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Evaluating three methods to estimate the number of individuals from a commingled context

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ABSTRACT

An estimate of how many individuals are represented in a commingled assemblage is important to interpret the wider context (archaeologically or forensically), for further analyses, and for palaeodemographic studies. The aim of this study was to establish whether the Minimum Number of Individuals (MNI) and Minimum Number of Elements (MNE) estimates produced by three different methods (traditional MNI (White, 1953); zonation method (Knüsel and Outram, 2004); the landmark method (Mack *et al.*, 2015)) are the same or, if different, to evaluate these differences. The methods were applied to an assemblage recovered from a Spanish medieval cemetery from Navarra and used to estimate the Number of Identified Specimens (NISP), the MNI and the MNE according to each method. Fragmentation analysis was also performed. The results indicate different values of MNE and MNI when applying different methods. White's MNI equaled 84; the MNI by zones 68; and the MNI by landmarks 61. All methods showed differences but the disparity between the traditional MNI and the MNI by landmarks was highest. Furthermore, the results indicate that different methods had a minimal impact on estimates of smaller bones. Individuals may be double counted by White's MNI count and the zonation method, when refitting exercises cannot be applied to all fragments from the same context or site, or if the 50% presence rule is not applied to the method. Finally, these findings have important implications for future analysis of commingled remains, because MNE and MNI estimates, as well as levels of fragmentation can impact on decisions made to further analyse the collection. Further research on a known collection is needed to identify the most reliable method to use.

1. Introduction

Commingled skeletal remains refer to the mixing of whole or fragmented skeletal elements of two or more individuals in a single context (Ubelaker, 2002). This commingling can come about through taphonomic factors, such as dispersal due to animal scavenging (Ubelaker, 2002; Garrido-Varas and Intriago Leiva, 2012), or intentional human behaviour linked to funerary practices or the post-funerary processing of human remains, such as the removal of the remains from a primary resting place to a secondary or tertiary one, or to several individuals being interred in a shared funerary structure (Gerdau Radonić and Herrera, 2010; Gerdau Radonić and Makowski, 2011). Commingled collections can also result from short-term commingling, such as mass burials due to epidemics or warfare (cf. Fiorato et al., 2000). Lastly, they can be the result of recovery procedures or laboratory commingling while being curated (Byrd and Adams, 2011; Osterholtz et al., 2013; Ubelaker, 2002).

A thorough analysis of commingled skeletal elements is made difficult because of their disarticulated and fragmented state. Commingled remains are often ignored or not analysed properly, possibly due to time constraints. Furthermore, standard osteological protocols are not always applicable (Fox and Marklein, 2013). Some of the main problems with the analysis of commingled remains include recognising why and how commingling has taken place, what skeletal elements are present, and the estimation of the number of individuals present (Mack et al., 2015; Ubelaker, 2002). It is necessary to address these problems when analysing commingled assemblages in order to provide valuable insights into demographic patterns and mortuary behaviours which may have generated the commingling (Gerdau Radonić and Herrera, 2010; Gerdau Radonić and Makowski, 2011; Mack et al., 2015; Ubelaker and Rife, 2008). Variations in element representation can help identify when and why element loss occurred (intentional vs. accidental selection, primary vs. secondary deposits) and can help reconstruct the population profile (Adams and Konigsberg, 2008; Gerdau Radonić and Makowski, 2011; Ubelaker, 1973). Osteologists are increasingly involved in mass disaster investigation, especially with regard to victim identification and injury pattern determination, both of which are helpful in reconstructing incidents (Kontanis and Sledzik, 2008). There is, therefore, need for a validated method to estimate the Minimum Number of Elements (MNE) and from it the Minimum Number of Individuals (MNI; Egana et al., 2008; Herrmann and Devlin, 2008).

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Fig. 1. Church of Santa María de Zamartze and the newly renovated annex house. (Photo: Valle de Tarazaga)

An objective and accurate estimate is important for both legal and scientific reasons (Adams and Konigsberg, 2008; Kontanis and Sledzik, 2008; Nikita and Lahr, 2011; Ubelaker, 2002).

Methods to estimate the number of individuals have been borrowed from zooarchaeology. The primary type of estimator used in human skeletal assemblages is the MNI (Byrd and Adams, 2011). Traditionally, osteologists have used White's (1953) method to estimate the MNI, variations of which appear in standard textbooks used in both zooarchaeology and human osteoarchaeology (e.g., Buikstra and Ubelaker, 1994: 9; Lyman, 2008: 38–82). In 2004, Knüsel and Outram published a variation of the zonation method for human remains. In 2015, Mack and colleagues further modified the zonation method and published the landmark method, which rather than focusing on zones within each skeletal element, focuses on well-known landmarks. Other examples of methods for sorting and quantifying remains include visual pair-matching (Byrd and Adams, 2011; Thomas et al., 2013), the estimation of the most likely minimum number of individuals (MLNI; Adams and Konigsberg, 2004), osteometric sorting (Byrd, 2008), DNA-sampling (Byrd and Adams, 2011), spatial analysis (Tuller et al., 2008), and a GIS-based approach (Marean et al., 2001; Herrmann et al., 2005; Herrmann and Devlin, 2008).

This study investigates whether the osteological MNE and consequently the MNI estimates derived from three different methods are equivalent or whether a difference in output can be observed. Osteological MNI and MNE estimates were established according to each method assessed. The differences in MNI and MNE values between methods were evaluated. Fragmentation analysis was carried out to show the percentage completeness and the Bone Representation Index (BRI) of the collection (Bello et al., 2003). The traditional MNI estimator as first outlined by White (1953), and described later by Lyman (2008: 38–82), was applied and compared to the zonation method (Knüsel and Outram, 2004) and the recently published landmark method (Mack et al., 2015). As the purpose of the study was to compare the estimates of three different methods per osteological element, teeth were excluded. Furthermore, only the landmark method includes teeth in its description (Mack et al., 2015).

2. Materials and archaeological context

The commingled human skeletal remains studied were recovered from the medieval cemetery of Santa María de Zamartze. This is a monastic complex situated close to the town of Uharte-Arakil, Navarra, Spain. The present-day monastery structure dates to the 12th century AD and has an adjoining medieval cemetery (AD 11th–13th century), east of the apse of the church, believed to be the main burial ground. The top levels of the cemetery contained a high number of commingled remains, which most likely happened through the movement of individuals from primary burials into secondary deposits to provide adequate space for newer depositions. Excavations have been on going since July 2011, led by Aditu Arkeologia Zerbitzuak S.L. (Fig. 1; Valle de Tarazaga, 2013).

The commingling at this site can be described as large-scale commingling (Byrd and Adams, 2011). The bones were mixed in a random manner and the fragmentation as well as the quantity of remains rendered difficult re-associating elements and fragments with each other. A total of 8847 fragments were analysed.[1] For the purpose of this study the whole of the site was treated as a single context.

3. Methods

3.1. Sorting

The specimens were separated into faunal and human remains. The human remains were catalogued and entered in an element-by-element database in a Microsoft Excel spreadsheet, alongside all available information. Fragments were first identified by element type, and when possible side and age category (adult/juvenile). Thereafter, conjoining exercises were carried out in order to refit fragments from the same bone (Ubelaker, 2002).

Due to the lack of space (approximately 50 cm by 160 cm were available as working space), it was not possible to layout all identical skeletal elements at one time. That is, for example, all humeral fragments from the entire commingled collection were not laid out at the same time. Therefore, it was necessary to count the specimens by contexts, limiting the refitting exercises. It is therefore possible that some elements were double counted in the traditional and zonation methods, as fragments of one element could have been in more than one context.

Elements were classified as either adult or juvenile. For the purpose of this study, further refined age assessments were not carried out on adult individuals. Bones with unfused epiphyses and which were within the juvenile size range, and hence too small for an adult,[2] were classified as juveniles and the age-at-death was calculated by epiphyseal union and diaphyseal length (Schaefer et al., 2009). In cases where a more precise age range was indeterminable beyond the delineation of juvenile (J), the classification of J was applied. Fully fused and adult-sized

[1] The contexts analysed were: SU 201, SU 211, SU 214, SU 222, SU 227–229, SU 232, SU 233, SU 235, SU 237–240, SU 242, SU 243, SU 247, SU 250, SU 251, SU 261, SU 266, SU 267, SU 273, SU 276, SU 282, SU 375, SU 507–509, SU 535, SU 604, SU 614, SU 628, SU 635, SU 654, SU 663, SU 665 and SU General

[2] Pathology was also excluded as a possible cause for the small size when possible.

bones were attributed to the adult category. It is possible that some bones were falsely placed in the adult category. For example, adolescents may have 'adult' diaphyseal dimensions and, if fusion lines and growth centres are not visible, this could lead to a misclassification (Mack et al., 2015; Scheuer and Black, 2000; Ubelaker, 1973). However, this should not affect the final estimate for MNE and MNI when all age categories are considered jointly.

Specimens which could not be identified by element were recorded in the database and categorised as either fragments of long bones, fragments of the cranium, or unidentified, and were not included in the final MNE and MNI counts. Those fragments for which side could not be determined were recorded by element but omitted from the final MNE and MNI estimates.

All of the identifiable specimens were recorded three times and entered into separate databases, one for each method used to estimate the MNE and the MNI. Most bones in the skeleton were used to estimate the MNI. However, though recorded, ribs three to twelve, phalanges, and vertebrae C3 to C7, T2 to T12, and L1 to L5 were excluded from the MNE and MNI estimates, as they are difficult to identify by number (and side for the phalanges) when fragmented and commingled (Snow and Folk, 1970).

Pathological conditions, trauma, or taphonomic changes observed were recorded and photographed. Visual pair-matching was not attempted. When visual pair-matching is included in MNI estimates the unpaired bones from one side are added to the total MNE count from the other side in order to estimate the MNI for that element. For example, if the MNE estimate was five left femora and six right femora, and two pairs can be identified in the set due to symmetry, the MNI from the femora would be estimated as follows:

two pairs + three unpaired left femora + four unpaired right femora = MNI of nine,

rather than the more conservative MNI estimate of six, taken from the maximum MNE given by the right side. However, the fact that a match has not been established between pairs does not mean that a match does not exist (Villena i Mota et al., 1996). Hence, visual pair-matching can lead to the double counting of individuals and inflated MNI estimates, particularly in large assemblages.

3.2. Minimum number of individuals: MNI

3.2.1. Traditional method (White, 1953)

The traditional MNI count is calculated by dividing the skeletal elements into right and left and using the most abundant number as the final estimate (White, 1953). This study used White's (1953) MNI method as described by Buikstra and Ubelaker (1994). Long bone fragments were sorted by element and recorded as either: complete (4), distal epiphysis (3), diaphysis (2) or proximal epiphysis (1), while separating the bones by age and recording adults and juveniles separately. Non-long bones were recorded by percentages in quarters: >75% (4), 50–75% (1), 50–25% (2) and <25% (3; Buikstra and Ubelaker, 1994). The method as described does not apply the 50% rule, which states recorded sections should only count towards the MNE when 50% or more is present. Therefore all sections of bone were recorded here as either absent or present. Then, the MNE was established by identifying the most abundant segment of an element. The MNI was determined by identifying the largest MNE from the left or the right side (Buikstra and Ubelaker, 1994; Byrd and Adams, 2011; Lyman, 2008).

3.2.2. Zonation system

For the zonation system, all specimens were recorded by element, side, age, and the zones described by Knüsel and Outram (2004). The zonation system was adapted from the method by Dobney and Rielly (1988) for faunal remains and is based on morphological zones. Watson (1979) defined diagnostic zones as "[…] areas on bones that were species-specific in morphology, present in both fused and unfused specimens, free of age biases and rarely broken". The strengths of using non-repeatable zones lies in the relative easiness of identifying fragments to zones. The method is also less affected by inter-observer error because it does not rely on the subjective estimation of proportions of a skeletal element (Dobney and Rielly, 1988).

Knüsel and Outram (2004) used the drawings of the original method by Dobney and Rielly (1988) as a template and adjusted descriptions when necessary to account for specifics in human anatomy. They kept the same number of zones for each bone and devised new zones for bones found in humans but not in other species. The bones, excluding the ones in the cranium, are divided from three to 15 zones. However, cranial bones are represented by a single zone each, e.g., the right temporal bone is defined as zone 7 and the occipital bone as zone 5. Carpals and tarsals (except the calcaneus and talus) are defined as complete bones. Zones should be recorded as either present or absent. Dobney and Rielly (1988) applied the 50% rule, as described above, in their method. Notwithstanding, Knüsel and Outram (2004) did not specify this rule, and zones are to be scored as present even if only a small part is observed; however, conjoining exercises between fragments are to be performed to identify fragments belonging to the same skeletal element. The MNE was calculated by indicating the most-represented zone on an element. The MNI was determined by identifying the highest MNE from a single side and separated by age category (Knüsel and Outram, 2004).

3.2.3 Landmark system

For this method, all fragments were also recorded by element, side, age, as well as by the landmarks described (Mack et al., 2015). The landmarks chosen by the authors are distributed over the complete element and are consistently present across all individuals. Landmarks are features such as articular surfaces, bony processes, nutrient foramina, clearly defined sections of a bone or those that are readily identifiable sections of long bone diaphyses selected from standard anatomical features of human osteology textbooks (Mack et al., 2015). Mack et al. (2015) provide drawings of the features they used, which results in a standardised method to estimate MNI by landmarks. All landmarks are scored as present or absent and only used for the final MNE estimate when >50% is observable (Mack et al., 2015). Sixty-five landmarks represent the cranium and the mandible (67 when teeth are recorded). Post-cranial bones are scored by recording from two to 18 identifiable features per element. Carpals and tarsals (except for the calcaneus and talus) are not counted by landmarks, but as complete bones. Therefore, it was unnecessary to also record these tarsal or carpal bones with this method because the count would be the same as for the zonation method. The MNE was established by identifying the largest number of non-repeating landmarks, while the MNI was determined by taking the largest MNE count from a single side, separated by age (Mack et al., 2015).

3.3. Fragmentation analysis

3.3.1. Percentage completeness

Several methods were used to calculate the fragmentation and preservation of bones. Percentage completeness was determined by dividing the number of landmarks/zones/segments recorded for a particular element (PP) by the number of specimens identified as pertaining to that element (NISP); the resulting value was in turn divided by the number of landmarks/zones/segments defined for that element (PD). This gives an estimate of the completeness of the element (Mack et al., 2015; Morlan, 1994):

$$(PP/NISP)/PD$$

where PP stands for 'Portions Preserved' (all landmarks/zones/segments recorded for an element), PD represents 'Portions Defined' (number of landmarks/zones/segments defined on a bone), and NISP is the total Number of Identified Specimens for that element (Lyman, 1994: 27). Therefore, for example, when calculating the percentage completeness of the femur using the results of the landmark method, the formula would be as follows:

(619/321)/13 = 0.14 (percentage completeness)

All portions (in this case landmark) identified and recorded (619 femoral landmarks recorded) are divided by the NISP of that element (321 identified femoral fragments). This value is then divided by the number of landmarks defined for the femur (13 in this case). This results in 14% completeness for the femur (0.14 ∗ 100 to convert to a per cent).

The NISP is the most basic quantitative number recorded in an osteological assemblage. It counts the number of skeletal elements identified to bone type and taxon,[3] and was first used in zooarchaeology (Lyman, 1994; Orton, 2012; Reitz and Wing, 2007). To calculate the NISP bones are sorted into taxa (when dealing with a mixed species assemblage) and then into skeletal element type.

3.3.2. Bone representation index

To evaluate the survival of skeletal elements, the BRI was calculated by comparing expected and observed MNE values for each method as follows:

$$(\text{MNE observed}/\text{MNE expected}) * 100$$

Thus, for example if we calculate the BRI for the femur by using the MNE by zone values, the formula would be:

$$(65/68) * 100 = 95.6\ (\text{BRI})$$

The expected MNE is 68, based on the MNI of the cranium, which gave the highest MNE estimate for the sample using the zonation method, and the observed MNE for the femur is 65. Multiplying this by 100 results in 95.6% of femora being present in the collection (Atici, 2013).

3.4. Percentage differences

A percentage difference between the MNE values for each method was calculated, where 100% represented the method returning the maximum MNE for a particular skeletal element. Resulting MNE counts that were consistent across all methods were excluded.

4. Results

4.1. Minimum number of elements and minimum number of individuals

The results of the MNI calculation are summarised in Table 1 and Fig. 2. The highest MNI was obtained through the traditional method, 84 (femur). The landmark method returned a more conservative estimate of 61 (femur). This is a difference of 23 individuals (27.39%) between the traditional MNI and the landmark method. The zonation method indicated an MNI of 68 (cranium).

When the results were separated between juveniles and adults, the traditional method estimated an MNI of 78 through the right femur, the zonation system 64 through the right temporal bone, and the landmark method 57 based also on the right femur (Table 2). The MNI for juveniles also shows different results for each method but with fewer disparities: the traditional MNI suggests six individuals, the MNI by zones five individuals, and the MNI by landmarks four individuals. All three estimates are based on the left femur (Table 3). These smaller differences may be due to the smaller sample size. The NISP for the juvenile remains was 337 as opposed to the NISP for adult remains, 8509. When the age-at-death was estimated among the juvenile sample, an MNI of six individuals emerged as the most likely result (Table 4). For the elements that generated differing MNE counts, the highest value was usually obtained using the traditional MNI, followed by the zonation system, and finally the landmark system (Fig. 2).

[3] In humans, it only represents specimens identified to bone type.

Table 1
Minimum Number of Individuals (MNI) results per method.

Method	Total	Adults	Juveniles
Traditional MNI	84	78	6
MNI Zones	68	64	5
MNI Landmarks	61	57	4

4.2. Fragmentation analysis

Percentage completeness was calculated for forty-two elements with no separation by context, to allow for a baseline of completeness across the site and within each method (Fig. 3). Carpals, tarsals (except for the talus and calcaneus), ribs, and vertebrae were not included in the calculation because the MNE results were the same for each method, and carpals and tarsals were complete when present. More than half of the skeletal remains available for study were in poor condition with <50% of the bone present. The major long bones averaged 20% completeness when calculated with the estimates from both the zonation and landmark systems. The ulna was the most complete bone (32% and 33%, respectively) and the femur was the least well-preserved bone (15% and 14%, respectively) according to these two methods. Estimates derived from the traditional MNI were similar. Major long bones displayed an average completeness of 25%. The ulna was again the best preserved bone with 33% but the least well-preserved bone in this case was the fibula (19%).

The cranium is the least well-preserved part of the skeleton according to the zonation and landmark systems with a percentage completeness of 9% and 5%, respectively, in contrast to the traditional MNI, which resulted in 26% completeness for the cranium. For the traditional MNI the clavicle is the least well-preserved bone with 15% completeness. On the contrary, small bones such as carpals and tarsals are relatively complete (over 75% completeness; Fig. 3). The foot and hand phalanges are the most complete bones, with 87% completeness when calculated according to the zonation and landmark system estimates, and 83% when using the traditional MNI estimates.

The results for the BRI indicate that skeletal elements are represented in varying proportions. For all three methods, it stands true that the cranium, mandible, humerus, femur, and tibia resulted in the most represented bones of the collection, whilst the hyoid, sternum, thoracic vertebra 1, ribs 1 and 2, and most carpals and tarsals were severely under-represented. Fig. 4 shows the total representation of the skeletal remains of the assemblage differentiated by method. The traditional MNI by White indicates that the femur is represented in higher numbers than the cranium and other long bones (Table 5). The MNI by zones shows the cranial bones to be the most represented in the collection, followed by lower and upper limb bones. A similar pattern is repeated in the MNI by landmarks, the femur and cranium are represented in higher numbers than other lower and upper limb bones.

4.3. Percentage difference

The Percentage Difference for all three MNE results was calculated to evaluate differences in the MNE values (Fig. 5). When the traditional MNE values are compared to those of the MNE by zones and the MNE by landmarks, the clavicle shows disparate results (traditional MNE = 11, MNE by zones = 21, MNE by landmarks = 21); however, there is no difference between the zonation and the landmark methods. The long bones show differences between the upper and lower limb bones for all methods. The difference in MNE estimates is highest overall between the traditional and the landmark methods. Exceptions are the tibia and the *os coxae* where the difference between MNE estimates is highest between the traditional method and the zonation method. Overall, the differences between MNE by zones and MNE by landmarks are less

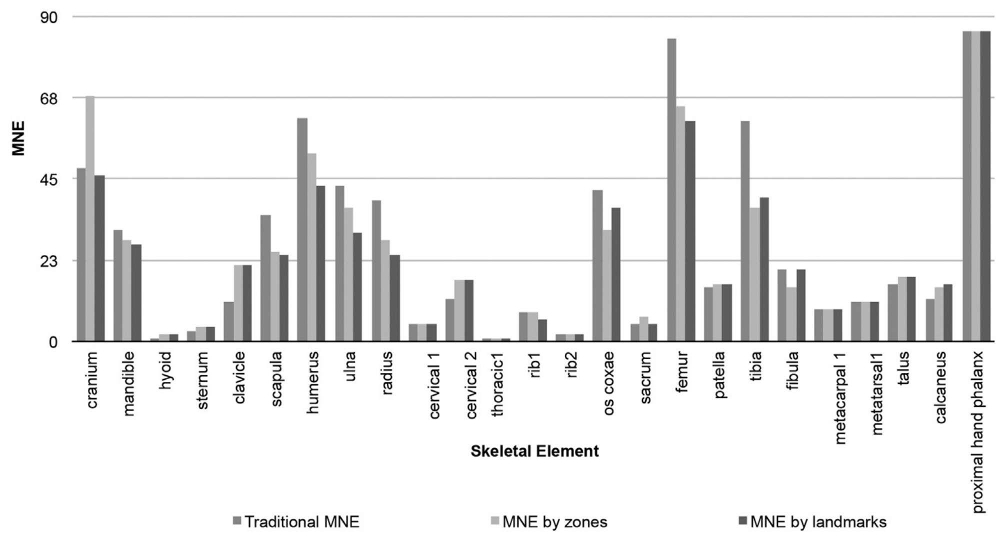

Fig. 2. Minimum Number of Individuals (MNI) calculated by anatomical units for the different methods.

numerous, except for the cranium, rib 1, the sacrum, the fibula and the long bones of the upper limb (Table 6).

5. Discussion

5.1. Minimum number of elements and minimum number of individuals

The results indicate that different estimates of MNE and MNI can be obtained while using different methods on the same collection. The traditional MNI method resulted in an estimated MNI of 78 adults and six juveniles (femur). This estimate is almost 30% more than the estimate obtained through the landmark method (61). Whilst this has important implications for the subsequent analysis of commingled remains, it does not immediately indicate which of the three methods is the most reliable approach for use in research, but it demonstrates the need to test the three methods on a known collection. Nevertheless, to our knowledge there are no collections for which the original number of individuals is known prior to commingling. It would therefore require the commingling of a known number of individuals from a collection, which poses both ethical and curatorial problems.

The traditional method has a long history (White, 1953) and can be applied without the need to refer to drawings of diagnostic zones or landmarks. Notwithstanding, this study shows that this method may double count individual skeletal elements under certain circumstances, for example when aggregation has an effect on MNI values. Aggregation can occur depending on the way in which the specimens are divided for analysis (Grayson, 1984; Reitz and Wing, 2007). Analysing a whole site should give a lower MNI than analysing the same site sub-divided by contexts or strata. The latter may increase the MNI estimate until MNI = NISP (Grayson, 1984). In this study, the site was treated as a single context (or aggregate), but all specimens could not be laid out and counted at one time for two reasons: (1) lack of space (Fig. 6) and (2) the need not to mix different archaeological contexts, limiting the number of specimens that could be analysed simultaneously. This may be a possible explanation for the discrepancy seen in the MNI values, which was as high as 23 individuals between the traditional method and the landmark method. In such conditions, the traditional method

Table 2
Maximum Minimum Number of Elements (MNE) count for the left or the right (when paired) per element for adults (metatarsals and metacarpals are represented here just by two examples).

Element	Max MNE Traditional (L/R)	Max MNE by zones (L/R)	Max MNE by landmarks (L/R)
Cranium	44 (L)	64 (R)	42 (R)
Mandible	29 (R)	27 (R)	26 (R)
Hyoid	1	2	2
Sternum	2	3	3
Clavicle	10 (R)	20 (L)	20 (L)
Scapula	33 (L)	23 (R)	22 (L)
Humerus	59 (R)	49 (R)	41 (R)
Ulna	41 (R)	35 (R)	28 (L + R)
Radius	37 (R)	27 (R)	22 (R)
Vertebra C1	5	5	5
Vertebra C2	12	17	17
Vertebra T1	1	1	1
Rib1	7 (L + R)	7 (L)	5 (L + R)
Rib2	2 (L + R)	2 (L + R)	2 (L + R)
Os coxae	39 (L)	29 (R)	34 (L + R)
Sacrum	5	7	5
Femur	78 (R)	60 (R)	57 (R)
Patella	14 (R)	15 (R)	15 (R)
Tibia	59 (R)	36 (R)	39 (R)
Fibula	19 (L)	14 (L)	19 (L)
Metacarpal 1	9 (R)	9 (R)	9 (R)
Talus	16 (L)	18 (L)	18 (L)
Calcaneus	11 (L)	14 (L)	15 (R)
Proximal hand phalanx	82	82	82

Table 3
Maximum Minimum Number of Elements (MNE) count for the left or the right side for juveniles by element.

Element	Traditional MNE (L/R)	MNE by zones (L/R)	MNE by landmarks (L/R)
Cranium	4 (L + R)	4 (R)	4 (R)
Mandible	2 (R)	1 (L + R)	1 (L + R)
Sternum	1	1	1
Clavicle	1 (R)	1 (R)	1 (R)
Scapula	2 (L + R)	2 (L)	2 (L)
Humerus	3 (L)	3 (L)	2 (L + R)
Ulna	2 (L + R)	2 (L + R)	2 (L + R)
Radius	2 (L)	1 (L)	2 (L)
Rib1	1 (L)	1 (L)	1 (L)
Os coxae	3 (L)	2 (L + R)	3 (R)
Femur	6 (L)	5 (L)	4 (L)
Patella	1 (L + R)	1 (L + R)	1 (L + R)
Tibia	2 (L)	1 (L + R)	1 (L + R)
Fibula	1 (L)	1 (L)	1 (L)

Table 4
List of identified juvenile elements by age categories.

Juveniles	Age	Element
Perinate	~38 weeks	Petrous pyramid
Infant	~3 months-1 year	Calcaneus, scapula, femur
Child	~1–5 years	*Os coxae*, tibia, metacarpal
Child	~11 years ± 30 months	Cranium
Child	~6–11 years	Cranium
Child	~2–11 years	Cranium

may over-estimate the number of individuals present by double counting certain elements, as it may not be possible to refit fragments from individual elements. In that case, a count by landmarks or zones may produce a more conservative MNE as it is estimated through the landmark or zone producing the highest count. For example, if a distal femur was fragmented into several parts, the medial condyle might be in one context whilst the lateral condyle might be found in another context. In this instance, the traditional MNI method could count the same femur twice, if it was not possible to ascertain that both halves fit together. The landmark and zoning system on the other hand would record medial and lateral condyles separately and count the fragments as part of one bone. Even more problematic can be diaphyseal fragments of long bones, where for example, fragments of long bone diaphysis belonging to one skeletal element may be located in different bags or contexts, but get treated as two separate skeletal elements as it is impossible to ascertain whether there is an overlap or not between the fragments.

The MNI method by zones (Knüsel and Outram, 2004) was chosen as it is well established in the zooarchaeological literature. It is relatively easy to follow as long as one has access to the zone drawings. The method suggests an MNI of 64 adults and five juveniles. The zonation system appeared less affected by the lack of conjoining exercises and the aggregation effect than the traditional MNI method. However, there is one weakness to the zonation method, and it is the cranium. Zooarchaeologists have discussed for years the benefits of small diagnostic zones and the use of easily distinguishable features over zones representing a whole element for the recording of fragmented material (Marean et al., 2001). Notwithstanding, Knüsel and Outram (2004) divided the cranium into 15 zones each corresponding to one cranial bone. Therefore, when confronted with highly fragmented crania the MNE estimates can be elevated by the inability of the method to recognise fragments of cranium pertaining to an individual skeletal element if the fragments cannot be conjoined. In this study, the MNI for the zonation method is based on the cranium (68); however, excluding the cranium, it rendered an MNI of 65 individuals in total (60 adults and five juveniles) based on the femur. Therefore, there may only have been limited double counting in this study. Lowering the count by three individuals meant the difference with the traditional MNI went from 19.05% to 22.62% (Fig. 5).

The landmark method was chosen because it was recently published and because it is based on the zonation method (Mack et al., 2015). The MNI estimates derived from the landmark system gave the lowest number of individuals for the collection, 57 adults and four juveniles. The method appears to lend itself well to treating a site as an aggregate. Issues such as the inability to perform conjoining exercises seem to affect it the least. The method also seems to lend itself well to dealing with fragmented material, possibly avoiding double counting skeletal elements and consequently individuals because features are only counted as present if 50% or more is represented.

Comparing the zonation system to the landmark system, it is apparent that many zones contain more than one landmark. For example, the femoral diaphysis is divided into 3 zones (6, 7, and 8; Knüsel and Outram, 2004), but the landmark method (Mack et al., 2015) distinguishes four landmarks (6, 7, 8, and 13) within it. Therefore, if a femoral shaft is identified and recorded as zone 6, the equivalent in the landmark system is landmarks 6, 7, and 13 (Fig. 7). This could be a reason why the landmark system provides lower MNI estimates than Knüsel and Outram's (2004) system. It also aligns it with observations made in zooarchaeology (Marean et al., 2001). Furthermore, the strength of the landmark method (Mack et al., 2015) is that it records robust and well-preserved segments of bones, easily identifiable and small, which can be advantageous for the quantification and subsequent interpretation of highly fragmented collections (Bello et al., 2003; Brickley and McKinley, 2001). This method appears to provide a truly *minimum* MNI. From a zooarchaeological perspective, there is little novelty in these findings (see e.g., Marean et al., 2001); however, they have important implications for the analysis of commingled remains in human osteology, where this area of research is to some degree under-developed.

Following guidelines from both zooarchaeology (e.g., Dobney and Rielly, 1988) and the landmark method (Mack et al., 2015), a way to counter double counting in both the traditional and zonation method, particularly when conjoining exercises cannot be carried out on the entire sample, would be to only include in the final MNE estimate the segments or zones that were only more than half complete. This was not performed in this case because the methods were applied as described

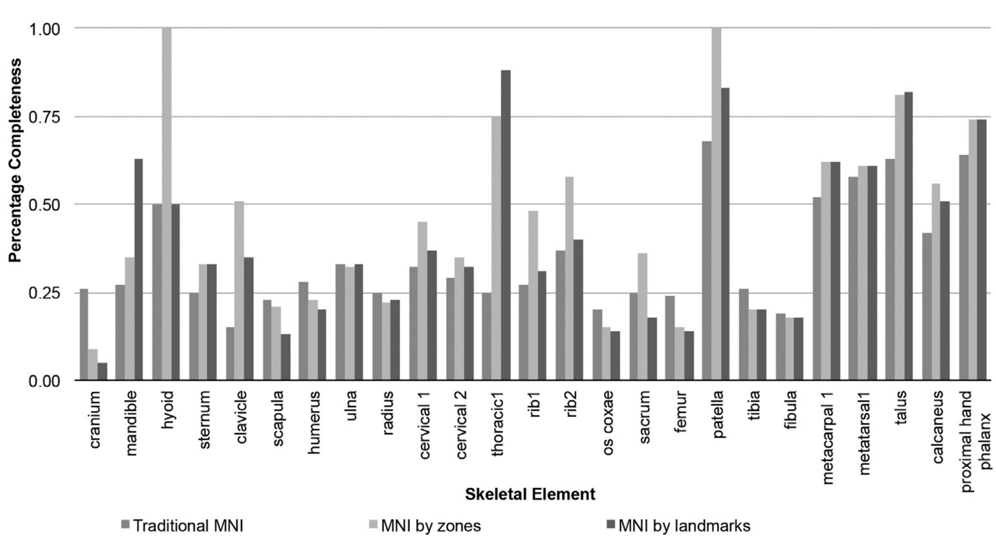

Fig. 3. The graph shows the percentage completeness for the three methods for all elements analysed.

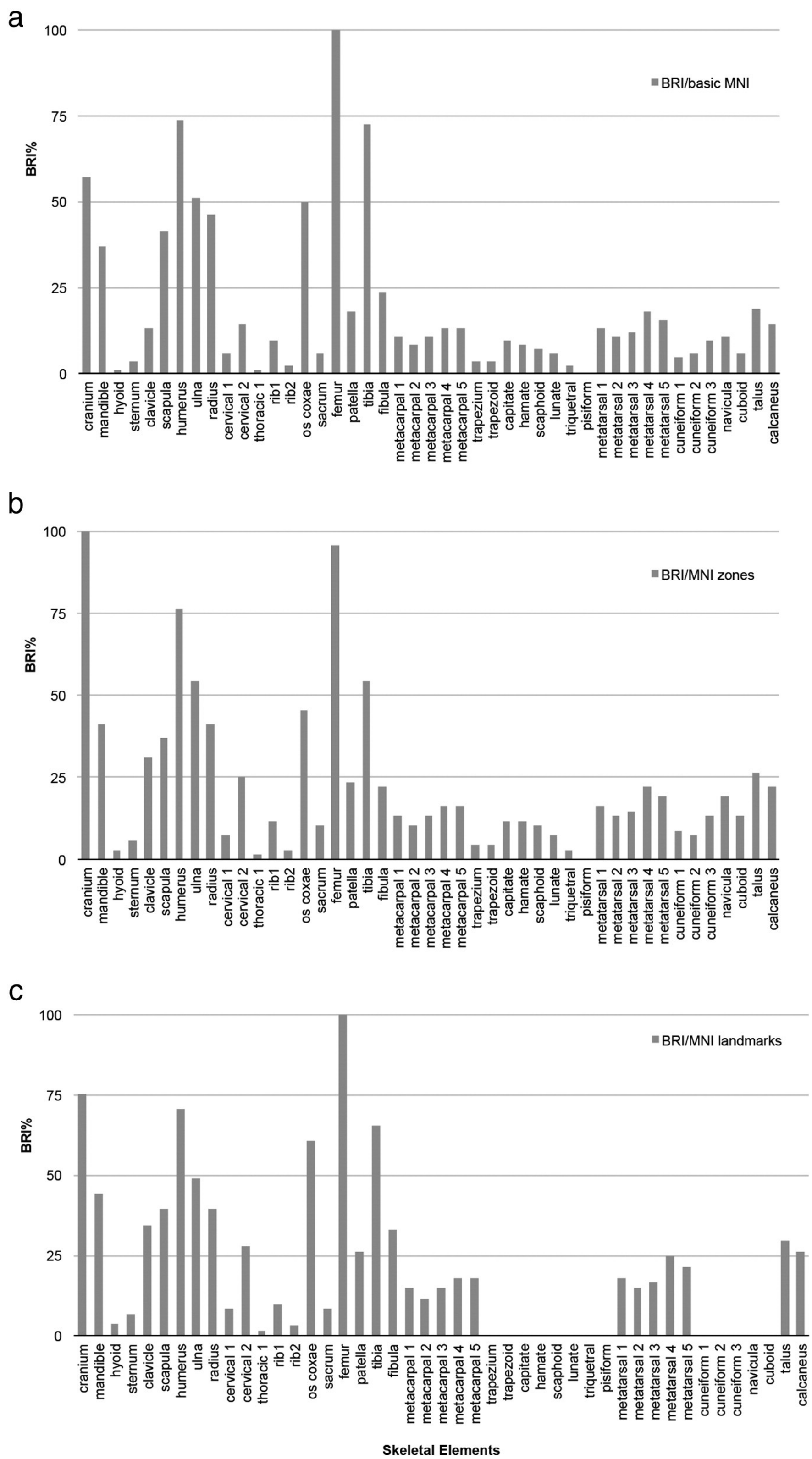

Fig. 4. (4a; top) Bone Representation Index (BRI) for the traditional MNI. (4b; middle) BRI for the MNI by zones. (4c; bottom) BRI for the MNI by landmarks.

in the published literature. For example, non-long bones were divided into quarters in the traditional method as applied here. To avoid double counting certain individuals, only the quarters that are >50% present should be included in the final estimate.

Differences in MNE counts between methods for the small bones were low, possibly because they are less likely to be fragmented. The results of the percentage completeness analysis showed that carpals and tarsals (except for the talus and calcaneus), when present, are almost complete. It has been observed that the good condition of small hand and foot bones can be linked to the reduction of the medullary cavity which contributes to their good preservation (Bello and Andrews, 2006; Guthrie, 1967). On the other hand, MNE values of the

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Table 5
Bone Representation Index (BRI %) for each method (all carpals and tarsals, except the talus and the calcaneus, are not recorded by landmarks and therefore the BRI has not been estimated for the landmark method).

Elements	BRI/basic MNI	BRI/MNI zones	BRI/MNI landmarks
Cranium	57.1	100	75.4
Mandible	36.9	41.2	44.3
Hyoid	1.2	2.9	3.8
Sternum	3.5	5.9	6.5
Clavicle	13	30.9	34.4
Scapula	41.6	36.8	39.3
Humerus	73.8	76.5	70.5
Ulna	51.2	54.4	49.2
Radius	46.42	41.2	39.3
Vertebra C1	5.9	7.3	8.2
Vertebra C2	14.3	25	27.9
Vertebra T1	1.2	1.5	1.6
Rib1	9.5	11.8	9.8
Rib2	2.4	2.9	3.3
Os coxae	50	45.6	60.6
Sacrum	5.9	10.3	8.2
Femur	100	95.6	100
Patella	17.8	23.5	26.2
Tibia	72.6	54.4	65.6
Fibula	23.8	22	32.8
Metacarpal 1	10.7	13.2	14.7
Metacarpal 2	8.3	10.3	11.5
Metacarpal 3	10.7	13.2	14.7
Metacarpal 4	13	16.2	18
Metacarpal 5	13	16.2	18
Trapezium	3.6	4.4	–
Trapezoid	3.6	4.4	–
Capitate	9.5	11.8	–
Hamate	8.3	11.8	–
Scaphoid	7.1	10.3	–
Lunate	5.9	7.3	–
Triquetral	2.4	2.9	–
Pisiform	0	0	–
Metatarsal 1	13	16.2	18
Metatarsal 2	10.7	13.2	14.7
Metatarsal 3	11.9	14.7	16.4
Metatarsal 4	17.8	22	24.6
Metatarsal 5	15.5	19.1	21.3
Cuneiform 1	4.8	8.8	–
Cuneiform 2	5.9	7.3	–
Cuneiform 3	9.5	13.2	–
Navicular	10.7	19.1	–
Cuboid	5.9	13.2	–
Talus	19	26.5	29.5
Calcaneus	14.3	22	26.2

Table 6
Percentage differences for methods between maximum MNE per skeletal element. For each element, the method with the highest count was considered 100%. MNE estimates with the same values for every method have been excluded. (All carpals and tarsals, except the talus and the calcaneus, are not recorded by landmarks.)

Element	Traditional MNE	MNE zones	MNE landmarks	Traditional %	Zones %	Landmarks %
Cranium	48	68	46	70.58	100	67.64
Mandible	31	28	27	100	90.32	87.09
Hyoid	1	2	2	50	100	100
Sternum	3	4	4	75	100	100
Clavicle	11	21	21	52.38	100	100
Scapula	35	25	24	100	71.42	68.57
Humerus	62	52	43	100	83.87	69.35
Ulna	43	37	30	100	86.05	69.77
Radius	39	28	24	100	71.79	61.54
Vertebra C2	12	17	17	70.59	100	100
Rib1	8	8	6	100	100	75
Os coxae	42	31	37	100	73.81	88.1
Sacrum	5	7	5	71.43	100	71.43
Femur	84	65	61	100	77.38	72.61
Patella	15	16	16	93.75	100	100
Tibia	61	37	40	100	60.66	65.57
Fibula	20	15	20	100	75	100
Talus	16	18	18	88.89	100	100
Calcaneus	12	15	16	75	93.75	100

larger bones show greater differences between methods (Fig. 3) and can be attributed to higher fragmentation, with only around 20% of the bones being well-preserved (Fig. 3). Previous research indicates that the fragmentation and preservation of collections can have an impact on quantification methods and can limit sample analysis in two ways: (1) through the exclusion of unidentifiable elements and (2) through the use of indiscriminate markers. Those limits have a greater effect on assemblages with low preservation and high fragmentation. The method used will define which fragments can be included in an MNI count (Bello et al., 2003). The smaller and more defined the zones and features, the more material can be included and the more accurate the estimate should be.

It is important to understand the impact of different results on paleodemographic analysis because the MNI is used as a point of departure in most of these assessments (Kendell and Willey, 2013). Demographic profiles are used to interpret social and cultural practices in the past and for identification processes in medico-legal circumstances (see, e.g., Brickley et al., 2015).

In this study, regardless of the method used, the long bones and cranium showed the highest MNE values, and the smaller bones provided the lowest values. This is not unusual in commingled assemblages, particularly if they are secondary deposits. That is to say, the remains were originally deposited and decomposed elsewhere (primary location), and once skeletonised were brought to their final place of deposition

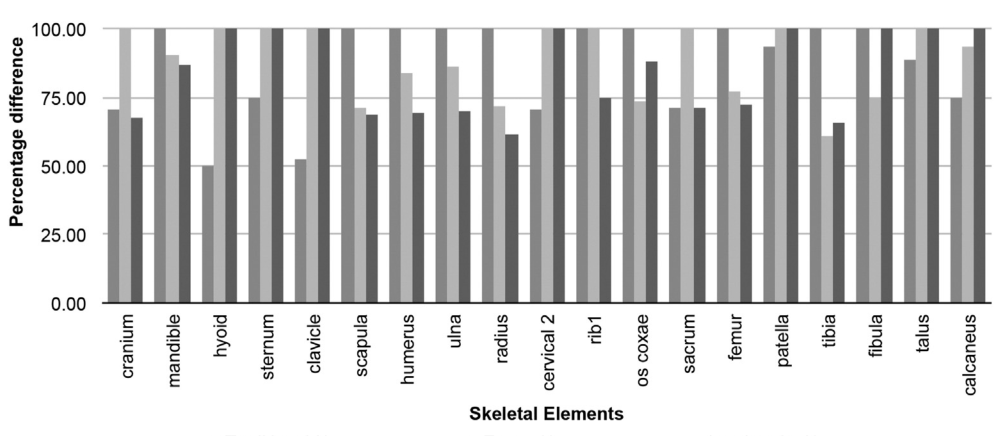

Fig. 5. Percentage differences between the methods for all skeletal elements, except MNEs with the same values for every method.

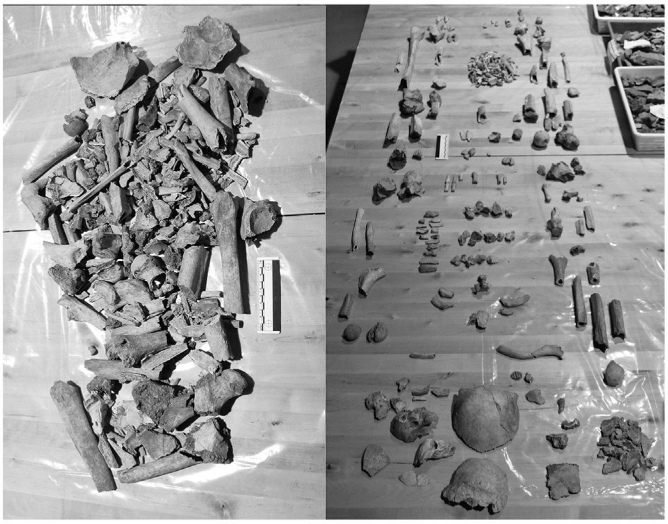

Fig. 6. The picture on the left shows some of the remains from context SU 508 without sorting; the picture on the right shows the same context spread out within the space available.

(secondary location).[4] In these situations, it is common for smaller bones to be missing (Gerdau Radonić and Makowski, 2011), as it is easier to recover and transport the larger bones from the primary site to the secondary site. In the case of Santa María de Zamartze the bones were not removed from the cemetery and placed in an ossuary, but the cemetery was re-utilised and bones were moved aside to make space for a new body, hence the commingled contexts. It appears that the smaller bones may have remained in situ, whereas the larger bones were displaced. Further analyses of the individual contexts are required to ascertain whether or not those burials contain more small and short bones. In the case of Santa María de Zamartze, choice of method does not seem to have affected the BRI results (Fig. 4 and Table 5), and therefore the subsequent interpretation of funerary behaviour.

5.2. Fragmentation analysis

All methods indicated high fragmentation levels and low percentage completeness for long bones and the cranium; however, percentage completeness estimates differed among the methods across most elements. The percentage completeness for the cranium ranged from 5% to 26%. These differences can lead to different interpretations of the preservation of the material. Measures of preservation can have an impact on decisions made to perform further analyses on a collection. If only 5% of the crania are deemed as being preserved, it may seem unreasonable to study the dental pathology of the collection. It may also appear unreasonable to subject the collection to destructive analysis if the material is so poorly preserved. Fortunately, at least for dental studies, an assessment of dental MNE and MNI can counter this impression by providing a more accurate assessment of the teeth available for analysis.

The smaller the fragments of diaphysis or cranial vault, the more difficult it is to ascertain to which particular long bone or cranial bone the fragment belongs. These unidentified fragments of long bone or cranial bone are not included in the percentage completeness estimate for each element. The MNE results indicate that diagnostic features of bone tend to be robust and survive well, despite high levels of fragmentation, as the most fragmented bones were the best represented. For this reason, it is possible that even though long bones and crania were assessed as the least well preserved, they were the elements most accounted for. If properly identified and tabulated, fragmented material can be useful

[4] Needless to say, archaeologically, it is difficult to ascertain whether or not there were more than two locations, hence the simplified distinction between primary and secondary deposits.

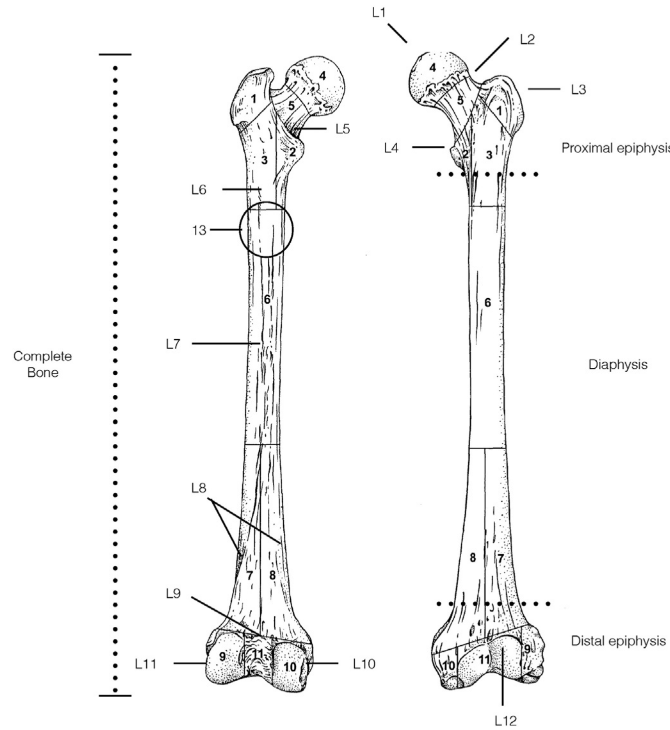

Fig. 7. The image shows a left femur. The numbers 1–11 indicate the zones used by Knüsel and Outram (2004); the labels L1-L12 show the landmarks used by Mack et al. (2015), and the dotted vertical and horizontal lines show the traditional MNI method as used for the long bones (complete, proximal epiphysis, diaphysis and distal epiphysis). (Image adapted from Knüsel and Outram (2004: Fig. 9)).

in MNI estimates. Commingled and fragmented remains should not be readily dismissed as lacking in information.

All methods tested here can perform analyses on highly fragmented material. It is likely that despite high fragmentation levels, if fragments can be refitted to recreate landmarks, zones, or sections of bone, the double-counting of individuals will be lessened as will the exclusion of fragments from the final estimate. The ability to do this will also be dependent on the osteologist's skills. The more skilled the osteologist, the more fragments he or she will be able to identify, the more conjoining exercises he or she will be able to perform, and the more minimal the MNI.

If material is very fragmented, and conjoining all fragments is not possible, then the landmark method and the zonation method (with the exception of the cranium) should be applied. For the zonation method, Knüsel (pers. communication 1/05/2016) has suggested using the cranial zones detailed by Hussain et al. (1994) for use in recording trauma, as they are smaller and better defined.

6. Conclusion

The commingled human remains from the medieval cemetery of Santa María de Zamartze were analysed following three different methods to estimate the MNE and the MNI of the assemblage. The analysis resulted in disparate outcomes for each method: the traditional MNI suggested a total of 84 individuals, the MNI by zones 68, and the landmark method an MNI of 61. On one hand, the traditional MNI and the MNI by landmarks showed different results for most skeletal elements. The MNI by zones and the MNI by landmarks, on the other hand, showed fewer differences overall. For small and well-preserved bones the choice of MNI method resulted in minimal differences in the final MNE values.

When conjoining exercises cannot be attempted on all the remains from one context, the traditional MNI count and the zonation method (especially the cranium) may result in fragmented elements being counted two or more times, if the 50% rule is not applied. The results

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of this study do not immediately suggest which of the three methods is more accurate. However, the results indicate that the landmark method (Mack et al., 2015) is the least likely to double count skeletal elements when confronted with highly fragmented remains and when conjoining exercises cannot be performed. In this study, this method provided the lowest estimate for the MNI, but showed less differences throughout with the zonation method, as opposed to the traditional MNI method. The results also highlight the importance of conjoining exercises, or including in the final estimate for MNE, and therefore MNI, only the landmarks, sections, or zones of bone that are 50% or more complete. It is unlikely that the choice of method would return such a disparate result from the analysis of a smaller collection of individuals, as exemplified by the juvenile sample here, or if the material is well-preserved and less fragmented.

The methods also provided different estimates in terms of percentage completeness for each element. However, across all three methods the smaller bones were the best preserved, and the larger and long bones were the least well-preserved. Finally, though the BRI estimates were different for each method, across all three methods the smaller and less fragmented bones were less well-represented, and the long and larger bones, despite being more fragmented, were better represented, and provided the MNI estimate for the collection. At least in this study, despite differences in percentage completeness and BRI results, the choice of method would not greatly impact the interpretations of these results.

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