Biomechanical Association of Dental and Temporomandibular Pathology in a Medieval Nubian Population

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ABSTRACT An analysis of the relationship between oral pathology and degenerative change at the temporomandibular joint (TMJ) was undertaken on an archaeological sample of 122 adult crania from the Medieval site of Kulubnarti in Sudanese Nubia. The crania were sorted into 2 groups: those demonstrating clearly visible bony changes at the joint (TMJ+) and those without visible change (TMJ−). These groups were compared according to 1) age; 2) sex; 3) active dental pathologies (abscesses, caries, partial socket resorption); 4) tooth loss with complete socket resorption; and 5) dental attrition.

No statistically significant association was evident between degenerative change at the TMJ and age, active dental pathologies, or dental attrition; however, sex differences and posterior tooth loss with complete socket resorption revealed a significant correspondence to degenerative TMJ changes. Both of these factors agree with the clinical literature and with biomechanical models (most notably that of Hylander) based upon modern populations. Furthermore, the results support the contention that paleopathological conditions can be analyzed from a clinical and functional biomechanical perspective.

Interest in disorders of the temporomandibular joint (TMJ) has mainly focused on the clinical and biomechanical aspects of this joint. A rapid rise in these disorders among modern populations has attracted much clinical attention, while biomechanical research has concentrated on the functional role of the mandible and associated musculature in mastication.

It has been estimated that between 50–80% of the American public suffers from some form of TMJ dysfunction (Gerschman and Reade, 1988; Lewis, 1988). This range in estimates reflects a continuing lack of systematic methodology for the definition, diagnosis, and treatment of such conditions (Weinberg, 1987).

Biomechanical considerations have focused extensively on the relationship between the mandible and temporal bone during mastication, and have led to considerable debate as to whether the mandible functions as a lever (Hylander, 1975; Picq et al., 1987), a link (Robinson, 1946; Taylor, 1986), or both (Gingerich, 1979). Hylander (1975) provided a detailed description of this debate and argued strongly in favor of the lever hypothesis.

The lever-action model has important implications for clinical research due to its predictive value (Fig. 1). According to this model, TMJ reaction forces are ordinarily larger on the balancing side than on the working side (where the bite force is exerted). Because individuals with dental pathologies (such as abscesses and caries) on one side of the mouth preferentially chew on the opposite (healthy) side, the lever-action model predicts that in these individuals the masticatory forces should pass mostly through the teeth on the healthy side and through the condyle on the diseased side. The reverse should occur if there is unilat-
eral disease in the TMJ rather than the teeth; that is, masticatory forces should pass primarily through the teeth on the side with the diseased joint, but through the condyle on the healthy side. Both these adaptations serve to reduce pain during mastication; however, they result in asymmetrical stress on the TMJ, and may lead to eventual joint degeneration.

In addition to left/right asymmetry, posterior (molar) tooth loss has been observed to contribute to TMJ degeneration in living populations. With the loss of posterior teeth, the frequency of anterior (incisal) biting and associated joint loading increases. Hylander (1978) has demonstrated that the mandible acts symmetrically as a lever during incisal biting and asymmetrically during molar biting. It is to be expected that abnormal joint forces such as those produced by severe asymmetric left/right molar chewing or excessive anterior chewing may lead to tissue remodeling and subsequent degeneration in the TMJ (Bell, 1986; Faulkner et al., 1985).

The relationship between TMJ morphology and anterior bite forces has also been examined from an evolutionary perspective. Hinton and Carlson (1979) observed a substantial size reduction in the glenoid fossa and mandibular condyle in ancient Nubian populations excavated near Wadi Halfa. This pattern of decreased joint size from Mesolithic through Christian times was interpreted as a response to facial reduction, reduced anterior bite forces, and reduced reaction forces in the TMJ.

While Hylander’s model has apparent utility in explaining morphological variation in archaeological populations, its utility for the analysis of bony TMJ changes in such populations has yet to be determined. Indeed, although degenerative joint changes in the appendicular and axial skeleton have been of considerable interest to paleopathologists, the TMJ has received little attention in spite of the clinical interest and biomechanical modeling available. Reasons for this lack of attention need no doubt include the fact that archaeological remains only provide a partial record of TMJ disease, and as Bell (1986) stated, “mastication involves many structures—bones, joints, muscles, teeth, glands, nerves of different types, blood vessels...” Studying one portion in isolation from the others can prove difficult. In addition, ancient populations frequently experienced a magnitude of dental disease and associated tooth loss during life far in excess of that anticipated by most biomechanical models (Armelagos, 1968; Bergman and Hansson, 1979; Brothwell, 1972).

Therefore, an examination of the cranial remains from a Medieval Nubian population was undertaken to determine the presence and extent of degenerative bony changes in the TMJ, and to assess the relationship between dental disease, tooth loss and TMJ degeneration in light of the lever-action model. Excellent preservation of complete crania and dentitions make this an ideal population for study. High rates of dental wear during life resulted in rapid and early antemortem tooth loss, particularly in the posterior dentition. This population therefore, provides an excellent sample for a determination of the extent to which a wide divergence from a healthy dental arcade conforms to Hylander’s predicted association between chewing patterns, joint forces and TMJ changes.

MATERIALS AND METHODS

The skeletal population used in this study was excavated by the third author in 1979 from the site of Kulubnarti in Northern Sudan. Kulubnarti is located in a region called the Batin et Hafar (“belly of rock”), an area described by Adams (1977, p. 26) as “the most barren and forbidding of all Nubian environments.” Subsistence in this region was marginal, even with low population densities. The ancient inhabitants of this area, like their modern counterparts, existed as sedentary agriculturalists practicing small
scale farming along the banks of the Nile (Carlson et al., 1974). The principal cultigens were cereal grains, including millet and sorghum. Milling, combined with the blowing sands of the Nubian Sahara, led to gritty contamination of foodstuffs. This resulted in a rapid rate of toothwear, a high frequency of apical abscess, and tooth loss by midlife.

Two cemeteries were excavated at Kulubnarti yielding a total of 418 individuals, representing both sexes and ages ranging from 5 months in utero to 51+ years. Preservation of the remains was remarkable. Many were naturally mummified due to the exceptionally dry climate; annual rainfall averages less than a millimeter per year. The earliest of the cemeteries is dated from early Christian times (c. 550–750 A.D.), the other from the remainder of the Christian era (c. 750–1500 A.D.).

The sample selected for the present study consisted of 122 adult (18 to 51+ years) crania from the combined Kulubnarti cemeteries. Subadults were excluded from the present analysis due to a lack of observable TMJ change and in order to avoid the complicating factor of dental eruption.

Following sample selection, a systematic macroscopic examination of the crania was undertaken to determine those individuals with clearly visible degenerative changes in the temporomandibular region (Fig. 2). Those demonstrating significant porosity of the articular eminence and/or bony exostoses in the TMJ were labeled as TMJ+. Due to the multicausality of such disorders, no attempt was made to determine the etiology of the problems in this category (Gerschman and Reade, 1988). Those displaying no evidence of joint change were classified as the TMJ− group.

Dental pathology, degree of socket resorption, and dental attrition were also examined. Dental pathologies (caries, abscesses) were recorded per tooth for each individual. Socket resorption was classified as either partial or complete and recorded for each tooth. Degree of tooth wear was scored using procedures described by Smith (1984). Smith’s method was selected because it allowed inclusion of the anterior dentition and provided an eight-step method of seriation. Subjects were categorized according to 1) age; 2) sex; 3) active dental pathologies at time of death including caries, abscesses, and partially resorbed sockets; 4) complete socket resorption; and 5) tooth wear. Age and sex for all individuals were previously established by Van Gerven et al. (1981) using multiple criteria.

Mean number of cavities, abscesses, and partially and completely resorbed sockets per individual were calculated for those in the TMJ+ and TMJ− groups. Mean stage of tooth wear was also calculated and compared for these two groups. Right/left wear asymmetry was determined by taking the absolute difference between the wear scores for left and right tooth antimeres. Variance was also computed for each group.

RESULTS AND DISCUSSION

As indicated in Table 1, of the 122 adult crania examined, 17 were classified as TMJ+, 105 as TMJ−. Comparison of the two groups by age using Student’s t revealed no statistically significant differences (Table 2). Mean age at death for the TMJ+ (34 yrs) and TMJ− (35 yrs) individuals differed by less than a year. However, small sample size may have contributed to this lack of association. Indeed, when grouped by decade, 50% of the TMJ+ individuals fell in the 40–51+ age group, suggesting a possible age effect.

There was no significant difference in the proportion of females to males in the TMJ− group. However, in the TMJ+ group, the ancient Nubians conformed to the modern clinical pattern. As with moderns, Nubian females outnumbered males ($\chi^2 = 2.88$; one tailed, $P < 0.05$). Indeed, the near 3:1 Nubian ratio approximates the modern clinical female-to-male ratio of 4:1 (Gerschman and Reade, 1988).

Analysis of active dental pathologies revealed that members of the TMJ+ group
demonstrated fewer abscesses (0.24/individual) and carious lesions (0.71/individual) compared to their TMJ− counterparts (0.79 and 1.39 respectively), the differences were not statistically significant. Mean number of partially resorbed sockets was highest in the TMJ+ group (2.88 compared to 2.27). However, overall, the number of active pathologies remained highest with the TMJ− individuals (4.45 vs. 3.82). This is not surprising given the expected delay between disruption in mastication and resultant bony changes at the TMJ.

Long-term disruption in mastication was assessed using complete socket resorption as a measure of protracted tooth loss prior to death. The analysis proved highly significant at $P < 0.01$ using Student’s t. TMJ+ individuals displayed nearly two times as many resorbed sockets (10.24/individual) as the TMJ− group (5.46/individual). Of the 10.24 totally resorbed sockets per individual, 80% were associated with the posterior dentition. This highly significant association between posterior tooth loss and disorders of the TMJ conformed to predictions based upon current clinical literature which lists such tooth loss as a major contributor to TMJ disorders (Bergman and Hansson, 1979; Christensen and Ziebert, 1986; Faulkner et al., 1987; Furstman, 1965; Granados, 1979; Hatjigiorgou et al., 1987; Weinberg, 1987).

Analysis of tooth loss produced patterns of sex difference and anterior/posterior loading consistent with the clinical and biomechanical literature (most notably Hylander 1975, 1978); however, analysis of tooth wear as an indicator of left/right asymmetry, was less successful. Based on Hylander’s model one would expect to find evidence of preferential chewing in the TMJ+ group on the same side as the disorder. No such trend was evident. Analysis of left/right differences in wear using Smith’s 8-stage system produced no correspondence between wear asymmetry and TMJ degeneration. Mean stage of wear for the TMJ+ group was 5.16, 4.97 for the TMJ− individuals. The average difference between wear on the left and right sides was less than one stage in Smith’s system for the TMJ+ group (0.87), as well as the TMJ− group (0.73). Asymmetry was also assessed by computing variance values from the TMJ+ and TMJ− groups. While the TMJ+ variance was larger (0.72 vs. 0.46), the values were not significant at the 95% confidence level.

In summary, while the present analysis failed to demonstrate a significant association between degenerative changes in the TMJ and active dental pathology or left/right chewing asymmetry, sex differences, and posterior tooth loss revealed a significant correspondence to bony TMJ degeneration. Age differences also showed a strongly related trend, although not significant at the 95% confidence level. These associations were highly consistent with the clinical literature, as well as Hylander’s lever hypothesis. Furthermore, the results support the contention that paleopathological conditions can be analyzed from a clinical and functional, biomechanical perspective.

### CONCLUSIONS

1. Of the 122 Nubian crania examined, 13.9% demonstrated degenerative changes in the temporomandibular joint.
2. A trend toward increased degeneration with increased age was evident, with 50% of...
the TMJ+ individuals aged 40 to 51+. The results were, however, insignificant at $P > 0.05$.

3. Sex differences related to TMJ degeneration corresponded to the modern pattern. There were more Nubian female sufferers than males; this agrees with current clinical estimates of a greater female-to-male ratio (Gerschman and Reade, 1988; Meng et al., 1987).

4. Active dental pathologies, as indicators of more recent disease events, showed no significant relationship to degenerative changes in the TMJ.

5. Total resorption of the alveolar bone was more prevalent in the TMJ+ individuals. Such tooth loss with complete socket resorption indicated a longer history of oral disease.

6. In the TMJ+ group, 80% of the completely resorbed sockets occurred in the posterior dentition.

7. Analysis of dental attrition provided no evidence for preferential left/right chewing among TMJ sufferers.

These results indicate a highly significant association between long term tooth loss and disorders of the TMJ. This agrees with the current clinical literature which lists loss of occlusion as a major contributor to such disorders (Bergman and Hansson, 1979; Christensen and Ziebert, 1986; Faulkner et al., 1987; Granados, 1979; Hatjigiorgis et al., 1987; Weinberg, 1987). It appears that within this population extensive loss of posterior teeth and subsequent anterior chewing was the principal factor in degeneration of the TMJ. Posterior loss led to increased loading at the TMJ, resulting in degenerative changes in the joint. The clear association between a shift in bite force from the molars to the incisors in the TMJ+ group is most easily interpretable if the mandible is viewed as operating as a lever (Christensen and Ziebert, 1986; Hylander, 1978).

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LITERATURE CITED


