n	77	73	72	86	86	86	86
Ohio Indians Woodland	Mean	8.4	20.1	167.8	19.1	17.3	25.6	163.6
	SD	0.9	1.7	23.1	1.6	1.4	1.6	15.0
	n	39	35	35	64	64	64	64
Tennessee Indians, Archaic	Mean	8.7	18.9	163.6	19.0	16.6	25.3	156.3
	SD	0.8	1.4	18.1	1.6	1.3	1.5	16.5
	n	32	25	25	42	41	41	40
Tennessee Indians, Mississippian	Mean	8.0	18.4	147.3	18.3	15.7	24.0	143.3
	SD	1.0	1.8	23.6	1.6	1.5	1.2	13.5
	n	35	27	27	46	45	45	45
Pueblo Indians, Southwest U.S.	Mean	9.2	17.9	164.0	17.6	16.6	23.9	145.4
	SD	1.0	1.8	26.7	1.6	1.5	1.7	16.0
	n	123	116	115	132	134	133	132
Anglo-Saxons	Mean	7.8	19.9	157.3	16.8	16.9	24.3	140.3
	SD	1.0	1.8	23.5	1.7	1.5	1.5	15.1
	n	45	39	39	49	49	49	49
American caucasoid	Mean	7.6	17.9	135.7	16.4	16.6	23.3	135.1
	SD	1.0	1.8	22.3	1.7	1.8	1.5	17.9
	n	57	57	57	57	57	57	57
17th Century British	Mean	7.3	18.0	131.9	16.1	16.8	23.0	134.4
	SD	0.8	2.2	24.7	1.7	1.1	0.9	12.7
	n	33	32	32	24	24	24	24

Table 4. Test for equality of adjusted means*: intergroup comparisons

Variable	Eskimo adjusted mean	American adjusted mean	d.f.	F-statistic	Significance
	Eskimo males versus American caucasoid males				
PGP–AT distance	18.2	17.7	(1,171)	2.43	0.1209
TS–AT distance	26.8	25.2	(1,171)	24.91	0.0000
Condylar breadth	21.5	20.7	(1,171)	7.18	0.0081
Condylar length	10.0	8.1	(1,171)	99.98	0.0000
Mandibular fossa area	168.2	154.5	(1,171)	13.16	0.0004
Condylar area	216.5	167.5	(1,171)	93.57	0.0000
	Eskimo females versus American caucasoid females				
PGP–AT distance	18.3	17.0	(1,98)	10.21	0.0019
TS–AT distance	25.1	23.7	(1,98)	15.01	0.0002†
Condylar breadth	19.1	18.4	(1,98)	3.85	0.0526
Condylar length	9.1	7.7	(1,98)	30.31	0.0000
Mandibular fossa area	158.1	140.8	(1,98)	15.70	0.0001
Condylar area	176.1	143.0	(1,98)	35.08	0.0001
	Eskimo females versus American caucasoid males				
PGP–AT distance	18.9	17.2	(1,140)	36.30	0.0000
TS–AT distance	25.8	24.7	(1,140)	14.30	0.0002
Condylar breadth	20.0	20.2	(1,140)	0.50	0.4823
Condylar length	9.5	7.8	(1,140)	73.09	0.0000
Mandibular fossa area	166.9	147.9	(1,140)	33.24	0.0000
Condylar area	188.8	157.4	(1,140)	41.93	0.0000

* Slopes for individual group regression lines are equal and non-zero except where noted. All means are in millimeters (linear dimensions) or square millimeters (area).

† Slopes of the two regression lines are different at $p \leqslant 0.0483$; due to the marginality of this value, the analysis was carried to completion.

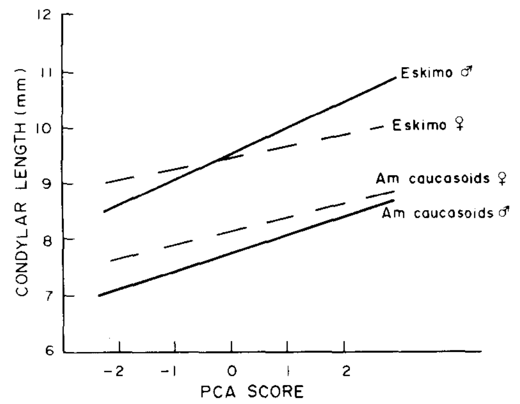

Fig. 1. Regression of condylar length on score for the first principal component for Eskimos and American caucasoids.

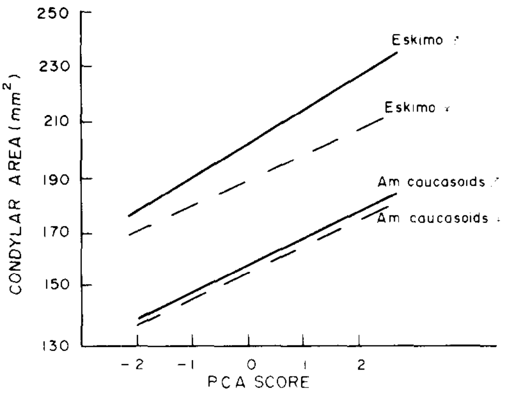

Fig. 3. Regression of condylar area on score for the first principal component for Eskimos and American caucasoids.

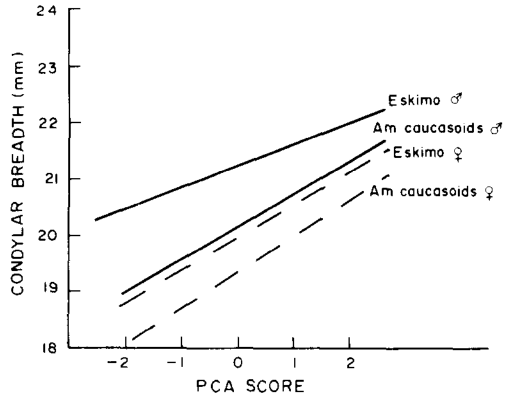

Fig. 2. Regression of condylar breadth on score for the first principal component for Eskimos and American caucasoids.

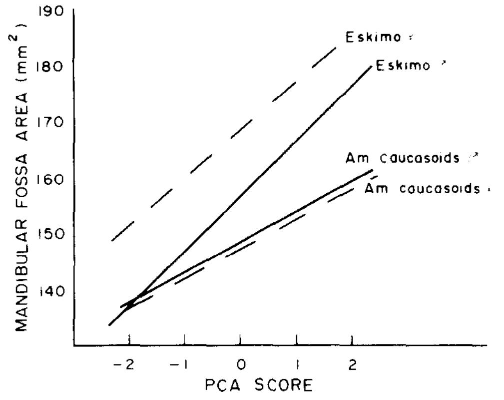

Fig. 4. Regression of mandibular fossa area on score for the first principal component for Eskimos and American caucasoids.

Table 5. Test for equality of adjusted means: within group comparisons

Variable	Male adjusted mean	Female adjusted mean	d.f.	F-statistic	Significance
	Eskimo males versus Eskimo females				
PGP–AT distance	18.2	19.7	(1,120)	9.60	0.0024*
TS–AT distance	26.7	26.6	(1,120)	0.00	0.9624
Condylar breadth	21.6	26.6	(1,120)	11.05	0.0012
Condylar length	10.0	9.8	(1,120)	0.53	0.4677
Mandibular fossa area	166.9	178.0	(1,120)	4.21	0.0422*
Condylar area	217.0	201.8	(1,120)	4.78	0.0308
	American caucasoid males versus American caucasoid females				
PGP–AT distance	16.9	17.3	(1,149)	1.47	0.2270
TS–AT distance	24.4	23.9	(1,149)	2.14	0.1453
Condylar breadth	19.7	18.9	(1,149)	4.99	0.0270
Condylar length	7.6	7.9	(1,149)	1.58	0.2106
Mandibular fossa area	144.5	143.4	(1,149)	0.07	0.7863
Condylar area	151.2	149.6	(1,149)	0.07	0.7802

* Females larger.

groups are highly patterned; hunter-gatherers have larger joint dimensions than agriculturalists, and industrialized American caucasoids and 17th century British have the smallest mean values. The view that intergroup differences in joint size may be related in part to different patterns of tooth use is given circumstantial support by the large joint dimensions in hunter-gatherers from widely separated regions of North America, and by the occurrence of similarly reduced MJ size in populations relying on a more easily masticated diet of cultigens in both North America (Tennessee Indians of Mississippian period) and Europe (Anglo-Saxons).

Sex dimorphism in joint size was present in every group, in agreement with work by Martin (1936), Morant (1936) and Lindblom (1960). However, the data of Table 5 suggest that the difference may be primarily one of absolute size. For the most part, male joint dimensions are not relatively larger than those in females, when corrected for craniofacial size. The main exception to this generalization is condylar breadth which appears to be consistently larger in males throughout the range of craniofacial size. The meaning of this finding is unclear. Wedel *et al.* (1978) concluded that condylar breadth reflects the influence of orofunctional demands based on its positive correlations to jaw dimensions. However, as males generally have larger jaws than females, this assertion is consistent with my data. At the same time, Eskimo females (Table 4 and Figs 1–4) have significantly larger dimensions for most joint measures than American caucasoid males. Interestingly, the single dimension in which Eskimo females are not larger is condylar breadth. As strenuous tooth-use and craniofacial muscularity are probably greater in Eskimo females than in American caucasoid males, it may be that condylar breadth is less sensitive than other aspects of joint size to orofunctional influences.

Perhaps the most interesting finding is that MJ size is not only absolutely but relatively larger in an aboriginal group (Eskimos) than in a recent group from an industrialized society (American caucasoid). That this difference relates to factors other than cranial size is underscored by the existence of larger dimensions for most joint measures in Eskimo females than in American caucasoid males, groups which have similar ranges of craniofacial size variation. The extent to which these intergroup differences in joint size are due to the influences of genetic factors or functional demands during growth cannot be assessed from these data.

There is appreciable evidence that the nature and intensity of orofunctional activities in aboriginal human groups (especially the Eskimo) differed considerably from that in more recent western societies, as attested by ethnographic accounts (DePoncins, 1941; Gould, 1968; Lous, 1970; Molnar 1972), comparative bite force data (Waugh, 1937; Heath, 1948; Neuman and DiSalvo, 1959; Linderholm and Wennstrom, 1970) and studies of dental attrition (Pedersen, 1949; Anderson, 1965; Merbs, 1968; Turner and Cadien, 1969; Hylander, 1977). Although little is known of the influence of genetic factors on MJ size, comparison of joint size in time-successive, genetically contiguous human groups which differ in mode of subsistence offers some possibility of identifying genetic and functional aspects of variation. There are secular trends in joint size reduction in populations undergoing the transition from hunter-gathering to sedentary agriculture in Africa (Hinton and Carlson, 1979) and in North America (Corruccini and Handler, 1980; Hinton, 1981c). In each instance, the changes in joint size were accompanied by indications of reduced demands on the masticatory system (Hinton, 1982). Thus, there are circumstantial reasons for believing that the intergroup differences I found are at least partly attributable to differences in oral function.

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