Frequency, Location, Morphology and Aetiology of Osseous Mandibular Condylar Concavities

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ABSTRACT The aim of this study was to examine the morphology, frequency, location and aetiology of osseous concavities (OC) in the mandibular condyle. The temporomandibular joints of 435 skeletonised individuals of known age, sex and ancestry were macroscopically examined for osseous concavities and signs of osteoarthritis. Descriptive statistics ($\chi^2$) were used to compare results. It was found that OCs were present in 17.5% of the sample and did not vary by sex or ancestry. Posteriorly positioned OCs accounted for 72% of all OCs, and the frequency of OCs decreased with increasing age in contrast to the pattern seen for osteoarthritis. It is concluded that OCs are either developmental defects related to the late maturity of the condyle, and/or a function of regressive remodelling with posterior displacement of the condyle. Copyright © 2006 John Wiley & Sons, Ltd.

Key words: mandible; condyle; concavities; OA; remodelling; pseudopathology

Introduction

The purpose of this study is to examine the morphology, frequency, location and aetiology of osseous concavities or depressions on the human mandibular condyle. The paired mandibular condyles form an articular relationship with the temporal bones of the cranium in what is termed a ginglymo-arthrodial joint. This descriptor refers to the ability of the joint to perform hinge-like and gliding forms of movement, although in practice a diverse range of movement is possible. Commonly this articulation is referred to as the temporomandibular joint (TMJ). Strictly speaking the mandibular condyle does not directly articulate with the glenoid cavity of the temporal bone, but rather forms an ‘articular disc (meniscus)-condyle complex’ that articulates with the temporal bone (Piette, 1993: 103–4).

Our interest in the presence of osseous concavities or depressions on the mandibular condyle dates to the observation of this phenomenon in ancient skeletonised human remains from northern Vietnam and Hokkaido, Japan. In the Bronze Age Vietnamese sample, 22% (9/41) of individuals with preserved condyles displayed concavities, while 78% (7/9) of those individuals with concavities were aged 30 years or younger at death (Oxenham, 2000), potentially suggesting an aetiology other than osteoarthritis (OA).

While there is a lack of standardisation in how these osseous concavities are described and named, they have attracted the attention of a number of researchers over the past several decades. Table 1 summarises the frequency of condylar concavities in dry bone, autopsy and radiological studies. Only 3/6 analyses report on
these concavities for the anterior, superior and posterior aspects of the condyle, and the majority of studies have an attenuated age range of subjects. Only one study provides the frequency of concavities on the superior condyle (56%), while posterior concavities generally occur at higher frequencies (up to 51%) than anterior concavities (as low as 1.5%).

Clearly, it is time to investigate the frequency and differential distribution of condylar concavities in a large age and sex representative sample. This study will: (1) record the frequency of condylar concavities by age, sex, ancestry and location on the condyle; (2) determine if there is a correlation between condylar concavities and osteoarthritis of the TMJ; and (3) review the likely aetiologies of these concavities.

### Methods

The mandibular condyles and glenoid fossae of 435 individuals of known age, sex, cause of death, ancestry and without obvious TMJ pathology, from the Robert J. Terry collection stored at the Smithsonian Institute, were examined by one of us (JW). Figure 1 shows that the age distribution of the sample is relatively even with the exception of the youngest and oldest age classes. Figure 2 summarises the sample by sex and ancestry for each age class. Individuals of European descent are poorly represented in the younger age classes.

An osseous concavity was defined as a circumscribed area of depressed cortical bone anywhere on the condylar surface. Previous experience in examining these concavities indicated that two morphological variants were particularly common (see Figure 3a and b). Osseous concavities were recorded as having one of three forms: types A, B, and a non-standard or morphologically variable type C (see Figure 3c). Type A is characterised by a sharp superior margin and diffuse or gently sloping inferior and mediolateral margins. Type B concavities differ from Type A in that all margins are diffuse or sloping. Both Type A and Type B concavities are relatively large with a mean area of approximately 40 mm². Type C are variable but tend to be small (average 8 mm² in area), have steep sides and relatively

<table>
<thead>
<tr>
<th>Sample</th>
<th>Total individuals</th>
<th>Age range in years (mean in parentheses)</th>
<th>Condyle</th>
<th>Frequency (by individual)</th>
<th>Frequency (by condyle)</th>
<th>Reference</th>
</tr>
</thead>
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<tr>
<td>Dry bone</td>
<td>125</td>
<td>Not provided</td>
<td>L&amp;R</td>
<td>12.4</td>
<td></td>
<td>Azaz &amp; Lustmann (1973)</td>
</tr>
<tr>
<td>Autopsy</td>
<td>100</td>
<td>20–53</td>
<td>L&amp;R</td>
<td>35</td>
<td></td>
<td>Mongini (1977)</td>
</tr>
<tr>
<td>Radiography</td>
<td>53</td>
<td>22–36 (26.5)</td>
<td>L&amp;R</td>
<td>1.8³</td>
<td></td>
<td>Baldioceda et al. (1990)</td>
</tr>
<tr>
<td>Autopsy</td>
<td>1193</td>
<td>3.3–18.7 (11.3)</td>
<td>L&amp;R</td>
<td>1.5³</td>
<td></td>
<td>Collins et al. (1991)</td>
</tr>
</tbody>
</table>

1See Figure 4 for condyle locations.
2Only posterior concavities recorded/assessed.
3Only anterior concavities recorded/assessed.
sharp margins. The location of a concavity was recorded as occurring on functionally differentiated areas of the condyle (see Hosoki et al., 1996; Luder, 1997), defined as anterior, superior or posterior (see Figure 4).

Dry bone indicators of osteoarthritis (see Buikstra & Ubelaker, 1994) in the form of marginal and/or joint surface osteophytosis, eburnation, joint mushrooming and localised porosity were recorded for each condylar head and

![Figure 1. Age distribution of the sample (n=435).](image1)

![Figure 2. Sex and ancestral composition by age class of the sample.](image2)
corresponding glenoid fossa on the temporal bone. With the exception of porosity, a single indicator of osteoarthritis was deemed sufficient to call the joint osteoarthritic.

The clinical identification of OA includes variables such as pain, joint mobility, joint stiffness, age, joint enlargement and synovial fluid composition (Moskowitz, 1993; Jones & Doherty, 1995; Creamer & Hochberg, 1997). Specific radiographic signs include marginal osteophytosis, asymmetric joint space narrowing, subchondral cysts and sclerosis of subchondral bone beneath sites of cartilage damage (Solomon, 1997). Clearly many of these variables generally only apply to living subjects.

In dry skeletal material a combination of clinical and other criteria believed to be associated with OA are recorded. These variables are osteophytic lipping of the joint margins, osteophytic development on the joint surface, porosity of the joint surface and eburnation of the joint surface. In response to poor levels of inter-observer error in recording such dry bone OA traits (see Waldron & Rogers, 1991), Buikstra & Ubelaker (1994) devised a set of standardised criteria for recording these variables. Of these traits there appears to be little argument that eburnation is pathognomonic for OA (although see Rothschild, 1997:530). A number of researchers have questioned the use of osteophytic development in identifying the presence of OA (Cockburn et al., 1979; Dieppe & Rogers, 1993; Rogers & Waldron, 1995; Buckwalter & Lane, 1997; Jurmain, 1999). However, while hypertrophic bone formation (marginal and joint surface osteophytes) and other

Figure 3. Morphological variants of mandibular osseous concavities. (a) Type A; (b) Type B; (c) example of the variable Type C.

Figure 4. Schematic (lateral) view of the mandibular condyle showing anterior (A), superior (S) and posterior (P) regions.
morphological changes to the joint surface (such as mushrooming) are not pathognomonic for OA, they are positively associated with the condition. The use of these bony traits in identifying individuals with OA, while not perfect, is believed to be robust enough to display a fairly accurate distribution of this condition in the sampled remains used for this study. If anything, the frequency of OA will probably be underestimated using bony signatures since clinical variables, including pain and joint space narrowing, are not assessable in osteological samples.

### Results

Of the 435 individuals examined, 17.5% displayed at least one condylar concavity (Table 2). There was little difference in the frequency of concavities by sex, with 17.8% of males and 17.0% of females affected. A higher, albeit non-significant ($\chi^2 = 1.75, P = 0.2$), frequency of subjects of European descent (13.8%) displayed concavities than subjects of African-American descent (9.2%). The frequency of concavities is not homogeneous by age ($\chi^2 = 15.84, P < 0.05$).
with the highest frequency between ages 14–19 (44.4%) gradually declining to a low of 4.5% between ages 50–59 and increasing again to a maximum of 15.2% in those individuals aged 80+ years.

There was little difference in expression of condylar concavities by side, with 32.9% on the left condyle only, 34.7% on the right condyle only, and 29.3% expressed bilaterally (Table 3). With respect to the location of concavities on the condyle, 12.6% of the 435 individuals examined displayed concavities to the posterior aspect of the condyle, 5.5% to the superior, and 0.7% to the anterior aspect of the condyle (Table 4). When only examining individuals with a condylar concavity, 72.4% expressed them posteriorly, 31.6% superiorly and 4.0% anteriorly (the sum is not 100% as five individuals displayed both superior and posterior concavities).

While anterior concavities are too rare to pursue any further, superior concavities were distributed relatively evenly across all ages ($\chi^2 = 5.74, P \leq 0.1$) with the exception of 50–59 years where no concavities were recorded. In contrast, the distribution of posterior concavities was not homogeneous ($\chi^2 = 16.49, P \leq 0.05$) and matched the overall distribution with the highest frequency in the 14–19 age group, gradually declining to 4.5% in the 50–59 year age group, climbing to around 10% in the 60–79 year groups, and finally finishing at a low of 4.1% in those aged 80+ years.

Of all condylar concavities recorded, 47.4% were Type A, 13.2% Type B and the remaining 39.5% of a variety of morphologies inconsistent with a regularised type (Type C). For posterior concavities, 61.8% are Type A, 18.2% Type B and 20% Type C. Regarding superior concavities, 25% were Type A and 75% Type C, with no Type B forms observed.

The distribution of TMJ osteoarthritis in the sample of 435 individuals is summarised in Table 5. The frequency of OA is lowest in the younger age groups and reaches a maximum of 33.3% in the 60–69 year group, falls to 14.3% in the 70–79 year group and then increases again to 30.3% for those individuals aged 80+ years. Figure 5 plots the frequency of individuals with posteriorly located condylar concavities against the frequency of individuals with OA by age. There is an inverse covariation in that the frequency of OA increases with increasing age while the frequency of condylar concavities decreases with increasing age.
**Discussion**

The results of this study suggest that the distribution of condylar concavities varies little by sex or ancestry. The only variable that seems to vary with the frequency of these concavities is age. Little can be said regarding concavities on the anterior aspect of the condyle due to their low frequency. It is possible that anteriorly situated concavities are variants of pterygoid fovea (insertion of the lateral pterygoid muscle). The frequency of pterygoid fovea has been noted to be similar in both adults and children and not associated with degenerative disease of the TMJ (Collins *et al.*, 1997; see also Friedlander *et al.*, 1992).

**Osteochondritis dissecans**

A wide range of disorders can affect the TMJ (see Lobbezoo *et al.*, 2004 for a review) including osteochondritis (osteocondrosis) dissecans (OCD). OCD is characterised by necrosis of the subchondral bone which can become detached and form a loose body within the joint space (Campos *et al.*, 2005). While there is a rich literature on the aetiology of OCD, Bohndorf (1998:105) summarised the consensus view implicating joint overuse and/or repetitive micro-trauma as particularly important. Schellhas *et al.* (1989:551) also suggested that mandibular condyle OCD is relatively common and often associated with internal derangement of the TMJ. While OCD in general can occur in both adolescents and adults, it tends to be more common in males (Campos *et al.*, 2005). When considering OCD as a candidate for the condylar concavities described in this study, it is important to note Bohndorf (1998:106): 'a general rule, most OCD lesions occur at the weight-bearing convex cartilage'. Schellhas (pers. comm.) also states that OCD is always in a weight-bearing area of whatever joint is involved.

While the relatively less common superiorly situated (convex load-bearing region) condylar concavities examined in this study may be related to OCD and avascular necrosis of the subchondral bone, the more common posteriorly situated (non-load-bearing) concavities cannot be seen as associated with OCD. Furthermore, the defects observed in this study do not preferentially affect males.

**Osteoarthritis**

The homogeneous distribution by age of concavities on the superior aspect of the condyle and the decrease in frequency of concavities on the posterior condyle with increasing age suggests that the aetiology of the condition is not associated with advancing age. Consistent with this, the finding that the frequency of TMJ osteoarthritis increases, while the frequency of posteriorly sited condylar concavities decreases, with advancing age suggests that the aetiology of these concavities is not related to osteoarthritic changes to the TMJ. Conversely, an unknown factor associated with condylar concavities may ameliorate or protect against the osseous signatures of OA.

Azaz & Lustmann (1973) examined 125 dry mandibles, of unreported sex and age distribution, for the frequency and manifestation of a number of anatomical variants. One of these variants was what they termed defects in the cortical layer of the condyle. Defects were present in 12.4% of all condyles but the frequency by location was not provided. They illustrated one well-differentiated defect localised to the anterior sector of the condyle (possibly a pterygoid fovea) and another large defect that had destroyed much of the superior sector of the condyle. They suggested that these defects were symptomatic of degenerative joint disease.

Hosoki *et al.* (1996) discussed in detail a number of case studies of individuals with osseous concavities on the posterior aspect of the mandibular condyle. They reported that 7/39 (17.9%) TMJs displayed concavities on the posterior condylar aspect, and suggested that concavities may remodel or alternatively develop into osteoarthritis.

Baldioceda *et al.* (1990) found a higher frequency of superior condylar concavities (56%) than posterior (25%) or anterior (19%), and indicated that this was due to differential loading of the condyle. The lack of evidence for OA in condyles with concavities led them to propose
that they do not contribute to OA and have the potential to remodel and ultimately resolve.

**Regressive remodelling**

Tasaki *et al.* (1996) found posterior disc displacement to be quite rare, the vast majority of displaced discs being in an anterior direction (particularly anterior, partial anterior and forms of anterolateral displacement). Anterior displacement of the articular disc often leads to significant posterior and some superior displacement of the mandibular condyle (e.g. Gateno *et al.*, 2004).

As noted, Baldioceda *et al.* (1990) suggested that condylar concavities have the potential to remodel and resolve. Mongini (1977) found that 35/100 individuals displayed posterior concavities and argued that this evidence for regressive remodelling was a function of posterior displacement of the condyle. Mongini (1977) also radiographed 69 individuals with TMJ pain-dysfunction syndrome and reported that 19/67 (28.4%) displayed anterior displacement and the same number posterior displacement of the condyle. Of those displaying posterior displacement, 5/19 (26.3%) had radiographic evidence of regressive remodelling of the posterior condyle which they used to support the view that condylar concavities are a result of regressive remodelling associated with condylar displacement.

Kurita *et al.* (2001) also found an association between severe anterior disc displacement and higher prevalence of resorption of the superolateral pole of the mandibular condyle. They see resorption of this aspect of the condyle as an adaptive response to increased mechanical forces on the attachment of the disc on the posterosuperolateral aspect of the condyle during anterior disc displacement.

Widmalm *et al.* (1994) noted that the prevalence of disc displacement increases, along with disc deformities and perforations, with increasing age. Isberg *et al.* (1998:255), however, argued that the high prevalence of defects or deformities in the elderly is due, in part, to a cumulative effect (defects formed in youth contribute to the elevated frequency seen in older age as these individuals contribute to the elderly cohort over time). Their own study indicated that TMJ disc displacement actually peaked in the second decade of life, the same period that displays the highest frequency of condylar concavities. Without data on pre-existing temporomandibular disorders (TMDs) in the skeletonised sample, the potential association between the peak incidence of TMDs and the peak frequency of condylar concavities in adolescence cannot be pursued here.

**Developmental considerations**

The mandible is one of the earliest bones to form from cartilage produced secondarily in membrane (Youdelis, 1965:192). Takenoshita (1982) noted that condylar shape is morphologically adult by 3 years (although final adult curvature was not achieved until adolescence) and that development continues until the third decade. Trabecular bone maturation is achieved at the close of the second decade or shortly afterwards. Trabecular coarsen and marrow spaces enlarge after the fourth decade. Cortical plate growth on the articular surface of the condyle continues until the third decade (Takenoshita, 1982). Luder (1997:19) found that ‘condyles from individuals in the third decade of life often exhibit hypertrophic growth cartilage in combination with active endochondral ossification and, for this reason, have to be considered “immature”, and that articular tissue organisation on the posterior condyle differs from that on the anterior and superior (putative load-bearing sectors) in being similar to that in the growth phase. The posterior condyle would also seem to be vascularised to a greater degree than other sectors of the condyle according to primate models (Piette, 1993:108).

Further, not only are the subarticular tissues thinner on the posterior aspect of the condyle (Piette, 1993), but so is the cortical bone (Pullinger & Baldioceda, 1989).

These developmental considerations suggest that condylar concavities may be a product of the late maturity and extended developmental period of the condyle than bony signatures of osteoarthritis or perhaps even regressive remodelling in response to pathological condylar displacement. This is perhaps more likely in the case of posterior concavities which account for 72.4% of all condylar concavities and where 32/55
(58.2%) of all posterior concavities are seen in individuals aged less than 30 years. The observation that 80% of posterior concavities were either Type A or Type B further suggests a similar aetiological agent. The apparent slight increase in posterior cavities in older age may be related to the observation that 46.2% of these concavities were variable Type C forms, compared with only 11.9% Type C concavities in those aged 14–59 years. Type C concavities, only relatively common in older age and comprising the majority of superior concavities, may have a non-developmental aetiology more related to degenerative change or regressive remodelling.

There are changes in the mechanics of mastication over the life span that may prove relevant to this discussion. While a multivariable issue, Karlsson & Carlsson (1990) in a study of human mastication have demonstrated that vertical mandibular displacement is greater in young adult males than elderly males. Kiliaridis et al. (1991) have further indicated that vertical mandibular displacement is greatest in young (9–10 years old) children. Hayasaki et al. (1998) detailed significant human masticatory changes (including mandibular movement) with developmental changes in the dentition (primary through mixed and secondary dentitions). Further, rat models indicate marked differences in condylar development (size and cartilage thickness/distribution) with variations in food hardness (Kiliaridis et al., 1999) during growth. Further research (particularly longitudinal) is needed before a potential association between the formation of osseous condylar concavities and masticatory changes and/or stresses on the developing mandibular condyle can be assessed.

Conclusions

This study was carried out in order to describe the frequency, position and morphology of condylar concavities, and the literature was examined for a possible aetiology of this condition. Condylar concavities, as defined in this study, are relatively common in that 17.5% of 435 individuals displayed at least one concavity. These concavities show no preference for manifesting in the left or right condyle and commonly occur bilaterally. The rarest form of concavity occurs in the anterior aspect of the condyles, then superiorly, and the most common position is posterior. The frequency of condylar concavities does not appear to vary by sex or ancestry; the frequency, particularly posteriorly, decreases with increasing age and inversely covaries with TMJ osteoarthritis, which increases with increasing age. Despite at least one study suggesting degenerative joint disease as an aetiological agent for condylar concavities (Azaz & Lustmann, 1973), it would appear contraindicated in our study.

Regressive remodelling is a possible candidate as a cause of condylar concavities. The prevalence of posterior concavities is consistent with the most common form of disc displacement (anterior) which leads to posterior displacement of the condyle. The frequency of TMJ displacement increases with age; its peak incidence is during adolescence, a period during which the highest frequency of condylar concavities is seen. The unique nature of the mandible (it is one of the first bones to ossify, while the condyle is the last articular region to mature) suggests a developmental aetiology for condylar concavities. The case is stronger for posterior concavities given that their frequency inversely covaries with age, and that the posterior aspect of the condyle is characterised by a cortical architecture and articular tissue properties associated with anatomical immaturity well into the third decade of life.

We propose that condylar concavities are pseudopathological in that they are not aetiologically associated with degenerative joint disease or any other form of trauma. Condylar concavities, particularly those manifesting posteriorly, are either (1) unresolved cortical defects related to the late maturation of the mandibular condyle, or (2) cortical defects caused by remodelling of an otherwise still immature joint in response to posterior displacement of the condyle during anterior displacement of the TMJ disc. These points should be borne in mind if surgical intervention is being considered based on the observation of such concavities during imaging of the TMJ in younger individuals.

Finally, the recording of condylar concavities, particularly on the posterior aspect of the condyle, may have a forensic or bioarchaeological application. From the perspective of individual
specimens, little can be said except that the presence of a posterior condylar defect (Type A or B) would indicate a higher probability of the condyle belonging to a younger (<30 years) individual. With a larger forensic or bioarchaeological sample, the frequency of posterior concavities by age would be a useful check against other forms of age-at-death assessment such as pubic symphysis morphology.

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References


