# The Prevalence and Possible Causes of Third Molar Agenesis in Post-Medieval Chichester

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*ABSTRACT* Third molar agenesis is a dental anomaly that occurs in approximately 25% of people worldwide and results in the complete absence of one or more of the third molars. A rise in the prevalence of congenitally absent third molars has been noted in modern clinical data, and it has been proposed as an evolutionary step in the dental reduction of the human dentition. Whilst research has been conducted in extant cohorts, relatively little has been published on third molar agenesis in archaeological assemblages. A post-medieval assemblage (AD 1550-1850), from Chichester, United Kingdom, was visually and radiographically analyzed to determine the prevalence of this anomaly. Mesiodistal and buccolingual measurements were taken on retained third molars to determine if there was an association between agenesis and reduced tooth size. Prevalence of agenesis was found to be comparatively high (42.7%) relative to contemporary and modern European samples, and tooth size reduction was documented. Consequently, it can be said that high rates of third molar agenesis are not simply a modern clinical phenomenon, as many prevalence rates in recent populations are lower. Temporal and regional patterns are, therefore, unclear. In order to better understand the trajectory and evolution of this anomaly, more archaeological assemblages ought to be examined.

Third molars are the last permanent tooth to develop, the most variable in size and morphology, and are also the most commonly congenitally absent tooth. According to Sujon et al. (2016), approximately 50% of modern (20th century onwards) human third molars are anomalous, either unerupted, partially erupted or absent. Congenital absence is known as dental agenesis, which results from a developmental anomaly in the dental epithelium or the underlying mesenchyme (Bhutta et al., 2014). Grewal's (1962) analysis of agenesis in the third molars of mice revealed that congenitally absent teeth begin as tooth germs but growth formation ceases at or before the cap stage of development, at which point the tooth germ resorbs. It may occur unilaterally, bilaterally, in combinations of three teeth, or completely, with all four absent. In their meta-analysis of modern data, Carter & Worthington (2015) found that 22.63% of people worldwide have some degree of third molar agenesis. The samples included in their analysis were gathered from various ethnicities and socioeconomic groups, with prevalence ranging from 5.32% - 56.0%.

The exact etiology of third molar agenesis is unknown, but a genetic component is well established (Carter & Worthington, 2015; Frazier-Bowers et al., 2002), and it is thought that delayed growth or a lack of space in the jaw may result in epigenetic absence (Anderson & Popovich, 1981; Kajii et al., 2004; Suri et al., 2004). Disease and nutrition have also been shown to affect the eruption and formation of third molars (Anderson & Popovich, 1981; Garn et al., 1961; Suri et al., 2004), adding to the already complex etiology of this trait. Grüneberg's (1951) experiments with mice indicate that agenesis is the phenotypic result of the extreme end of a size continuum. Mice with absent third molars more often displayed small and variable remaining third molars, and as the dental lamina became smaller, the more likely growth and tooth formation were to cease development and resorb.

It has frequently been reported that third molar agenesis occurs more often in modern populations than in the past (Alam et al., 2014; Kajii et al., 2004),

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with some claiming the third molar is likely to disappear from the human dentition altogether (Raloti et al., 2013). A general reduction in tooth size has taken place throughout hominid evolution, with a rapid reduction in size occurring in the Upper Palaeolithic (50,000 – 10,000 YA) and again in the early Holocene (10,000 - 8,000 YA) (Hillson, 2005). While the impetus behind these changes is unclear, many associate the diminution of teeth with the atrophy of the masticatory complex due to increasingly soft diets, advancement of food processing techniques, and the diminished use of the mouth as a tool (Brace et al., 1987; Carlson & Van Gerven, 1977). The agriculturalization that took hold in the early Holocene is thought to have furthered this trend in dental reduction, leading to what may be a further evolutionary step in dental reduction, the congenital loss of the third molar (Sengupta et al., 1999).

In this study, the past prevalence of third molar agenesis is examined in a post-medieval assemblage from Chichester, providing new insights into patterns in agenesis and the role of dental size reduction and its occurrence. This investigation will also test whether this anomaly represents a recent secular trend and will add to our limited understanding of third molar agenesis in archaeological assemblages.

**Materials**

The skeletal assemblage under analysis comes from The Litten cemetery at Eastgate Square in Chichester, West Sussex. Chichester has a long history of occupation, with evidence of Roman defensive ditches found at The Litten cemetery (Hart, 2012), and continuous settlements recorded from the Anglo-Saxon period onwards (Dhaliwal et al., 2019). In the later medieval period (14th century), Chichester flourished as one of the more important ports in the country, with dominance over the wool trade and a strong agricultural economy (Hart, 2012). A grain-based economy continued in the post-medieval period (1550-1850), although the town's import declined as the wool trade waned. Chichester also appears to have experienced a population surge between 1670-1801, with the number of inhabitants doubling from 2,400 to 4,752 due to increasing trade with London and other domestic markets (Dhaliwal et al., 2019). This assemblage was excavated from a cemetery that seems to have been established in the 12th century with the construction of the chapel and altar of St. Michael, which are no longer standing. Interment officially ceased in 1859, although family plots remained active until the end of the 19th century (Hart, 2012). The vast majority (66%) of human remains recovered date to the post-medieval period and represent a range of social strata, with the bulk of individuals (1,365), both from the medieval and post-medieval periods, buried in the simple shroud style (Rando, 2016). In the present study, only post-medieval skeletons were analyzed for third molar agenesis.

Excavation of the site began in advance of its redevelopment, with 93 burials excavated by Pre-Construct Archaeology Ltd. (PCA) in 2005 and 2006, and the remaining 1637 skeletons excavated by Archaeology South-East (ASE) between August of 2011 and January of 2012 (Hart, 2012). Four hundred and thirty skeletons from these excavations that have been retained for analysis at the University College London Institute of Archaeology due to high preservation levels or presence of pathological conditions. Of these skeletons, 311 matched the preservation levels required (alveolar bone and dentition present) to warrant examination and only 116 had a minimal level of antemortem tooth loss that allowed for inclusion in this study. Of these 116 skeletons, 89 had complete dentitions without any data missing. The remaining skeletons had missing data in either one (n=18) or two (n=9) of the dental quadrants. These skeletons were incorporated into the analysis when the lack of data did not affect the results (see below). In total, 46 males, 36 females and 34 skeletons of indeterminate sex were analyzed, comprising 83 adults and 33 subadults.

**Methods**

*Selection, Visual Assessment, Aging and Sex Estimation*

Skeletons were carefully selected according to a set of criteria designed to minimize the effects of antemortem tooth loss. Skeletons with fewer than four teeth lost antemortem were included in the analysis. In addition, only skeletons of a maximum age of a pubic symphysis phase 4 (Brooks & Suchey, 1990) and a auricular surface phase 4 (Lovejoy et al., 1985) were incorporated in order to mitigate a greater risk for antemortem tooth loss with increasing age. The age at which third molars initiate crown formation varies more than any other tooth (AlQahtani et al., 2010). AlQahtani et al. (2010) reported a median dental age of 8.5 years for the initiation of crown development, and Ubelaker (1989) provides a dental age of 10 years +/- 30 months for the initiation of crown mineralisation in both the maxillary and mandibular third molars. In this

study, only subadults with a minimum dental age of 12.5 years were included, following the dental age categories established by AlQahtani et al. (2010). According to Garn et al. (1963), 99% of third molars begin their cusp mineralisation by the age of 14 years. However, due to the relatively small number of individuals that fit the criteria for analysis in this assemblage, the dental development stage of 12.5 years, defined by AlQahtani et al. (2010), was selected as a minimum in order to maximize the available data.

Mandibles and maxillae were visually observed for the presence or absence of third molars using the following criteria to determine a lack of agenesis:

The tooth is in the alveolus.

The tooth was lost post-mortem, with a well-defined alveolus present.

The tooth was lost antemortem but the alveolus is still in the process of resorbing, and no other pathological or taphonomic process could be responsible for the feature.

The second molar in the particular quadrant has an identifiable distal approximal wear facet (indicating it had once been in contact with a third molar).

An unerupted or impacted third molar is visible through radiographic analysis.

Third molar agenesis was diagnosed based on the absence of these criteria. If the maxillae or mandible met these requirements it was x-rayed to ensure that the third molar was not impacted, developing within the crypt, or had failed to erupt. If radiographic analysis did not reveal a third molar it was therefore determined to be congenitally absent. Impaction was assessed based on abnormal angulation of the tooth in the alveolus or crypt (after Raloti et al., 2013).

Sex determination was used to examine differences in size or agenesis prevalence. This was based on a combined assessment of pelvic morphological traits (after Phenice, 1969), including the greater sciatic notch and composite arch (after Bruzek, 2002), as well as measurements of the proximal humeral and femoral heads (maximum diameters after Bass, 1995) and an assessment of the sexually dimorphic features of the skull (after Ubelaker, 1989). The latter two methods were only employed if the features of the pelvis were slightly ambiguous, or if the pelvic bones were missing or too poorly preserved. The dimorphic traits of the pelvis are generally regarded to be more reliable indicators of sex than features of the skull (Bruzek, 2002). The skeletons were assigned sex of male, possible male, indeterminate, possible female, and female. However, due to the small size of the sample possible males and possible females were collated with the respective sex.

*Measurements*

Measurements of third molars were taken in accordance with the cervical method developed by Hillson et al. (2005) using specialized Paleo-Tech calipers (also developed by Hillson and colleagues, 2005). Cervical measurements are usually not affected by the level of crown wear, and as individuals with an advanced age were not included, tooth wear on third molars was generally not an issue. Individuals with carious lesions affecting the crown could also be included.

Mesiodistal measurements were taken by placing the tips of the calipers on the mesial and distal enamel, just occlusal to the cervico-enamel junction (CEJ) and at the midpoint between the buccal and lingual sides of the tooth (see Hillson et al., 2005). Buccolingual measurements were also taken on the buccal and lingual surface at the midpoint of the enamel, slightly occlusal of the CEJ, between the mesial and distal surfaces of the tooth. It is important to note that these measurements were taken at the midpoints and are not maximum measurements, however, if an enamel extension was present at the midpoint, the tip of the caliper was placed at whichever side of the extension provided the maximum measurement for the midpoint, following Hillson et al. (2005). The tips of the calipers that meet end-to-end were used with loose teeth and for the buccolingual measurements of teeth in the alveoli whenever possible. The caliper tips that meet at an angle were most useful for the mesiodistal measurements of teeth fixed in alveoli, and for the upper third molars, this measurement was approached lingually as these teeth tend to taper lingually, thereby ensuring a precise measurement.

*Analysis*

Inter- and intraobserver error tests were performed to ensure reproducibility and accuracy of results. Third molars, especially those in the upper dentition, have a variable morphology and can be difficult to measure due to their irregular and oblong crown morphology (Hillson et al., 2005). However, by ensuring the measurements are taken at the midpoint on the CEJ through careful and methodical application of technique, it is possible to achieve consistent results. Two observers unfamiliar with measurement technique of Hillson et al. (2005) took mesiodistal and buccolingual measure-

ments on the same set of ten third molars (five upper and five lower) following the system described above. The values were then compared using SPSS 21 software to determine mean difference and 95% confidence interval (CI). The buccolingual measurements with Observer 2 differed by as much as 0.5 mm, with one measurement revealing a 0.88 mm difference. However, the measurements of Observer 1 closely resembled those of the researcher and therefore these differences were not explored further. In addition, Observer 1 frequently reported slightly lower measurements than those of the researcher, most probably due to measurements taken on the CEJ or on the root surface, rather than on the enamel slightly occlusal to the CEJ. Intra-observer tests for mesiodistal measurements (MD=-0.098, SD=0.13481) remained close to ±0.2 mm, a range ideal for tooth measurements, but the range for buccolingual measurements was slightly higher (MD=0.027, SD=0.21103). To correct for this, a larger sample size should be used in future studies in order to determine if the degree of error is acceptable.

SPSS 21 Statistics software was used to assess the prevalence of third molar agenesis in the Chichester assemblage and analyze patterns within the sample. The data were divided into three groups: no data missing, one quadrant missing, and two quadrants missing. It is ideal to collect data on complete remains, but information was recorded on all three groups in order to gain as much data as possible.

T-tests were performed to determine whether sizes differences exist in the mesiodistal and buccolingual measurements of third molars between those with and without third molar agenesis. Difference in sizes between males and females were also compared statistically to determine the impact of sexual dimorphism on the results. Following this test, males and females were analyzed separately for size differences in third molars. T-tests were also used to determine if significant differences in size existed between the various distributions and patterns of third molar agenesis.

**Results**

The total prevalence of third molar agenesis in adult and subadult skeletons in the Chichester cohort with data present for all dental quadrants is 42.7% (n=38/89). When incorporating those with data missing from one quadrant the prevalence falls to 40.2% (n=43/107) and is slightly higher when including those with missing data in two quadrants at 41.4% (n=48/116) (Table 1). Subadults with complete data yielded a prevalence of 45.8% (n=11/24), and this remained consistent at 45.5%

*Table 1. Agenesis prevalence recorded for all skeletons, separated into groups defined on the inclusion of missing data.*

| | Agenesis | N | Percent | 95% CI |
|---|---|---|---|---|
| Skeletons with no missing data | Absent | 51 | 57.3 | ± 10.28 |
| | Present | 38 | 42.7 | ± 10.28 |
| | Total | 89 | 100 | |
| Including those with data missing from one dental quadrant* | Absent | 64 | 59.8 | ± 9.29 |
| | Present | 43 | 40.2 | ± 9.29 |
| | Total | 107 | 100 | |
| Including those with data missing from one and two dental quadrants* | Absent | 68 | 58.6 | ± 8.96 |
| | Present | 48 | 41.4 | ± 8.96 |
| | Total | 116 | 100 | |

*Due to the small number of individuals in the assemblage, the inclusion of individuals with data missing was explored. No significant differences were found between prevalence in any of the groups, and it is therefore acceptable to use individuals with data missing as representative of the assemblage.

*Table 2. Agenesis prevalence recorded for subadult skeletons, separated into groups defined on the inclusion of missing data.*

| | Agenesis | N | Percent | 95% CI |
|---|---|---|---|---|
| Skeletons with no missing data | Absent | 13 | 54.2 | ± 19.93 |
| | Present | 11 | 45.8 | ± 19.93 |
| | Total | 24 | 100 | |
| Including those with data missing from one dental quadrant | Absent | 17 | 56.7 | ± 17.73 |
| | Present | 13 | 43.3 | ± 17.73 |
| | Total | 30 | 100 | |
| Including those with data missing from one and two dental quadrants | Absent | 18 | 58.6 | ± 17.60 |
| | Present | 15 | 45.5 | ± 17.60 |
| | Total | 33 | 100 | |

(n=15/33) when subadult individuals with data missing were included (Table 2). Subadult prevalence is higher, but not significantly greater, $\chi^2$ (1, n=89) = 0.13, $p$ = 0.72, than the 41.5% prevalence among adults with complete data in this assemblage (n=27/65) (Table 3). When adults with one (n=30/77) and two (n=33/83) dental quadrants of data missing were included, this lowered the prevalence of agenesis to 39.0% and 39.8%, respectively, although the difference between adult and subadult prevalence remained statistically non-significant, $\chi^2$ (1, n=107) = 0.17, $p$ = 0.68, and $\chi^2$ (1, n=116) = 0.32, $p$ = 0.57.

Males in this assemblage show a 38.9% prevalence of agenesis (n=14/36), whereas females express a prevalence of 39.3% of third molar agenesis (n=11/28). Third molar agenesis in the maxilla was less common than third molar agenesis in the mandible, and the right side was more frequently affected by agenesis than the left (Table 4). The number of teeth missing followed a pattern in frequency of two, one, three, four, with agenesis of two molars occurring almost twice as frequent as one, and the absence of three and four was less

*Table 3. Agenesis prevalence recorded for adult skeletons, separated into groups defined on the inclusion of missing data.*

| | Agenesis | N | Percent | 95% CI |
|---|---|---|---|---|
| Skeletons with no missing data | Absent | 38 | 58.5 | ± 11.98 |
| | Present | 27 | 41.5 | ± 11.98 |
| | Total | 65 | 100 | |
| Including those with data missing from one dental quadrant | Absent | 47 | 61.0 | ± 10.89 |
| | Present | 30 | 39.0 | ± 10.89 |
| | Total | 77 | 100 | |
| Including those with data missing from one and two dental quadrants | Absent | 50 | 60.2 | ± 10.53 |
| | Present | 33 | 39.8 | ± 10.53 |
| | Total | 83 | 100 | |

*Table 4. The distribution of third molar agenesis between males, females, and the total assemblage, on the right and left sides and in the maxilla and mandible.*

| | Males | | | Females | | | Total (Including Indeterminate Sex) | | |
|---|---|---|---|---|---|---|---|---|---|
| | Right | Left | Total | Right | Left | Total | Right | Left | Total |
| Maxilla | 9 | 6 | 15 | 6 | 4 | 10 | 21 | 17 | 38 (46%) |
| Mandible | 7 | 8 | 15 | 7 | 7 | 14 | 23 | 22 | 45 (54%) |
| Total | 16 | 14 | 30 | 13 | 11 | 24 | 44 | 39 | 83 |

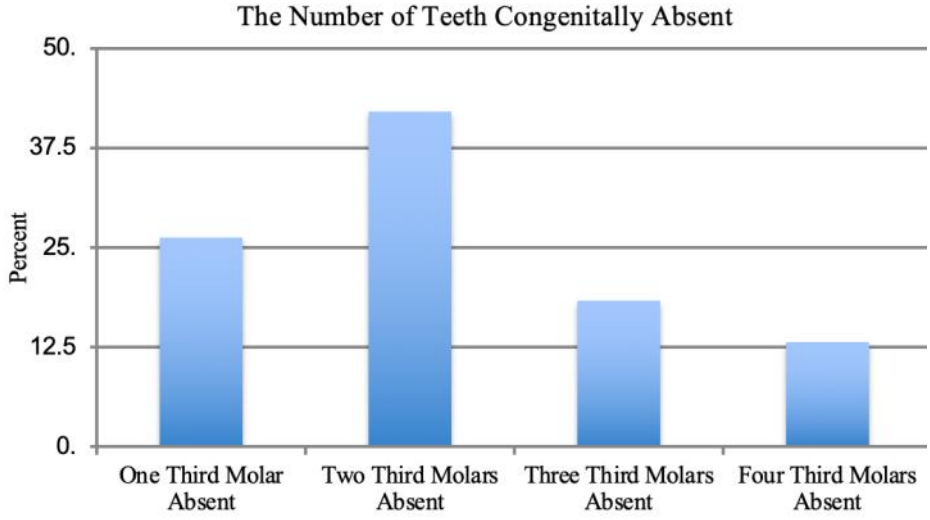


Figure 1. The frequencies in the number of third molars congenitally absent in individuals with agenesis and all data present in this assemblage. Two third molars absent occur much more often in this assemblage than one third molar absent, and three and four are least common.

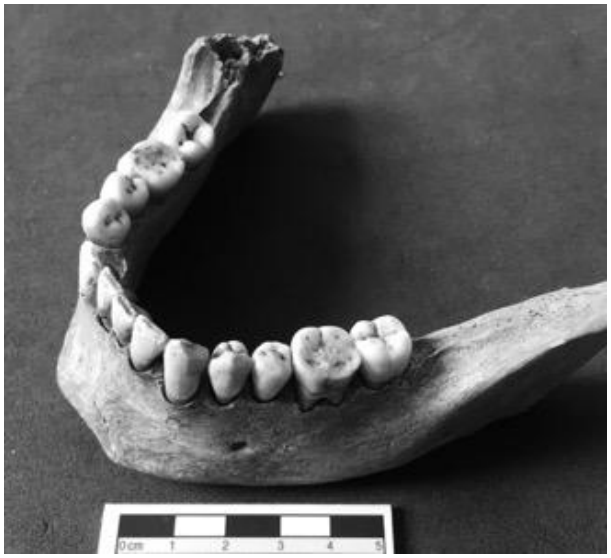

Figure 2. A mandible demonstrating bilateral agenesis of the third molars from the Chichester assemblage (Author's own 2017).

common (Figure 1). Bilateral agenesis (Figure 2) occurred more frequently than unilateral, or both unilateral and bilateral agenesis in one dentition, for example if unilateral agenesis occurred in the upper arcade and bilateral agenesis in the lower arcade (Table 5).

*Table 5. Laterality of third molar agenesis in the Chichester assemblage. Bilateral agenesis occurs in over half of those with third molar agenesis.*

| | n | Percent |
|---|---|---|
| Unilateral | 11 | 28.9 |
| Bilateral | 20 | 52.6 |
| Both | 7 | 18.4 |

Significant differences in tooth size were found between male and female third molars in this assemblage. The buccolingual dimensions of the ULM3, URM3, LRM3 and the mesiodistal dimensions of URM3, LLM3 and LRM3 (Table 6) produced significant differences between sexes, with mean male measurements being larger.

Two significant differences ($p < 0.05$) were found in the buccolingual dimensions of the ULM3 ($p = 0.048$, 95% CI [-1.04, -.005]) and URM3 ($p = 0.009$, 95% CI [-1.15, -.17]), in which those individuals with agenesis showed reduced dimensions compared to individuals without third molar agenesis (Table 7). When separated by sex, only males with agenesis retained a significant reduction in size ($p < 0.05$) in the ULM3 buccolingual dimension (Table 8). Third molars visibly reduced in size and complexity, known as "vestigial third molars" as described by Nanda (1954), were noted in seven skeletons that also displayed third molar agenesis.

T-tests did not reveal significant differences in the mesiodistal or buccolingual dimensions of third molars between individuals with one or three third molars congenitally absent, bilateral maxillary or mandibular agenesis, and those without agenesis. There was a significant difference ($p > 0.05$) in the mesiodistal dimensions of LLM3 in those with three third molars missing and bilateral maxillary agenesis; however, the 95% CI for those with agenesis of three molars was not significant due to the small number of individuals with the measurements (Table 9).

**Discussion**

To date, the literature on third molar agenesis in past assemblages is extremely sparse, and while it is at times included in the skeletal analysis (Iseri & Uzel, 1993; Munson, 2001; Öhrström et al., 2015; Lieverse et al., 2014), it is not extensively discussed. Only a few studies (Castro, 1989; Henriksson et al., 2019; Nelsen et al., 2001; Sengupta et al., 1999; Vodanović, 2012) record assemblage-wide data on third molar agenesis as part of broader analyses of dental anomalies.

In this study, 116 post-medieval skeletons from The Litten Cemetery in Chichester were analyzed to determine the past prevalence of third molar agenesis and to test any association with reduction in molar size. 42.7% of adult and subadult skeletons with complete data (n=51/89) demonstrated M3 agenesis. When those with one or two dental quadrants missing are included (to test a larger dataset), this frequency lowered to 40.2% and 41.4%, respectively (see Table 1). While this difference may be attributed to the inclusion of more data, it is also possible that the difference is the result of missing data resulting in undiagnosed agenesis. However, the difference is not statistically significant, and it is therefore acceptable to include the individuals with incomplete data as members of the assemblage. The inclusion of data groups with missing dental quadrants was also explored for subadults and adults separately, and no significant differences in the prevalence of agenesis was found between these groups. In this assemblage, 45.5% (n=18/33) of subadults have third molar agenesis. This indicates that antemortem tooth loss is less likely to have an effect on the prevalence of agenesis as subadults are exposed for less time to the pathological processes

*Table 6. Differences between the size of male and female third molars. Male third molars are significantly larger than female third molars (in bold).*

| | Sex | n | Mean | Sig. (2-tailed)* | Mean Difference | Std. Error Difference | 95% Confidence Interval of the Difference | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | Lower | Upper |
| ULM3 Buccolingual | Male | 24 | 10.3717 | **0.005** | 0.82461 | 0.27705 | 0.26423 | 1.38499 |
| | Female | 17 | 9.5471 | | | | | |
| URM3 Buccolingual | Male | 17 | 10.2271 | **0.054** | 0.51984 | 0.26034 | -0.00984 | 1.04951 |
| | Female | 18 | 9.7072 | | | | | |
| LLM3 Buccolingual | Male | 23 | 8.647 | 0.064 | 0.55629 | 0.29138 | -0.03465 | 1.14723 |
| | Female | 15 | 8.0907 | | | | | |
| LRM3 Buccolingual | Male | 24 | 8.5521 | **0.015** | 0.60708 | 0.23828 | 0.1255 | 1.08866 |
| | Female | 18 | 7.945 | | | | | |
| ULM3 Mesiodistal | Male | 24 | 6.7313 | 0.164 | 0.27596 | 0.19442 | -0.1173 | 0.66921 |
| | Female | 17 | 6.4553 | | | | | |
| URM3 Mesiodistal | Male | 17 | 6.7335 | **0.028** | 0.49353 | 0.2147 | 0.05672 | 0.93034 |
| | Female | 18 | 6.24 | | | | | |
| LLM3 Mesiodistal | Male | 24 | 8.8667 | **0.024** | 0.57042 | 0.24262 | 0.07926 | 1.06157 |
| | Female | 16 | 8.2963 | | | | | |
| LRM3 Mesiodistal | Male | 24 | 9.0913 | **0.017** | 0.64958 | 0.26195 | 0.12016 | 1.17901 |
| | Female | 18 | 8.4417 | | | | | |

*Table 7. T-test results of size comparison between those with M3 agenesis and those without M3 agenesis.*

| | Agenesis | n | Mean | Sig. (2-tailed)* | Mean Difference | Std. Error Difference | 95% Confidence Interval of the Difference | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | Lower | Upper |
| ULM3 Buccolingual | Present | 14 | 9.6021 | **0.048** | -0.52331 | 0.25882 | -1.04179 | -0.00484 |
| | Absent | 44 | 10.1255 | | | | | |
| URM3 Buccolingual | Present | 14 | 9.5486 | **0.009** | -0.66248 | 0.24341 | -1.15138 | -0.17358 |
| | Absent | 38 | 10.2111 | | | | | |
| LLM3 Buccolingual | Present | 9 | 8.0111 | 0.129 | -0.46178 | 0.29957 | -1.06291 | 0.13935 |
| | Absent | 45 | 8.4729 | | | | | |
| LRM3 Buccolingual | Present | 10 | 8.1040 | 0.461 | -0.20722 | 0.279 | -0.76591 | 0.35146 |
| | Absent | 49 | 8.3112 | | | | | |
| ULM3 Mesiodistal | Present | 14 | 6.4464 | 0.2 | -0.25221 | 0.19454 | -0.64191 | 0.1375 |
| | Absent | 44 | 6.6986 | | | | | |
| URM3 Mesiodistal | Present | 14 | 6.6021 | 0.817 | -0.05207 | 0.22443 | -0.50285 | 0.39872 |
| | Absent | 38 | 6.6542 | | | | | |
| LLM3 Mesiodistal | Present | 9 | 8.3522 | 0.232 | -0.31674 | 0.26231 | -0.84242 | 0.20895 |
| | Absent | 48 | 8.6690 | | | | | |
| LRM3 Mesiodistal | Present | 10 | 8.8960 | 0.68 | 0.12682 | 0.30555 | -0.48505 | 0.73868 |
| | Absent | 49 | 8.7692 | | | | | |

*Significant differences found in the ULM3 buccolingual and the URM3 buccolingual measurements (in bold). All skeletons were used in order to increase the number of individuals analyzed. Separate analyses revealed similar results and therefore data groups were collated. Equal variances are assumed.

*Table 8. T-test results of size comparison between males with M3 agenesis and males without M3 agenesis. Only the ULM3 shows significant differences in size (in bold). Equal variances are assumed.*

| | Agenesis | n | Mean | Sig. (2-tailed) | Mean Difference | Std. Error Difference | 95% Confidence Interval of the Difference | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | Lower | Upper |
| ULM3 Buccolingual | Present | 5 | 8.7980 | **0.022** | -1.15123 | 0.45548 | -2.11680 | -0.18566 |
| | Absent | 13 | 9.9492 | | | | | |
| URM3 Buccolingual | Present | 7 | 9.2929 | 0.118 | -.62631 | 0.38043 | -1.42894 | 0.17632 |
| | Absent | 12 | 9.9192 | | | | | |
| LLM3 Buccolingual | Present | 2 | 7.4500 | 0.209 | -.81200 | 0.61855 | -2.13040 | 0.50640 |
| | Absent | 15 | 8.2620 | | | | | |
| LRM3 Buccolingual | Present | 3 | 8.0800 | 0.697 | 0.16118 | 0.40688 | -0.69365 | 1.01600 |
| | Absent | 17 | 7.9188 | | | | | |
| ULM3 Mesiodistal | Present | 5 | 6.3560 | 0.779 | -0.11785 | 0.41199 | -0.99123 | 0.75554 |
| | Absent | 13 | 6.4738 | | | | | |
| URM3 Mesiodistal | Present | 7 | 6.1900 | 0.882 | -0.05417 | 0.35974 | -.081315 | 0.70481 |
| | Absent | 12 | 6.2442 | | | | | |
| LLM3 Mesiodistal | Present | 2 | 8.3800 | 0.854 | 0.08313 | 0.44391 | -0.85792 | 1.02417 |
| | Absent | 16 | 8.2969 | | | | | |
| LRM3 Mesiodistal | Present | 3 | 8.8800 | 0.438 | 0.41118 | 0.51857 | -0.67831 | 1.50066 |
| | Absent | 17 | 8.4688 | | | | | |

*Table 9. Example of analysis in size patterns between the distributions of agenesis in the dentition. The small number of individuals with measurements available for each tooth dimension in each group made it impossible to determine significant relationships between the variables.*

| Measurement | Type | n | Mean | Sig. (2-tailed) | Mean Difference | 95% Confidence Interval of the Difference | |
|---|---|---|---|---|---|---|---|
| | | | | | | Lower | Upper |
| LLM3 Mesiodistal | Bilateral Maxillary Agenesis | 4 | 8.905 | 0.02 | 1.15 | 0.29535 | 2. 00465 |
| | Agenesis of Three Teeth | 2 | 7.755 | 0.02 | 1.15 | -3.3154 | 0.7904 |
| LLM3 Buccolingual | Bilateral Maxillary Agenesis | 4 | 8.57 | 0.149 | 0.795 | -0.44409 | 2.03409 |
| | Agenesis of Three Teeth | 2 | 7.775 | 0.149 | 0.795 | -1.77698 | 2.12698 |
| LRM3 Mesiodistal | Bilateral Maxillary Agenesis | 4 | 8.907 5 | 0.145 | -1.2625 | -3.3154 | 0.7904 |
| | Agenesis of Three Teeth | 1 | 10.17 | 0.145 | -1.2625 | -0.44409 | 2.03409 |
| LRM3 Buccolingual | Bilateral Maxillary Agenesis | 4 | 8.575 | 0.794 | 0.175 | -1.77698 | 2.12698 |
| | Agenesis of Three Teeth | 1 | 8.4 | 0.794 | 0.175 | -0.44409 | 2.03409 |

that stimulate antemortem tooth loss.

The prevalence of 42.7% in this assemblage is significantly higher ($p < .05$) than those reported for British clinical samples in which data was gathered from dental radiographs. Shinn (1976) found that 12.72% (n=318/2500) of patients referred to an orthodontic hospital in Southampton had third molar agenesis, whereas Gravely (1965) found that 25.9% (n=21/81) of patients exhibited third molar agenesis. From the Bristol Dental Hospital, Sengupta et al. (1999) found that 22% (n=22/100) of people were found to have third molar agenesis. In other groups of European ancestry prevalences of 28.2% (Krekeler et al., 1974), 28.5% (Trondle, 1973), 29.3% (Weise & Bruntsch, 1965) and 33% (Elomaa & Elomaa, 1973) have been reported. In European-derived North American samples, frequencies of 25.7% (Keene, 1965), 22.3% (Thompson et al., 1974) and 31.5% (Harris & Clark, 2008) have been observed. The frequency of M3 agenesis found in this study is comparable to the 44% prevalence reported in extant Asian and Native North American populations (Carter & Worthington, 2015). Clinical accounts of third molar agenesis in Asia appear to be higher than most European groups: 30% in a Malaysian Malay population (Alam et al., 2014), 33% in a Chinese Malaysian population (Alam et al., 2014), 50% in Nepal (Upadhyaya et al., 2012), 32.3% in Japan (Endo et al., 2015) and 38.4% in Bangladesh (Sujon et al., 1984). Ren & Kumar (2014) also report a prevalence of agenesis of 48% of males and 64% of females from southern India, but only 25 individuals of each sex were analyzed, and therefore the small sample size may not be representative.

Prevalence rates in archaeological assemblages are also extremely variable, in addition to the way in which data are collected and reported. In the present study, third molar agenesis is reported per individual, but due to preservation requirements or research questions, other studies separate data by the upper and lower dental arcade, the dental quadrant, or as an overall tooth count, making statistical comparisons with such research difficult. The Late Antique (n=117) and early medieval (n=245) assemblages from eastern Croatia examined by Vodanović (2012) produced third molar agenesis prevalences of 30.21% and 15.64% respectively, with the change in frequency attributed to population replacement in the early medieval period. Radiographic assessment was not performed, and the frequency of third molar agenesis is presented separately for the upper and lower arcade, rather than for each individual. Without radiographic assessment unerupted third molars may be mistaken for agenesis, creating the potential for a slightly higher prevalence than may otherwise be reported.

Castro (1989) found comparatively low prevalences of 7.6% in Gran Canaria, 10.8% in Tenerife, and 9.4% in the Canary Islands in archaeological assemblages dating from the 1st century B.C. – 14th century A.D. In this study, a total of 1,790 maxillae and 1,920 mandibles were visually analyzed for third molar agenesis. Due to the majority of mandibles having been separated from their skulls, Castro (1989) calculated the frequency of agenesis separately between the upper and lower dental arches. The author divided the total number of congenitally absent third molars by the total number of third molars that would be expected if third molar agenesis was absent in each individual to determine prevalence.

Nelsen et al. (2001) found third molar agenesis to be prevalent in 23.5% of individuals (n=12/51) from the Iron Age cemetery of Noen U-Loke, in Thailand. The authors did not use radiographic analysis. This prevalence is significantly lower, $\chi^2$ (1, n=140) = 5.2, $p$ = 0.023, than the prevalence of 42.7% recorded in the present study. The Noen U-Loke assemblage also has a high prevalence of lateral incisor agenesis, with 79% of individuals missing at least one lateral incisor. The authors hypothesize that endogamy and isolation likely factored in to the high prevalence of lateral incisor hypodontia. However, this does not appear to have a marked effect on the prevalence of third molar agenesis, as the modern worldwide average described by Carter & Worthington (2015) is 22%. In order to understand if endogamy and isolation affected the prevalence of third molar agenesis in this assemblage, analysis of other archaeological assemblages from the time period and the area with more genetic diversity would be necessary in order to confidently assess typical third molar agenesis prevalence.

The methods of archaeological analysis employed by Henriksson et al. (2019) in their analysis of medieval and modern Norwegian assemblages align closely with the present study. The authors used both radiographic and visual analysis to determine 36 of 130 medieval skeletons had third molar agenesis. A decrease in third molar agenesis from medieval (27.7%) to modern times (17.2%) was detected. The frequency of third molar agenesis found in the present study (42.7%) is significantly higher, $\chi^2$ (1, n=219) = 5.3, $p$ = 0.021, than the frequency recorded in the medieval Norwegian

assemblage. Henriksson et al. (2019) proposes that the higher rate of third molar agenesis in the medieval assemblage compared with the modern Norwegian sample may be due to the biological relationships present in the cemetery of St. Olav, as opposed to the unrelated sample of modern Norwegian 15 year olds. A strong genetic influence could also be present in the Chichester assemblage, and may be a primary factor in the relatively high frequency of 42.7%, although further analysis is required to explore this.

Sengupta et al.'s (1999) analysis of Victorian skeletons from the Spitalfields cemetery in London represents the closest archaeological comparison to the present study, both temporally and geographically. The frequency of third molar agenesis was determined by assessing each dental quadrant as a separate specimen, and both visual and radiographic analysis were used. The prevalence of third molar agenesis presented here (42.7%) is significantly higher, $\chi^2$ (1, n=140) = 5.2, $p$ = 0.023, than the prevalence of 23.5% recorded at Spitalfields (n=12/51), and is much greater than the frequency of 14% observed in the medieval burials at St. Peter's Church, Barton-on-Humber, also examined by Sengupta et al. (1999). Due to the proximity and temporal overlap with the Chichester assemblage, it is likely familial genetic predispositions towards third molar agenesis were present in the Chichester assemblage.

In addition to a genetic component, diet could have factored in to the rates of third molar agenesis in Chichester. In post-medieval Britain, the diet was heavily impacted by the industrial revolution of the 17th century, with food becoming sweeter and increasingly processed (Rando et al., 2014). Refined flour and white bread became popular, and in 18th – early 19th century London, potatoes, bread, and tea were a dietary staple (Mant, 2015). Increasingly processed diets reduce dental wear on the occlusal and interproximal surfaces of teeth. As teeth wear down more space becomes available in the jaw due to the mesial drift of teeth, and without this wear, dental crowding and impaction are more likely to occur (Sengupta et al., 1999). Rando et al. (2014) compared the mandibular morphology of medieval and post-medieval Londoners and found a decrease in the robusticity of bone associated with masticatory muscles in post-medieval skeletons. The strong association between the hardness of diet, cranio-facial development, and the resulting formation of dental anomalies has been demonstrated in the literature, and likely contributed to third molar agenesis in the Chichester assemblage (Corruccini et al., 1983; Corruccini & Lee, 1984; John et al., 2012; Yamada and Kimmel, 1991). However, the Spitalfields assemblage (Sengupta et al., 1999) was also exposed to these influences and has a much lower prevalence (23%) of third molar agenesis. Therefore, dietary influences alone cannot account for the high prevalence rates found in the Chichester assemblage.

It is also relevant to consider the how the biocultural environment, the relationship between biological and cultural elements, may have impacted growth in post-medieval Chichester. Despite the resistance of tooth formation to growth disruptions (Hillson, 2005), delayed dental eruption is often reported in individuals with systemic disease, in the absence of essential nutrients, or in individuals living in a low socioeconomic setting (Cardoso, 2007; Suri et al., 2004). Delayed formation and eruption has also been correlated with increased frequency of third molar agenesis, and reduced morphological complexity in first and second molars (Anderson and Popovich, 1981). Research has shown that the pre-natal environment and the quality of breastfeeding during tooth development also affect the size of the third molars (Garn et al., 1980; Grüneberg, 1951; Grüneberg, 1963; Lumey and Stein, 1985). In Chichester in the early 17th century and again in 1665, the plague was present, and smallpox peaked in 1722, 1740, 1759 and 1775 (Morgan, 1992). In the 19th century, "the health of Chichester often lagged behind the rest of the country" (Morgan, 1991:23), with epidemics linked to water and sewage, such as cholera and typhoid fever, occurring at regular interval. Statistics from 1871-1880 put Chichester amongst the highest number of cases of consumption and typhoid fever in the country, and historical records detail poor sanitation and a lack of the necessary infrastructure for clean water supply and sewage drainage (Morgan, 1992). Such adverse conditions would certainly have disrupted growth, and may have also had an impact on the development of third molars.

*Size Reduction and Agenesis*

Third molars highly reduced in size, both in mesiodistal and buccolingual dimensions, and/or simplified in morphology, are often referred to as vestigial molars (Nanda, 1954), a term that implies an evolutionary trend towards dental reduction. These third molars are easily recognized upon visual assessment. In Nanda's (1954) analysis of vestigial third molars, all individuals with diminution also had third molar agenesis in other dental quadrants. Size reduction has also been demonstrated in

dentitions with agenesis of other tooth types (Baum & Cohen, 1971). Grüneburg (1951) proposed that agenesis is the most severe expression of a size continuum, in which the tooth germ falls below a critical threshold and formation ceases. From this evidence it might be expected that individuals in the Chichester assemblage who demonstrate third molar agenesis would have other third molars reduced in size and would be smaller upon comparison with those that do not have third molar agenesis.

In this assemblage, all individuals demonstrating vestigial third molars (n=7) (Figure 3) had third molar agenesis, except for one skeleton that was missing data on the URM3. It is likely the number of vestigial third molars in this assemblage would have been higher had post-mortem loss not been a factor, and if third molars in alveolar tooth crypts had been measured radiographically.


Figure 3. Left portion of a mandible demonstrating a third molar reduced in size and morphology (Author's own 2017). The remaining third molars are congenitally absent.

Buccolingual measurements of the maxillary third molars in individuals with agenesis were significantly smaller ($p < 0.05$) than those without agenesis in this study (Table 7). Maxillary third molars are more frequently reported congenitally absent than mandibular third molars in the literature (Carter & Worthington, 2015). Given that the buccolingual dimensions of maxillary third molars in this assemblage were smaller in those with agenesis, it is possible to infer maxillary molars are more vulnerable not only to agenesis, but to diminution as well; however, mandibular agenesis was found to be slightly more common in this assemblage (54% vs 46%, Table 4), though this difference was not statistically significant, $\chi^2$ (1, n=166) =1.18, $p = 0.278$.

Baum & Cohen (1971) collected buccolingual and mesiodistal measurements of all teeth, except third molars, from a clinical sample of European-derived ancestry in the Northeastern United States. They analyzed size reduction in the presence of dental agenesis in tooth types other than the third molar. In contrast to the present study, the authors found that mesiodistal dimensions demonstrated a statistically significant association with size reduction and agenesis in 70% of tooth types, excluding third molars. Buccolingual dimensions were, however, only reliable indicators of the association between size reduction and agenesis in measurements of the canines. Garn et al. (1968) investigated the relationship between buccolingual and mesiodistal dimensions. While the two are correlated, the results reveal more autonomy than commonality governing morphological expression, although the further distal in the dental arcade the tooth, the higher the correlation between the two dimensions. Therefore, it might be expected that both the mesiodistal and buccolingual dimensions of third molars would demonstrate an association with size reduction and agenesis. The fact mesiodistal measurements did not show a statistically significant association between size reduction and agenesis in this study may be due the small number of individuals in this cohort, the highly variable morphology of third molars, or it could be an indication that the relationship between buccolingual and mesiodistal dimensions is both population dependent and complex.

Another factor complicating results is the significant differences ($p < 0.05$) in size between the third molars of males and females (see Table 6). To explore this further, an analysis of the relationship between size and agenesis was conducted separately. Removing indeterminate sex from the pool of measurements eliminated 29% of the assemblage. Males (n=46) continued to present significantly smaller third molars in the presence of third molar agenesis compared to those without agenesis in the buccolingual dimension of the upper left third molar. The smaller female sample size (n=36) made testing the correlation between agenesis with smaller tooth size more difficult.

The final question of analysis in this study focused on detecting patterns in size reduction amongst those with third molar agenesis. Khalaf (2016) analyzed the relationship between size reduction and agenesis in all tooth types in individu-

als with mild (≤2 teeth congenitally missing), moderate (3-5 teeth congenitally missing) and severe (≥6 teeth congenitally missing) hypodontia. They found that size reduction in the remaining teeth increased with the severity of hypodontia. With this research in mind and Grewal's (1951) evidence of third molar diminution in mice, it was hypothesized that individuals in the Chichester assemblage with three third molars congenitally absent might have a smaller remaining third molar than those with less third molars congenitally absent. In addition to relationships in size within third molar agenesis, any differences that existed between certain groups of third molar agenesis and those without agenesis, for example those with three congenitally absent third molars and those without third molar agenesis, were tested to determine if size differences in third molars could be found between these groups. Unfortunately, this reduced the number of individuals in each measurement category and it was not possible to reach statistical significance (see Table 9). Size patterns within third molar agenesis have yet to be explored in modern or archaeological data, and therefore further testing is required.

**Conclusions**

Rates of third molar agenesis recorded in modern clinical data are often interpreted as a secular trend in which the third molar, now deemed redundant due to decreased dental wear, low masticatory stress and soft diets, will eventually cease development and potentially disappear from the human dentition. Although there is an established genetic component, the etiology is far from clear. Research on archaeological assemblages is vital in order to better understand the trajectory and origin of this phenomenon, and this study provides a valuable contribution to the relatively little that is known about third molar agenesis prevalence in the past. In post-medieval Chichester, third molar agenesis occurred in 42.7% of individuals. This result is higher than any reported for a clinical British sample, and it is also significantly higher than the prevalence reported from the Victorian Spitalfields assemblage (Sengupta et al., 1999), indicating that an inheritance pattern may be present amongst the skeletons from the post-medieval assemblage of the Litten cemetery in Chichester. While reduced dental wear and masticatory stimulation may contribute to the frequency of agenesis in this assemblage, a strong genetic influence combined with the adverse community health conditions may prove to be important etiological components of third molar agenesis and avenues for future research.

Significant differences in the size of third molars between those with third molar agenesis and those without were found, although only two of the eight measurements analyzed were found to be significant. If third molars are indeed vestigial, more studies with larger sample sizes will be needed to further test any temporal trend. This includes the examination of archaeological as well as clinical samples.

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