Bioarchaeology International
Volume 2, Number 4: 255–282
DOI: 10.5744/bi.2018.1027

Unraveling the Motives behind Multiple Burial in St. Rombout's Cemetery in Mechelen, Belgium, Tenth–Eighteenth Centuries A.D.

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ABSTRACT The numerous multiple burials found in St. Rombout's parish cemetery in Mechelen, Belgium, dating from the tenth to eighteenth centuries A.D., raise questions about the circumstances of their construction. Simultaneous burial generally indicates an unusual mortality. This study explores possible circumstances of death to establish whether socioeconomic factors influenced the selection of individuals. A multidisciplinary approach associating the archaeological context with demographic and pathological data was used to examine possible motives for simultaneous burial. Two groups of multiple burials were selected, which were distinguished by their location in the cemetery and the number of phases of deposition and orientation. One group was radiocarbon-dated to the second half of the fifteenth–early seventeenth century and the other to after A.D. 1640.

The multiple burials were compared with each other and with contemporaneous single burials. Differences between the groups suggest different circumstances of death, although a macroscopic study did not reveal specific causes. While elevated mortality caused the construction of multiple burials, selection of individuals was influenced by socioeconomic background. The high number of adolescents and young adults, mostly male, differed from a natural mortality profile and from the single burials. Individuals from multiple burials showed a higher prevalence of growth disturbances, mechanical stress from a young age, and pathological lesions. The earlier group could be associated with abrupt mortality crises, while the later group may be associated with a Spanish military hospital.

Keywords: multiple burial; mortality crisis; post-medieval burial

La présence de nombreuses sépultures multiples du cimetière paroissial de St. Rombout à Malines, Belgique, pose question concernant les circonstances de leur origine. Un dépôt simultané indique normalement une mortalité exceptionnelle. Le but de cette étude était d'inférer les circonstances probables de la mort de ces individus et d'établir si des facteurs sociaux ou économiques ont pu influencer leur recrutement. En utilisant une approche multidisciplinaire, qui associait l'information archéologique avec les données démographiques et pathologiques, il fut possible d'étudier les raisons potentielles de ces dépôts simultanés. Deux groupes de sépultures multiples furent distingués sur la base de leur localisation dans le cimetière, le nombre de phases de dépôt et l'orientation des corps. Un premier groupe a été attribué par datation C14 à la deuxième partie du quinzième siècle au début du dix-septième siècle et le second est postérieur à 1640 AD.

Les sépultures multiples ont été comparées les unes avec les autres et avec les dépôts individuels contemporains. Les différences entre les groupes suggèrent des circonstances de la mort différentes, même si l'étude n'a pas révélé de causes spécifiques. Bien que le recours à des sépultures multiples fut causé par une mortalité élevée, l'étude a montré que le recrutement des individus pourrait avoir été influencé par leur statut socio-économique. Dans les deux groupes, on a observé une surreprésentation des adolescents et des jeunes adultes, plutôt de sexe

Received 2 March 2018
Revised 12 August 2018
Accepted 19 August 2018

masculin. Ceci diffère d'une mortalité naturelle et des profils de mortalité des sépultures individuelles. Les individus des sépultures multiples présentaient une plus haute prévalence en troubles de la croissance, en stress mécanique dès le jeune âge et en lésions associées avec des maladies. Le groupe le plus ancien, caractérisé par une seule phase de dépôt, serait en relation avec des crises de mortalité abruptes au sein de la paroisse, le groupe plus récent pourrait être associé avec un hôpital militaire espagnol.

In late medieval (A.D. 1050–1550) and post-medieval (1550–1850) northwestern Europe, the majority of the population was buried in single inhumations (Cherryson et al. 2012; Gilchrist and Sloane 2005), although individuals could be buried together (Gilchrist and Sloane 2005:156–157; Harding 2002:65–84). Plural burials contain two or more individuals. A distinction should be made between multiple and collective burials. In multiple burials, individuals are buried simultaneously or within a short period, often coinciding with elevated mortality. In collective burials, individuals are deposited in successive phases over a longer period that may result from attritional mortality or a prolonged, unusual mortality. Multiple and collective burials can be distinguished by disarticulation in underlying skeletons. When bodies are placed in an existing grave, after some time they may disturb bones of earlier deposits, whereas bodies buried simultaneously lack such disruptions. Because displacements only occur after the ligaments decompose, different phases of body deposition within the first few weeks of one another cannot be differentiated (Castex and Blaizot 2017; Castex et al. 2014:299–300; Duday 2009:98–104). Primary multiple burial implies individuals died at or around the same time. Unfortunately, disarticulations that indicate collective burial can only be observed when there is contact between individuals (Castex et al. 2014:300; Duday 2007).

The observation of multiple burial identifies an elevated mortality, which may be isolated (e.g., accidents), or prolonged and extensive (e.g., epidemics). A group of contemporaneous multiple burials often indicates an extensive mortality crisis (Castex et al. 2014; Duday 2007). Parishes in the medieval and post-medieval periods could adapt burial practices during periods of elevated mortality. Varied burial types were used, from traditional single inhumations to large mass graves (Castex 2008:25–29; Cherryson et al. 2012:105–113; Gilchrist and Sloane 2005:74–77; Harding 2002:65–84). Historical sources indicate that traditional single deposition was only gradually and partially abandoned during periods of elevated mortality. Mass graves were viewed with distaste and avoided if possible (Harding 1993, 2002:65–66). Most multiple burials were plain earth graves, with carefully deposited bodies (Kacki and Castex 2012:9–18). The number of individuals, construction of the grave, and care afforded to bodies varied according to local traditions and circumstances (Castex et al. 2014; Cherryson et al. 2012:105–113; Gilchrist and Sloane 2005: 74–77; Harding 2002:65–84). Multiple burials have been excavated in parish cemeteries, in catastrophe cemeteries, and associated with hospitals (Castex et al. 2014; Connell et al. 2012; Gilchrist and Sloane 2005: 74–77; Réveillas and Castex 2010). Only simultaneous burials clearly indicate an elevated mortality. While single burials could also be used to bury victims from a mortality crisis, it can be difficult to identify them.

Attritional or natural mortality profiles are related to the normal rate of deaths during the use of a cemetery, characterized by high numbers of very young and older individuals. An unusual mortality deviates from this pattern and can indicate an elevated risk of death, such as a catastrophic mortality with a high risk of death for all ages. Mortality profiles can, therefore, offer suggestions for the cause of death. The impact of a mortality crisis depends on its nature—and on differences in the exposure and susceptibility of individuals. For example, different epidemics and conflicts may affect distinct groups of a population. This differential impact can create selection based on age and sex (Castex 2008:23–27; Duday 2009:89–100; Gowland and Chamberlain 2005; Margerison and Knüsel 2002:134–135). Episodes of high mortality can reflect an equal risk of death across age categories, but they can also resemble an attritional profile with a proportionately elevated mortality, such as during famines (Chamberlain 2006:69–78). Epidemic profiles are related to the nature of the disease and who is affected; some diseases target young individuals, while others affect all ages, and not everyone may be exposed. Conflict profiles depend on whether victims are soldiers, civilians, or clergy (Castex 2008; Chamberlain 2006:69–78). Anomalies in demographic profiles may also be due to the composition of the living population or group from which the burials derive or from differential funerary practices (Castex 2008:31–33).

To deduce the specific cause of a mortality crisis, a representative sample of individuals is required. While the composition of skeletal assemblages is influenced by mortality patterns, which may offer suggestions for circumstances of death, excavated collections are rarely complete. Not all individuals may be buried in the same area or in a similar way, burials may be disturbed by taphonomic processes or later interference, and cemeteries are not always fully excavated (Chamberlain 2006:4; Mays 1998:13–14; Séguy 2006; Sellier 2011; Waldron 1994:10–16). When crisis burials are incorporated in regular burial grounds, it can also be difficult to identify all burials associated with the elevated mortality, since historical and archaeological sources indicate that victims could be buried in different grave types. Although representative samples are rare, the study and comparison of those individuals who are present in the assemblage can still provide information on circumstances of death, through anomalies in mortality profiles. The analysis of a *recrutement*[1] also allows the study of mortuary practices and social organization, since the inclusion of individuals in cemeteries and graves can be influenced by age, sex, and socioeconomic background, and considers what the collection represents (Robb et al. 2001:216; Sellier 2011).

Pressures of space and time, and sanitary hazards, would have been important motives for multiple burial (Castex et al. 2008:1–3). The varied burial types used during mortality crises, however, suggest additional considerations. Social background and economic factors likely influenced who was buried in multiple graves (Cherryson et al. 2012:105–113; Harding 2002:68). Comparing individuals from different grave types can therefore provide information on the different factors that influenced burial choice. Frailty may also have resulted in a higher risk of death for individuals included in multiple burials. While the specific cause of death may be difficult to establish, differential funerary practices provide information to interpret differences in patterns of demography and pathology that may indicate an unusual mortality and whether socioeconomic background also influenced burial type.

Age, gender, and status can influence lifestyle and activities and promote different risks of injury and disease (Buzon 2012; Gowland and Knüsel 2006; Sofaer 2006). The prevalence of stress indicators, such as disturbances in growth and nutrition, trauma, mechanical stress, infection and mortality patterns may thus be related to the socioeconomic background of an individual. People with a lower and poorer social position are thought to be more susceptible to disease, have a shorter stature, and die at a younger age, owing to an unfavorable environment, higher degrees of mechanical stress, and possible malnutrition (Buzon 2012; Robb et al. 2001). However, stress does not always result in skeletal lesions, stress indicators tend to be multifactorial, and individuals may have a variable response (Goodman et al. 1988; Temple and Goodman 2014; Wood et al. 1992). Although pathological lesions do not offer unequivocal information on status, observing patterns in different types of lesions, combined with archaeological characteristics, and particularly the use of non-normative burials such as multiple graves, may suggest differences in social background and circumstances of death (Holloway 2008:132; Murphy 2008:xii–xiii).

Excavations on St. Rombout's parish cemetery in Mechelen, Belgium (tenth–eighteenth centuries A.D.), revealed 4,158 individuals in 3,617 graves, which varied in the presence of a container, objects, or a grave lining, and in body position and orientation. The number of individuals in the grave also varied, with evidence for single, collective, and multiple burial. Sixty-five multiple burials were recorded among the single depositions (Van de Vijver et al. 2018). A subsample of 351 individuals from 267 graves was subjected to archaeo-anthropological analyses. The aim of this article is to examine the motives for the use of simultaneous burial and circumstances of death, who was buried in the multiple burials, and whether their socioeconomic background influenced their inclusion. The unusual nature of this burial type, which was viewed with aversion and used during periods of elevated mortality, suggests they may include individuals with a poorer or deviant social background. The study encompassed a contextual analysis of the multiple burials, combining the characteristics of the grave with the skeletal study, and comparing the results with individuals in contemporaneous single depositions.

Two groups of multiple burials are discussed. Anomalies in their demographic profiles are analyzed to determine selections based on age or sex, which may indicate a selective mortality and/or sex- or age-related burial practices. Patterns in the prevalence of pathological changes are compared among the multiple burials and between multiple and single depositions to explore possible causes of death or differences in the occurrence of growth disturbances, trauma, mechanical stress, and exposure and susceptibility to disease, which may suggest different lifestyles and activities. Results may offer information on the circumstances of the elevated mortality leading to simultaneous burial and the identity of those included in the multiple burials. The results are compared with documentary sources and other sites to suggest motives for multiple burial in this parish cemetery.

1. *Recrutement* is a French term that refers to the origin of a skeletal sample and how the individuals represented in the burials may have been selected (Sellier 2011).

Material and Methods

Material

St. Rombout's parish cemetery was partially excavated between 2009 and 2011. Its function as a burial ground goes back at least to the tenth century A.D., when it was associated with a secular chapter. The chapter acquired parish rights in 1134, and from that time most parish inhabitants were buried in the cemetery (Van de Vijver et al. 2018; Van den Wijngaert 1974; Van Mingroot 1978). However, wealthier individuals could be buried in religious institutions, and there was an overflow cemetery outside the city (fourteenth to possibly sixteenth century) as well as a leprosy and plague hospital (Fonds Berlemont, map 182; Van de Vijver et al. 2018). The composition of the buried population may also have been affected by a Spanish military hospital located next to the churchyard between 1585 and 1715. It was a medical facility of the Spanish Habsburg dynasty for Spanish and Italian troops. Although the organization and buildings have been studied, we know little of the patients, as the archives were mostly destroyed. An inventory (1637) mentioned 330 beds, leading to an estimate of over 2,000 patients, but capacity varied. Patients could be injured, but they also suffered from infections and psychological disorders (Installé 1996:203; Parilla Hermida 1964; Parker 1996:141; Van Meerbeeck 1950). Studies have indicated that infection, not violence, caused most deaths among early modern soldiers (Cunningham and Grell 2000). Publications contain no references to how many patients died or where they were buried. The inventory indicates that grave-digging tools and a box for corpses were kept in a depot, suggesting patients were likely buried nearby (Van Meerbeeck 1950:99–101). A later illustration did not show burial grounds.[2] The proximity of St. Rombout's cemetery suggests patients could have been buried here. Discrepancies in age and sex composition—particularly a female overrepresentation in the seventeenth- and eighteenth-century parish death registers (male-to-female sex ratio: 0.9:1) as opposed to a strong male overrepresentation (1.5:1) in the excavated assemblage—also suggest the possible presence of other groups (Van de Vijver et al. 2018). Unfortunately, we cannot be certain patients from the hospital were buried in the churchyard or estimate the potential influence on the buried population.

St. Rombout's cemetery was abandoned in 1785 and converted into a park and later a parking lot (Van de Vijver et al. 2018). In the late medieval and post-medieval periods, Mechelen was a prominent town with approximately 20,000 inhabitants (Verbeemen 1953). St. Rombout's parish was a wealthy urban area with several central functions and richer trades and crafts (Depuydt et al. 2013; Van de Vijver et al. 2018). The excavation recorded 4,158 individuals in 3,617 graves. The oldest layer was dated mainly to the twelfth–fourteenth centuries, the middle layer to the fifteenth–sixteenth centuries, and the youngest to the seventeenth–eighteenth centuries (Van de Vijver et al. 2018).

Most burials were single, primary inhumations of a supine, extended body on a west-east orientation. Variation was mainly expressed by differences in arm position, minor deviations in the west-east orientation, presence of a coffin or objects, or indications for collective burial. A limited number showed unusual characteristics, including an irregular body orientation or position, a grave lining, or evidence of simultaneous burial (287 individuals). A mass grave of executed brigands from 1798 was not included in this study since it postdates the cemetery (Van de Vijver and Kinnaer 2014). Preliminary on-site age estimation resulted in 128 infants (0–1 year), 253 children (1–12 years), 564 adolescents (12–18 years), 3,135 adults (over 18 years), and 78 individuals of indeterminate age. Preliminary sex estimation resulted in approximately 60% males in the fifteenth–eighteenth-century layers and more equal ratios in the twelfth–fourteenth-century layer. The skeletal remains were well preserved, although many were incomplete due to later disturbance (Van de Vijver et al. 2018). Detailed study was performed on 351 individuals from one fully excavated trench, which contained the oldest and youngest layers, where the grave context was more than 50% complete.

Of these 351 individuals from the parish cemetery, 103 were recorded in 19 multiple burials and 248 in single depositions. Simultaneity was determined based on the superposition and contact between skeletons and a lack of disturbance in underlying depositions. Graves with both one and several phases of simultaneous deposition were recorded. Multiple burials were more common in the fifteenth–eighteenth-century layers. The graves contained between two and 14 individuals. Most displayed carefully arranged supine, extended bodies. Seven smaller graves showed irregular positions (Depuydt et al. 2013). Information on all individuals from the multiple burials in the studied sample can be found in the supplementary table.

Since the multiple burials were interspersed among the single graves from the parish cemetery, it is impossible to distinguish groups related to the same circumstances with certainty. The often long-term use of medieval and post-medieval urban cemeteries

2. Plan of the hospital from 1755 by Ferdinand Hancko, lieutenant of the Artillery, Algemeen Rijksarchief Brussel, Kaarten en plannen, nrs. 1920 en 1921.

frequently requires the use of wide periods, as was also the case in Mechelen (Cherryson et al. 2012:160; Gilchrist 2012:46). Two groups of multiple burials are presented, which may be associated with similar motives and circumstances. They were located in the same area of the cemetery (Fig. 1), but the groups are distinguished by the organization of the graves, the treatment of bodies, and radiocarbon dates. Burials containing five or more individuals were selected since they are more likely related to more widespread events. The smaller multiple burials also demonstrated more variation. Smaller multiple burials and single graves may have been related to the circumstances that led to the construction of the larger multiple burials. However, it is impossible to establish such an association with certainty.

Four assemblages used as comparison included contemporaneous plague, parish, and two hospital cemeteries with multiple burials. Similarities or differences may offer interpretations for Mechelen. The cemetery of the convent of Maria Troon in Dendermonde, Belgium (sixteenth century), is related to plague based on archival records (Goudie-Falckenbach et al. 2012). St. Benedict's parish cemetery in Prague, Czech Republic, revealed multiple burials in the youngest phase (seventeenth–eighteenth century). They have been associated with plague, although a monastery or military hospital has also been proposed (Castex et al. 2011). The burials from the hospital of St. Catherine in Verdun, France (seventeenth–eighteenth century), have been associated with epidemics and perhaps famine, based on mortality profiles and archives (Réveillas 2010; Réveillas and Castex 2010). The priory and hospital of St. Mary Spital in London, United Kingdom (twelfth–sixteenth centuries), was included because the study also compared mortality and pathological profiles between attritional and mass graves related to epidemics and famine (Connell et al. 2012).

Methods

Study of the characteristics of the burials and the identification of simultaneity were based on archaeothanatology, which combines the principles of human decomposition with extensive registration on site to reconstruct the original conditions (Castex and Blaizot 2017; Duday 2009).

The skeletal remains were studied from a paleodemographic and paleopathological point of view, using macroscopic methods. Age estimation for immature

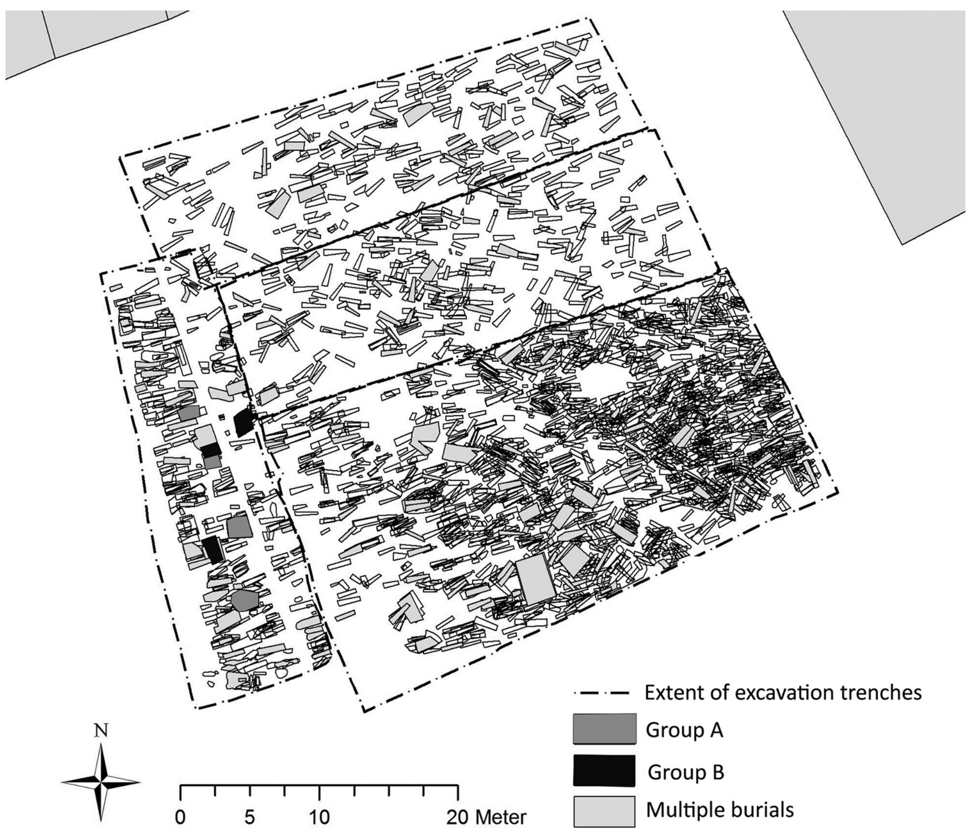

Figure 1. Overview of the fifteenth–eighteenth-century layers across the excavated area, with indication of the location of the burials from groups A and B and the multiple burials that were not retained for detailed analysis (© Stad Mechelen | Dienst Archeologie).

individuals depended on dental formation (Moorrees et al. 1963a, 1963b) and tables for timing of epiphyseal fusion and diaphyseal length in Scheuer and Black (2000). Adult age was estimated by observing changes in the pubic symphysis (Brooks and Suchey 1990) and auricular surface of the ilium (Buckberry and Chamberlain 2002; Schmitt 2005). Brothwell (1981:69) was used to record dental attrition. Since molar attrition decreased from the pre-medieval to post-medieval period, due to differences in diet and coarseness of food, it was only used to complement other methods and not to determine a specific age at death (Maat 2001). Sex estimation for mature individuals was based on the morphology of the pelvis and skull (Buikstra and Ubelaker 1994; Ferembach et al. 1980); on *Probabilistic Sex Diagnosis,* which uses measurements of pelvic bones (Murail et al. 2005); and on humeral and femoral head diameters when the pelvis or skull was absent (Milner and Boldsen 2012).

Mortality quotients, the probability of death within groups (Chamberlain 2006:28), were calculated to compare profiles with model life tables, among burial types, and with other populations. Mortality quotients were based on individuals under 30 years old. Immature age estimation is more specific, since it relies on skeletal and dental development (Roberts 2009:127). Because life tables use intervals different from those used to compare mortality profiles and pathological lesions in this study, which reflect developmental age, individuals were also placed into five-year intervals, save for 20–29 years, under 1 year, and 1–4 years old, based on dental development and epiphyseal fusion for adolescents. Values for a life expectancy at birth between 25 and 35 years were used as comparison for expected mortality patterns of preindustrial populations (Ledermann 1969).

Paleopathological analyses followed standard methods (Brickley and McKinley 2004; Buikstra and Ubelaker 1994), and interpretations were based on handbooks (Aufderheide and Rodríguez-Martín 1998; Ortner 2003; Roberts and Manchester 2005; Waldron 2009). Stature was estimated through maximum length of the left femur (Trotter and Gleser 1952). Skeletal changes and stress indicators are presented that may provide information on socioeconomic background and motives for multiple burial. Stress is defined as a "non-specific physiological disruption," and the observation of skeletal changes implies survival (Lewis and Roberts 1997; Mays 2012; Selye 1976; Temple and Goodman 2014; Wood et al. 1992). Most skeletal pathological changes have varied etiologies, and a specific diagnosis can be difficult. Several changes were analyzed, through presence or absence, including growth disturbances, injuries and lesions related to physical stress, and disease. Broad categories of lesions were used to analyze comprehensive patterns and explore differences between groups of burials. The common odds ratio was calculated to account for differences in the age structures of the different groups (Waldron 2009:254–255), using age categories that were present in all groups and for lesion types that were observed in each age category and group.

Statistical analyses were carried out using IBM SPSS Statistics 20 to determine significant differences between groups. Associations between nominal scale variables were analyzed using contingency tables and calculated through Pearson's chi-square test or Fisher's exact test. Associations between two data sets in ordinal scale variables were calculated with the Kolmogorov-Smirnov test. Ratio scale patterns were studied using t-test statistics, with post hoc Bonferroni correction. When $p \leq 0.050$, associations were deemed significant.

Results

Archaeothanatological study

Two groups of multiple burials were distinguished based on burial characteristics (Table 1). Group A included burials with one phase of deposition. Group B included burials with several phases separated by a layer of soil. Radiocarbon dates indicate that the two groups were also separated in time. Overall, multiple burials were recorded across the excavation, and groups A and B were concentrated to the west (Fig. 1).

The four graves in group A were dated to the second half of the fifteenth–early seventeenth century (Table 1). The graves contained between five and 12 superposed individuals (Fig. 2), deposited in one phase, without clear layers. Preservation of labile anatomical connections, a lack of bone movements outside the volume of the body, and preservation of bones in unstable positions indicate plain earth inhumation. Synchronous decomposition nevertheless caused movements of smaller bones toward the bottom of the graves. Two individuals showed strong lateral constraint, which may signify wrapping. All bodies displayed regular positions: supine with the legs extended and the arms extended, flexed, or crossed. Most were oriented approximately west-east; only one individual in burial 131 and two in burial 287 were placed head-to-toe, in an opposite orientation. Burial 131 also contained lime (Schotsmans et al. 2015).

Group B included three graves. Radiocarbon dating placed the burials after A.D. 1640. Although radiocarbon dates are inaccurate after 1650, they separate group B from group A (Table 1). The graves included between seven and 14 depositions. Individuals were deposited in two to five phases, with two to five

Table 1. Description of the multiple burials in the two selected groups. In GR131 and GR145, two articulated depositions may belong to the same individual based on spatial association and similarities in morphology and age estimation, resulting in five as opposed to six individuals.

Group	Grave	Radiocarbon Date*	Number of Individuals	Orientation	Demographic Composition	Remarks
A	131	339 ± 29 B.P. (RICH-23261) (95.4% probability A.D. 1470–1640)	6 (5)	WSW-ENE/ ENE-WSW	Three adolescents (12–17); one young adult (18–25), male; two middle adults (26–50), both male.	Two articulated depositions may be related to the same individual; chunks of lime were found in the grave fill.
	145	385 ± 32 B.P. (RICH-23266) (63.4% probability A.D. 1440–1530; 32.0% probability A.D. 1550–1640)	6 (5)	W-E	One adolescent (12–17); four young adults (18–25), one male, three indeterminate sex; one indeterminate adult (> 18), male.	Two articulated depositions may be related to the same individual.
	261	407 ± 30 B.P. (RICH-23256) (80.1% probability A.D. 1430–1530; 15.3% probability A.D. 1570–1630)	10	W-E	Three adolescents (12–17); six young adults (18–25), five male, one indeterminate sex; one middle adult (26–50), male.	
	287	405 ± 34 B.P. (RICH-23254) (75.0% probability A.D. 1430–1530; 20.4% probability A.D. 1570–1630)	12	W-E/E-W	Six adolescents (12–17); four young adults (18–25), two male, one female, one indeterminate sex; two middle adults (26–50), one male, one female.	
B	203	177 ± 31 B.P. (RICH-23255) (18.0% probability A.D. 1650–1700; 49.9% probability A.D. 1720–1820; 5.8% probability A.D. 1830–1880; 21.7% probability A.D. 1910 . . .)	10	SSE-NNW/ NNW-SSE	Four adolescents (12–17); five young adults (18–25), all male; one adult (> 18), indeterminate sex.	Four phases with between two and four individuals.
	275	216 ± 30 B.P. (RICH-23267) (30.9% probability A.D. 1640–1690; 42.6% probability A.D. 1730–1810; 21.9% probability A.D. 1930 . . .)	14	S-N/N-S	Four adolescents (12–17); three young adults (18–25), all male; five middle adults (26–50), all male; two individuals, indeterminate age (>18).	Five phases with between one and five individuals. Between the second and third phase is a layer with disturbed crania and long bones.
	324	97 ± 29 B.P. (RICH-23257) (27.1% probability A.D. 1680–1740; 68.3% probability A.D. 1800–1930)	7	NW-SE/ SE-NW	Three adolescents (12–17); three young adults (18–25), all male; one middle adult (26–50), male.	Two phases with three and four individuals. The intermediate layer contains several disturbed crania.

*All dates were calibrated using the OxCal3.10 program (available at https://c14.arch.ox.ac.uk/oxcal.html; Bronk Ramsey 1995, 2001) with IntCal13 curves (Reimer et al. 2013).

individuals in each layer (Fig. 3). In burial 275, one phase contained one individual. Most phases showed indications for the simultaneous deposition of individuals, resulting in successive phases of multiple burial within the same grave. The time between phases cannot be determined, although the use of a soil layer suggests graves could have been left open for some time. The depositions were plain earth burials, based on preservation of labile anatomical connections and volume in pelvic bones, preservation of bones in unstable positions, and lack of bone movements outside the volume of the body. There was no lateral constraint. Except for one individual in burial 275, who was deposited on the left side, all individuals presented regular supine positions, with extended legs and arms extended, flexed, or crossed. This group showed unusual orientations, with individuals placed head-to-toe along an approximate south-north or southwest-northeast axis, deviating from the common west-east orientation in Christian burials. Overall, 32 individuals from group A, 28 from group B, 77 fifteenth–sixteenth century single depositions, and 65 seventeenth–eighteenth-century single depositions were analyzed.

Mortality Profiles

Among the 137 adults from the multiple and single depositions, 99 were identified as male, 27 as female, and 11 of indeterminate sex (Table 2; Fig. 4a). Only two females were recorded in the multiple graves, both in burial 287 from group A. The sex ratio for the fifteenth–sixteenth-century single depositions (2.2:1.0) was much lower than that of group A (7.0:1.0), but this difference was not significant. There is a significant difference between the seventeenth–eighteenth century single depositions (3.5:1.0) and the lack of females in group B ($\chi^2 = 4.417$, $df = 1$, Fisher's exact test: $p = 0.047$). The difference in sex ratio between the two groups of multiple burials was not significant.

Figure 2. Illustration of a multiple burial from group A. Twelve individuals were deposited in one phase along a west-east axis (GR287) (© Stad Mechelen | Dienst Archeologie).

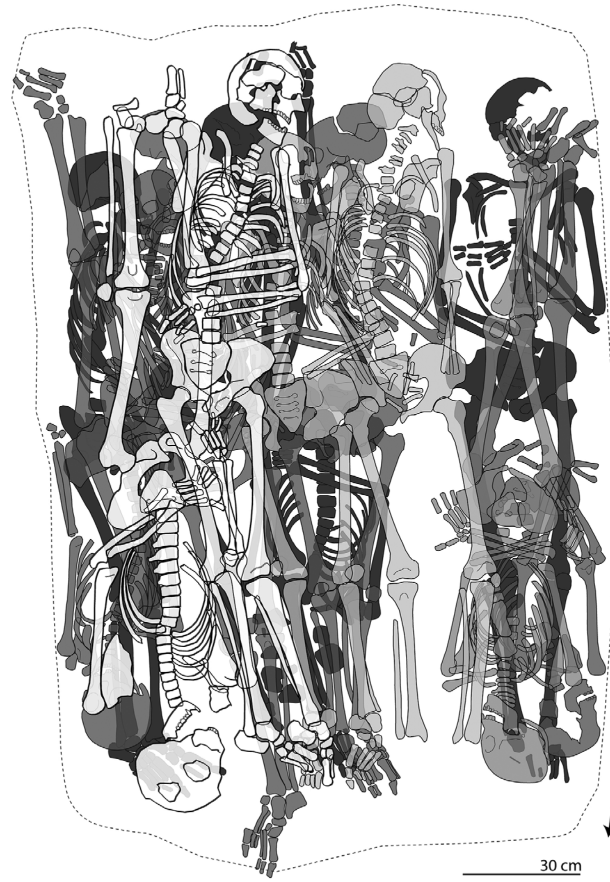

Figure 3. Illustration of a multiple burial from group B. Fourteen individuals were deposited in five phases, with a deviant orientation and individuals placed head to toe (GR275). Darker individuals were recorded in deeper phases.

The distribution of age categories between group A and contemporaneous single depositions was significantly different according to the Kolmogorov-Smirnov ($p \leq 0.050$) and Pearson's chi-square test ($\chi^2 = 14.811$, df = 5, $p = 0.011$, shown in Table 2 and Fig. 4b). There were no significant differences between group B and the seventeenth–eighteenth-century single depositions, although group B also showed a larger number of individuals under 26 years old. There was a stronger presence of adolescents and young adults in the multiple burials of both groups, with only individuals between 12 and 50 years old. The categories between 12 and 25 years represented 81.3% in group A and 78.6% in group B, as opposed to 42.9% in the fifteenth–sixteenth-century single depositions and 44.7% in the seventeenth–eighteenth-century

Table 2. Overview of the composition by age and sex in the single depositions from the different periods and groups A and B.

	Single Burials 15th–16th Centuries				Group A				Group B				Single Burials 17th–18th Centuries			
Age Category	Male	Female	Total	%	Male	Female	Total	%	Male	Female	Total	%	Male	Female	Total	%
Perinatal (0–1 month)	—	—	1	1.3	—	—	0	0.0	—	—	0	0.0	—	—	2	3.1
Infant (1–12 months)	—	—	0	0.0	—	—	0	0.0	—	—	0	0.0	—	—	0	0.0
1–5 years	—	—	3	3.9	—	—	0	0.0	—	—	0	0.0	—	—	0	0.0
6–11 years	—	—	0	0.0	—	—	0	0.0	—	—	0	0.0	—	—	2	3.1
12–17 years	—	—	17	22.1	—	—	12	37.5	—	—	11	39.3	—	—	17	26.2
18–25 years	13	2	16	20.8	9	1	14	43.8	11	0	11	39.3	10	1	12	18.5
26–50 years	17	11	29	37.7	4	1	5	15.6	6	0	6	21.4	19	2	21	32.3
> 50 years	5	2	8	10.4	0	0	0	0.0	0	0	0	0.0	1	4	5	7.7
> 18 years	1	1	3	3.9	1	0	1	3.1	0	0	0	0.0	2	2	6	9.2
Total			77				32				28				65	

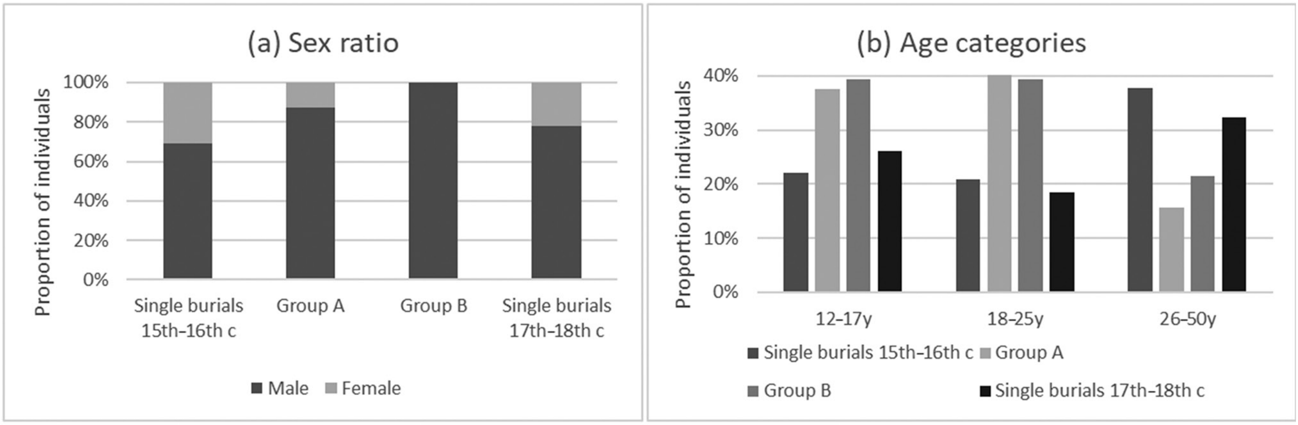

Figure 4. Histograms illustrating the differences in sex ratio (a) and age distribution (b) among groups.

depositions. The young adult category was larger in group A than in group B, while the middle adult category (26–50 years) was somewhat larger in group B, without significant differences.

Mortality quotients showed similarities in the curves (Fig. 5a), while no group resembled model life tables. The fifteenth–sixteenth-century single depositions showed an underrepresentation under 10 years and under 5 years old for the seventeenth–eighteenth-century layer. Both displayed an overrepresentation of the 15–19-year interval, the seventeenth–eighteenth-century layer in particular. The 20–29-year interval conformed to natural mortality patterns. The 10–14-year interval fell within natural mortality patterns for single and multiple burials. Multiple burials from both groups showed an absence under 10 years and an overrepresentation of all intervals over 14 years, with a much higher number of adolescents and young adults than would be expected for a natural mortality pattern and in the single depositions. While group B displayed similarities with single depositions between 15 and 19 years, there was a strong rise in the following interval. Group A, on the other hand, showed a peak between 15 and 19 years with a lower proportion for the interval of 20–29 years, which is still overrepresented. Although the overrepresentation between 15 and 19 years was observed in all groups, proportions were higher in multiple burials, especially in group A.

The plague cemetery of Maria Troon in Dendermonde showed an equal sex ratio, less marked peaks, and a lower overrepresentation for intervals over 14 years old compared to the multiple burials from Mechelen (Fig. 5b). The pattern is similar to other plague sites (Castex 2008), with an underrepresentation under 5 years and an overrepresentation of all intervals over 4 years (Goudie-Falckenbach et al. 2012; Gueguen 2012). The multiple burials from the hospital of St. Catherine in Verdun also presented a more equal sex ratio and more equal mortality rates across intervals, with only a mild overrepresentation between 5 and 14 years (Réveillas 2010; Réveillas and Castex 2010).

The curve from St. Benedict's parish cemetery in Prague displayed similarities. Here, too, the main increase appeared after 14 years, although individuals under 10 years old were present. There was a less marked overrepresentation between 15 and 19 years and a stronger increase between 20 and 29 years. The curve mainly showed similarities with group B. The sex ratio in Prague was 5.1:1.0, a pattern associated with documentary evidence for a monastery or military hospital. The profile deviated from a natural mortality and that expected of the plague, but is considered to suggest epidemics (Castex et al. 2011). St. Rombout's cemetery also showed similarities with St. Mary Spital in London, although mortality quotients could not be compared. The mass graves also showed higher proportions of non-adults than the attritional graves, although sex ratios were more equal and individuals less than 25 years old never constituted more than 45% (Connell et al. 2012).

Pathological changes

Evidence for violence

Perimortem traumatic lesions or weapon-related injuries were not observed. Twelve individuals presented a minor, healed cranial depressed fracture (Table 3; Fig. 6a), which may have resulted from a blow to the head (Ortner 2003:137–143). The fractures were recorded on the frontal bone and in a lesser degree on parietal bones and zygomatic process of the frontal bone, and only in males over 11 years old. There were no significant associations with age. Group A showed more cranial fractures than contemporaneous single depositions. Only one individual displayed a fracture

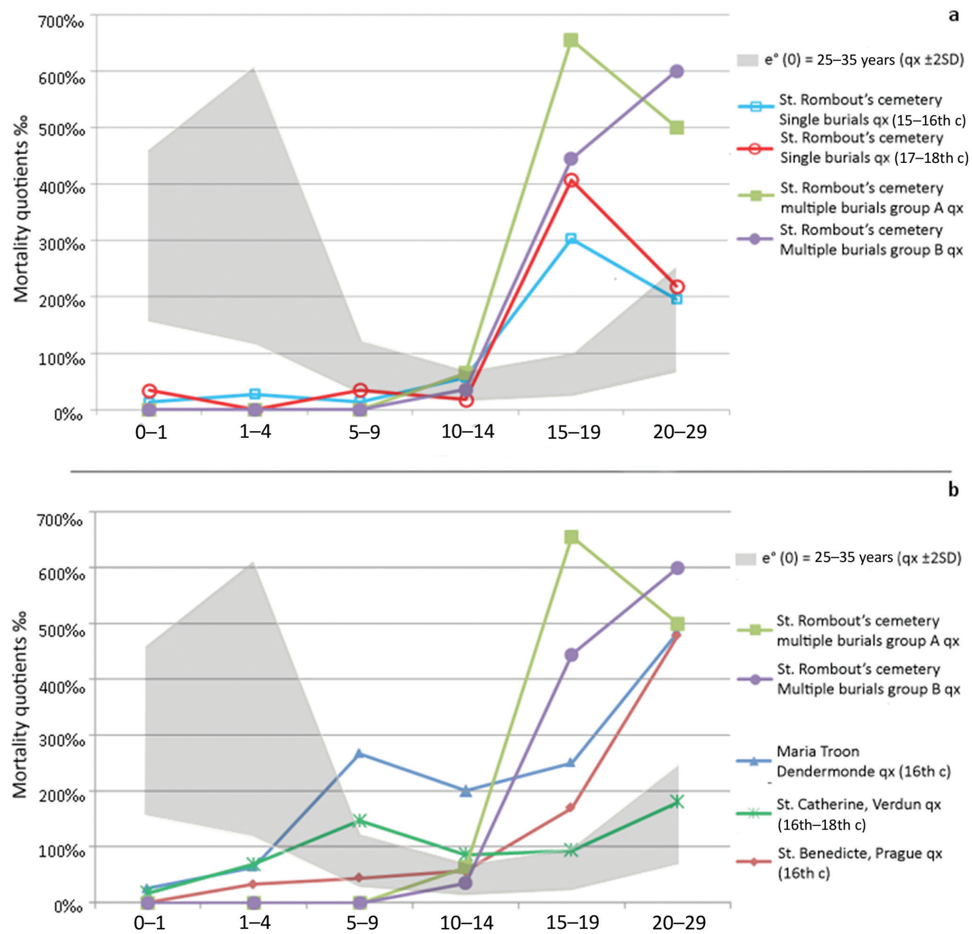

Figure 5. (a) Mortality quotients for individuals under 30 years old for the fifteenth–eighteenth-century single depositions, groups A and B from St. Rombout's cemetery. (b) Mortality quotients for individuals under 30 years old for groups A and B from St. Rombout's cemetery, the plague cemetery of Maria Troon, Dendermonde ($n = 65$, from Gueguen 2012), the hospital cemetery of St. Catherine, Verdun ($n = 17$, from Réveillas 2010), and the cemetery of St. Benedict, Prague ($n = 95$, from Castex et al. 2011). Comparison with the life tables of Ledermann (1969) for a life expectancy at birth e (0) between 25 and 35 years.

in group B, which was lower than the seventeenth–eighteenth-century single depositions and group A. There were no significant differences among the groups.

Growth and nutrition

There were no significant differences in mean male stature (Fig. 7) according to the independent samples t-test, which might have indicated differences in nutrition, genetic background, environment, or disease (Goodman 1993:282–283). The fifteenth–sixteenth-century single depositions showed a mean male stature (168.7 cm ± 5.1) similar to group A (169.9 cm ± 6.3), while group B showed a shorter male stature (167.1 cm ± 5.9) than the single depositions from the seventeenth–eighteenth century (170.4 cm ± 6.2).

Dental enamel hypoplasia, defects in enamel formation through malnutrition or disease (Hillson 2000:250), was noted in 44 individuals (Table 3; Figs. 8 and 9a). There was no significant association with age; prevalence was higher in the youngest and oldest age categories in the fifteenth–sixteenth-century single depositions, increased with age in the seventeenth–eighteenth-century single depositions, was highest between 18 and 25 years in group A, and decreased with age in group B. There was a significantly higher prevalence in group A compared to the fifteenth–sixteenth-century single depositions ($\chi^2 = 5.929$, df = 1, $p = 0.015$), and prevalence was also higher in each age category, although no longer significantly. The common odds ratio was 3.96, a considerable deviation from unity (1.0), which suggests the difference was unrelated to the variation in age structure between the groups. While prevalence was also higher in group B than in contemporaneous single depositions, overall and

Table 3. Overview of the true prevalence of pathological lesions for the single depositions and groups A and B for the different age and sex categories. Statistically significant associations are indicated in bold. The common odds ratio was calculated for lesions where each age category between 12 and 50 years presented at least one example. The true prevalence is based on the proportion of affected bones compared to well-preserved elements; the total number of observed lesions (crude prevalence) is indicated in parentheses. PNBF = periosteal new bone formation. NA indicates that no individuals could be observed.

Pathological lesion	Group	Total	%	Perinate	Infant	1–5 Years	6–11 Years	12–17 Years	18–25 Years	26–50 Years	> 50 Years	Common Odds Ratio	Male	Female
Cranial vault fracture	*Single 15–16th century*	6/56	10.7	0/1 (0.0%)	NA	0/2 (0.0%)	NA	1/12 (8.3%)	1/13 (7.7%)	3/19 (15.8%)	1/7 (14.3%)		5/26 (19.2%)	0/13 (0.0%)
	Group A	2/13	15.4	NA	NA	NA	NA	1/4 (25.0%)	1/7 (14.3%)	0/2 (0.0%)	NA		1/7 (14.3%)	0/1 (0.0%)
	Group B	1/26	3.8	NA	NA	NA	NA	0/9 (0.0%)	0/11 (0.0%)	1/6 (16.7%)	NA		1/17 (5.9%)	NA
	Single 17–18th century	3/45	6.7	0/1 (0.0%)	NA	NA	0/1 (0.0%)	0/14 (0.0%)	1/10 (0.0%)	2/13 (15.4%)	0/4 (0.0%)		3/21 (14.3%)	0/6 (0.0%)
Enamel hypoplasia	*Single 15–16th century*	**13/54**	**24.1**	NA	NA	NA	NA	5/15 (33.3%)	2/13 (15.4%)	4/18 (22.2%	2/6 (33.3%)	A—15–16th: 3.96; A—B:	5/25 (20.0%)	3/13 (23.1%)
	Group A	**9/16**	**56.3**	NA	NA	NA	NA	3/6 (50.0%)	5/8 (62.5%)	1/2 (50.0%)	NA	1.59; B—17–18th:	5/7 (71.4%)	1/1 (100.0%)
	Group B	11/25	44.0	NA	NA	NA	NA	5/9 (55.6%)	4/10 (40.0%)	2/6 (33.3%)	NA	1.86	6/16 (37.5%)	NA
	Single 17–18th century	14/44	31.8	NA	NA	NA	NA	3/15 (20.0%)	4/11 (36.4%)	5/13 (38.5%)	2/4 (50.0%)		8/22 (36.4%)	2/5 (40.0%)
Cribra orbitalia	*Single 15–16th century*	6/42	14.3	NA	NA	0/1 (0.0%)	NA	3/10 (30.0%)	2/11 (18.2%)	1/14 (7.1%)	0/4 (0.0%)		2/22 (9.1%)	1/9 (11.1%)
	Group A	0/11	0.0	NA	NA	NA	NA	0/4 (0.0%)	0/6 (0.0%)	0/1 (0.0%)	NA		0/6 (0.0%)	NA
	Group B	4 (5)/25	16.0	NA	NA	NA	NA	1/8 (12.5%)	2/11 (18.2%)	1/6 (16.7%)	NA		3/17 (17.6%)	NA
	Single 17–18th century	2/39	5.1	0/1 (0.0%)	NA	NA	0/1 (0.0%)	0/14 (0.0%)	1/7 (14.3%)	0/11 (0.0%)	1/4 (25.0%)		1/18 (5.6%)	1/4 (25.0%)
Bowing lower legs	*Single 15–16th century*	1/53	1.9	0/1 (0.0%)	NA	0/2 (0.0%)	NA	0/14 (0.0%)	0/9 (0.0%)	0/20 (0.0%)	1/4 (25.0%)		1/20 (5.0%)	0/13 (0.0%)
	Group A	1/24	4.2	NA	NA	NA	NA	0/9 (0.0%)	1/10 (10.0%)	0/5 (0.0%)	NA		1/11 (9.1%)	0/2 (0.0%)
	Group B	**3/26**	**11.5**	NA	NA	NA	NA	3/10 (30.0%)	0/10 (0.0%)	0/6 (0.0%)	NA		0/16 (0.0%)	NA
	Single 17–18th century	**0/53**	**0.0**	0/2 (0.0%)	NA	NA	0/2 (0.0%)	0/13 (0.0%)	0/7 (0.0%)	0/19 (0.0%)	0/5 (0.0%)		0/25 (0.0%)	0/9 (0.0%)
Fractures	*Single 15–16th century*	34/77	44.1	0/1 (0.0%)	NA	1/3 (33.3%)	NA	5/17 (29.4%)	7/16 (43.8%)	17/29 (58.6%)	3/8 (37.5%)	A—15–16th: 0.57;	23/36 (63.9%)	4/16 (25.0%)
	Group A	9/32	28.1	NA	NA	NA	NA	2/12 (16.7%)	5/14 (35.7%)	2/5 (40.0%)	NA	A—B: 0.57; B—17–18th:	7/14 (50.0%)	0/2 (0.0%)
	Group B	11/28	39.3	NA	NA	NA	NA	4/11 (36.4%)	5/11 (45.5%)	2/6 (33.3%)	NA	1.38	7/17 (41.2%)	NA
	Single 17–18th century	23/65	35.4	0/2 (0.0%)	NA	NA	0/2 (0.0%)	4/17 (23.5%)	3/12 (25.0%)	10/21 (47.6%)	3/5 (60.0%)		15/32 (46.9%)	4/9 (44.4%)

(*continued*)

Table 3. Overview of the true prevalence of pathological lesions for the single depositions and groups A and B for the different age and sex categories. Statistically significant associations are indicated in bold. The common odds ratio was calculated for lesions where each age category between 12 and 50 years presented at least one example. The true prevalence is based on the proportion of affected bones compared to well-preserved elements; the total number of observed lesions (crude prevalence) is indicated in parentheses. PNBF = periosteal new bone formation. NA indicates that no individuals could be observed. (*continued*)

Pathological lesion	Group	Total	%	Perinate	Infant	1–5 Years	6–11 Years	12–17 Years	18–25 Years	26–50 Years	> 50 Years	Common Odds Ratio	Male	Female
Multiple fractures	*Single 15–16th century*	14/77	18.2	0/1 (0.0%)	NA	0/3 (0.0%)	NA	1/17 (5.9%)	1/16 (6.3%)	9/29 (31.0%)	2/8 (25.0%)		11/36 (30.6%)	1/16 (6.3%)
	Group A	3/32	9.4	NA	NA	NA	NA	1/12 (8.3%)	2/14 (14.3%)	0/5 (0.0%)	NA		2/14 (14.3%)	0/2 (0.0%)
	Group B	6/28	21.%	NA	NA	NA	NA	3/11 (27.3%)	1/11 (9.1%)	2/6 (33.3%)	NA		3/17 (17.6%)	NA
	Single 17–18th century	7/65	10.8	0/2 (0.0%)	NA	NA	0/2 (0.0%)	1/17 (5.9%)	1/12 (8.3%)	4/21 (19.0%)	1/5 (20.0%)		6/32 (18.8%)	0/9 (0.0%)
Fractures: upper limb	*Single 15–16th century*	6 (8)/70	8.6	0/1 (0.0%)	NA	1/3 (33.3%)	NA	1/16 (6.3%)	**0/14 (0.0%)**	4/28 (14.3%)	0/7 (0.0%)		**3/32 (9.4%)**	0/15 (0.0%)
	Group A	5/21	23.8	NA	NA	NA	NA	0/8 (0.0%)	**3/9 (33.3%)**	2/4 (50.0%)	NA		**5/10 (50.0%)**	0/2 (0.0%)
	Group B	4/25	16.0	NA	NA	NA	NA	0/10 (0.0%)	2/9 (22.2%)	2/6 (33.3%)	NA		4/15 (26.7%)	NA
	Single 17–18th century	5 (7)/52	9.6	0/1 (0.0%)	NA	NA	0/2 (0.0%)	0/14 (0.0%)	0/8 (0.0%)	3/19 (15.8%)	2/40 (5.0%)		4/26 (15.4%)	1/7 (14.3%)
Fractures: lower limb	*Single 15–16th century*	7/51	13.7	NA	NA	0/2 (0.0%)	NA	1/14 (7.1%)	2/8 (25.0%)	3/20 (15.0%)	0/4 (0.0%)		6/19 (31.6%)	0/13 (0.0%)
	Group A	2/20	10.0	NA	NA	NA	NA	1/8 (12.5%)	1/8 (12.5%)	0/4 (0.0%)	NA		1/9 (11.1%)	0/2 (0.0%)
	Group B	6/26	23.1	NA	NA	NA	NA	2/10 (20.0%)	3/10 (30.0%)	1/6 (16.7%)	NA		4/16 (25.0%)	NA
	Single 17–18th century	4/50	8.0	0/2 (0.0%)	NA	NA	0/2 (0.0%)	1/13 (7.7%)	0/5 (0.0%)	2/19 (10.5%)	0/5 (0.0%)		2/24 (8.3%)	1/9 (11.1%)
Rib fractures	*Single 15–16th century*	4 (5)/65	6.1	0/1 (0.0%)	NA	0/2 (0.0%)	NA	0/16 (0.0%)	0/14 (0.0%)	3/26 (11.5%)	1/6 (16.7%)		4/13 (30.8%)	0/13 (0.0%)
	Group A	0/24	0.0	NA	NA	NA	NA	0/9 (0.0%)	0/10 (0.0%)	0/4 (0.0%)	NA		0/12 (0.0%)	0/1 (0.0%)
	Group B	0/27	0.0	NA	NA	NA	NA	0/10 (0.0%)	0/11 (0.0%)	0/6 (0.0%)	NA		0/17 (0.0%)	NA
	Single 17–18th century	4/49	8.2	0/1 (0.0%)	NA	NA	0/2 (0.0%)	1/16 (6.3%)	0/10 (0.0%)	2/15 (13.3%)	1/3 (33.3%)		3/26 (11.5%)	0/3 (0.0%)
Vertebral fractures	*Single 15–16th century*	11 (13)/63	17.4	0/1 (0.0%)	NA	0/3 (0.0%)	NA	1/15 (6.7%)	5/14 (35.7%)	5/24 (20.8%)	1/6 (16.7%)		8/29 (27.6%)	2/13 (15.4%)
	Group A	1/20	5.0	NA	NA	NA	NA	1/7 (14.3%)	0/10 (0.0%)	0/3 (0.0%)	NA		0/11 (0.0%)	0/1 (0.0%)
	Group B	3/25	12.0	NA	NA	NA	NA	3/10 (30.0%)	0/9 (0.0%)	0/6 (0.0%)	NA		0/15 (0.0%)	NA
	Single 17–18th century	6 (7)/42	14.3	0/1 (0.0%)	NA	NA	0/2 (0.0%)	1/15 (6.7%)	2/10 (20.0%)	2/11 (18.2%)	0/2 (0.0%)		5/20 (25.0%)	0/3 (0.0%)

Schmorl's nodes	*Single 15–16th century*	27/70	38.6	0/1 (0.0%)	NA	0/3 (0.0%)	NA	6/15 (40.0%)	10/15 (66.7%)	10/29 (34.5%)	1/7 (14.3%)	A—15–16th: 0.93;	15/34 (44.1%)	4/14 (28.6%)
	Group A	13/27	48.1	NA	NA	NA	NA	5/11 (45.5%)	7/11 (63.6%)	1/4 (25.0%)	NA	A—B: 0.60;	7/13 (53.8%)	0/2 (0.0%)
	Group B	**18/28**	**64.3**	NA	NA	NA	NA	6/11 (54.5%)	8/11 (72.7%)	4/6 (66.6%)	NA	B—17–18th: 4.09	**12/17 (70.6%)**	NA
	Single 17–18th century	**17/61**	**27.9**	0/1 (0.0%)	NA	NA	0/2 (0.0%)	3/17 (17.6%)	5/12 (41.7%)	8/20 (40.0%)	0/4 (0.0%)		**11/31 (35.5%)**	1/7 (14.3%)
Enthesopathy	*Single 15–16th century*	51/77	66.2	0/1 (0.0%)	NA	1/3 (33.3%)	NA	9/17 (52.9%)	10/16 (62.5%)	23/29 (79.3%)	6/8 (75.0%)	A—15–16th: 0.56;	29/36 (80.5%)	9/16 (56.3%)
	Group A	**16/32**	**50.0**	NA	NA	NA	NA	5/12 (41.7%)	**7/14 (50.0%)**	3/5 (60.0%)	NA	A—B: 0.16;	8/14 (57.1%)	2/2 (100.0%)
	Group B	**23/28**	**82.1**	NA	NA	NA	NA	**9/11 (81.8%)**	**10/11 (90.9%)**	4/6 (66.6%)	NA	B—17–18th: 3.36	14/17 (82.4%)	NA
	Single 17–18th century	**39/65**	**60.0**	0/2 (0.0%)	NA	NA	0/2 (0.0%)	**6/17 (35.3%)**	6/12 (50.0%)	17/21 (80.9%)	5/5 (100.0%)		22/32 (68.8%)	8/9 (88.9%)
Enthesopathy upper limb	*Single 15–16th century*	40 (41)/70	57.1	0/1 (0.0%)	NA	1/3 (33.3%)	NA	7/16 (43.8%)	9/14 (64.3%)	18/28 (64.3%)	5/7 (71.4%)	A—15–16th: 0.83;	23/32 (71.9%)	8/15 (53.3%)
	Group A	**10 (12)/21**	**47.6**	NA	NA	NA	NA	5/8 (62.5%)	2/9 (22.2%)	3/4 (75.0%)	NA	A—B: 0.19;	4/10 (40.0%)	1/2 (50.0%)
	Group B	**20 (21)/25**	**80.0**	NA	NA	NA	NA	**9/10 (90.0%)**	7/9 (77.8%)	4/6 (66.6%)	NA	B—17–18th: 3.45	11/15 (73.3%)	NA
	Single 17–18th century	30 (35)/52	57.7	0/1 (0.0%)	NA	NA	0/2 (0.0%)	**6/14 (42.9%)**	3/8 (37.5%)	13/19 (68.4%)	4/4 (100.0%)		16/26 (61.5%)	6/7 (85.7%)
Enthesopathy lower limb	*Single 15–16th century*	**25 (30)/51**	**49.0**	NA	NA	0/2 (0.0%)	NA	2/14 (14.3%)	5/8 (62.5%)	14/20 (70.0%)	2/4 (50.0%)		**15/19 (78.9%)**	6/13 (46.1%)
	Group A	**4 (6)/20**	**20.0**	NA	NA	NA	NA	0/8 (0.0%)	3/8 (37.5%)	1/4 (25.0%)	NA		**2/9 (22.2%)**	2/2 (100.0%)
	Group B	10/26	38.5	NA	NA	NA	NA	**4/10 (40.0%)**	3/10 (30.0%)	3/6 (50.0%)	NA		6/16 (37.5%)	NA
	Single 17–18th century	11 (13)/50	22.0	0/2 (0.0%)	NA	NA	0/2 (0.0%)	**0/13 (0.0%)**	0/5 (0.0%)	8/19 (42.1%)	2/5 (40.0%)		8/24 (33.3%)	3/9 (33.3%)
Osteoarthritis	*Single 15–16th century*	**29/76**	**38.1**	0/1 (0.0%)	NA	0/3 (0.0%)	NA	0/17 (0.0%)	1/15 (6.7%)	20/29 (68.9%)	7/8 (87.5%)		**17/35 (48.6%)**	10/16 (62.5%)
	Group A	**1/27**	**3.7**	NA	NA	NA	NA	0/10 (0.0%)	0/12 (0.0%)	1/5 (25.0%)	NA		**0/13 (0.0%)**	1/2 (50.0%)
	Group B	6/27	22.2	NA	NA	NA	NA	0/11 (0.0%)	3/10 (30.0%)	3/6 (50.0%)	NA		**6/16 (37.5%)**	NA
	Single 17–18th century	23/64	35.9	0/1 (0.0%)	NA	NA	0/2 (0.0%)	0/17 (0.0%)	1/12 (8.3%)	12/21 (57.1%)	5/5 (100.0%)		16/32 (50.0%)	6/9 (66.6%)
Osteoarthritis appendicular skeleton	*Single 15–16th century*	**20/76**	**26.3**	0/1 (0.0%)	NA	0/3 (0.0%)	NA	0/17 (0.0%)	1/15 (6.7%)	13/29 (44.8%)	6/8 (75.0%)		**10/35 (28.6%)**	8/16 (50.0%)
	Group A	**1/27**	**3.7**	NA	NA	NA	NA	0/10 (0.0%)	0/12 (0.0%)	1/5 (20.0%)	NA		**0/13 (0.0%)**	1/2 (50.0%)
	Group B	**1/27**	**3.7**	NA	NA	NA	NA	0/11 (0.0%)	1/10 (10.0%)	0/6 (0.0%)	NA		1/16 (6.3%)	NA
	Single 17–18th century	**16/64**	**25.0**	0/1 (0.0%)	NA	NA	0/2 (0.0%)	0/17 (0.0%)	0/12 (0.0%)	9/21 (42.9%)	4/5 (80.0%)		10/32 (31.3%)	5/9 (55.5%)

(*continued*)

Table 3. Overview of the true prevalence of pathological lesions for the single depositions and groups A and B for the different age and sex categories. Statistically significant associations are indicated in bold. The common odds ratio was calculated for lesions where each age category between 12 and 50 years presented at least one example. The true prevalence is based on the proportion of affected bones compared to well-preserved elements; the total number of observed lesions (crude prevalence) is indicated in parentheses. PNBF = periosteal new bone formation. NA indicates that no individuals could be observed. (*continued*)

Pathological lesion	Group	Total	%	Perinate	Infant	1–5 Years	6–11 Years	12–17 Years	18–25 Years	26–50 Years	> 50 Years	Common Odds Ratio	Male	Female
Osteoarthritis spine	*Single 15–16th century*	11 (12)/70	15.7	0/1 (0.0%)	NA	0/3 (0.0%)	NA	0/16 (0.0%)	0/15 (0.0%)	8/28 (28.6%)	3/7 (42.9%)		6/34 (17.6%)	4/13 (30.8%)
	Group A	0/22	0.0	NA	NA	NA	NA	0/9 (0.0%)	0/10 (0.0%)	0/3 (0.0%)	NA		0/11 (0.0%)	0/1 (0.0%)
	Group B	2/26	7.7	NA	NA	NA	NA	0/10 (0.0%)	1/10 (10.0%)	1/6 (16.7%)	NA		2/16 (12.5%)	NA
	Single 17–18th century	9 (13)/54	16.7	0/1 (0.0%)	NA	NA	0/2 (0.0%)	0/16 (0.0%)	1/11 (9.1%)	4/19 (21.1%)	2/3 (66.7%)		8/30 (26.7%)	1/4 (25.0%)
PNBF: General	*Single 15–16th century*	37/77	48.0	0/1 (0.0%)	NA	0/3 (0.0%)	NA	14/17 (82.4%)	11/16 (68.8%)	**9/29 (31.0%)**	3/8 (37.5%)	A—15–16th: 1.07;	16/36 (44.4%)	6/16 (37.5%)
	Group A	20/32	62.5	NA	NA	NA	NA	8/12 (66.7%)	6/14 (42.9%)	**5/5 (100.0%)**	NA	A—B: 0.59;	9/14 (64.3%)	2/2 (100.0%)
	Group B	19/28	67.8	NA	NA	NA	NA	8/11 (72.7%)	8/11 (72.7%)	3/6 (50.0%)	NA	B—17–18th: 1.15	11/17 (64.7%)	NA
	Single 17–18th century	37/65	56.9	1/2 (50.0%)	NA	NA	1/2 (50.0%)	11/17 (64.7%)	8/12 (66.6%)	12/21 (57.1%)	1/5 (20.0%)		20/32 (62.5%)	3/9 (33.3%)
PNBF: Diffuse spread	*Single 15–16th century*	10/73	13.7	0/1 (0.0%)	NA	0/3 (0.0%)	NA	3/17 (17.6%)	5/15 (33.3%)	1/27 (3.7%)	1/8 (12.5%)		5/33 (15.2%)	2/16 (12.5%)
	Group A	4 (7)/20	20.0	NA	NA	NA	NA	2/8 (25.0%)	2/9 (22.2%)	0/3 (0.0%)	NA		1/11 (9.1%)	1/1 (100.0%)
	Group B	6/26	23.1	NA	NA	NA	NA	2/10 (20.0%£)	3/10 (30.0%)	1/6 (16.7%)	NA		4/16 (25.0%)	NA
	Single 17–18th century	20 (21)/60	33.3	1/1 (100.0%)	NA	NA	1/2 (50.0%)	6/16 (37.5%)	4/12 (33.3%)	6/21 (28.6%)	1/5 (20.0%)		9/31 (29.0%)	2/8 (25.0%)
PNBF: Visceral ribs	*Single 15–16th century*	25/65	38.5	0/1 (0.0%)	NA	0/2 (0.0%)	NA	**12/16 (75.0%)**	8/14 (57.1%)	3/23 (13.0%)	2/6 (33.3%)	A—15–16th: 0.34;	10/31 (32.3%)	3/13 (23.1%)
	Group A	5/24	20.8	NA	NA	NA	NA	**1/9 (44.4%)**	2/10 (20.0%)	2/4 (50.0%)	NA	A—B: 0.47;	3/12 (25.0%)	0/1 (0.0%)
	Group B	9/27	33.3	NA	NA	NA	NA	2/10 (20.0%)	5/11 (45.5%)	2/6 (50.0%)	NA	B—17–18th: 1.23	7/17 (41.2%)	NA
	Single 17–18th centuries	13 (14)/49	26.5	0/1 (0.0%)	NA	NA	0/2 (0.0%)	5/16 (31.3%)	2/10 (20.0%)	4/15 (26.7%)	0/3 (0.0%)		8/26 (30.8%)	0/3 (0.0%)

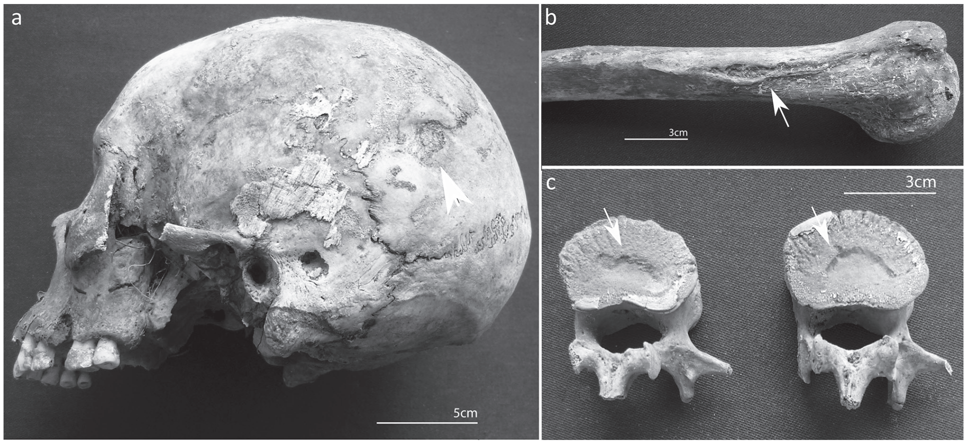

Figure 6. Illustration of pathological lesions related to physical stress and possible violence: (a) healed cranial depressed fracture (GR311-2, fifteenth–sixteenth-century layer); (b) enthesopathy of the proximal right humerus (GR275-11); (c) Schmorl's nodes in thoracic vertebrae (GR131-3).

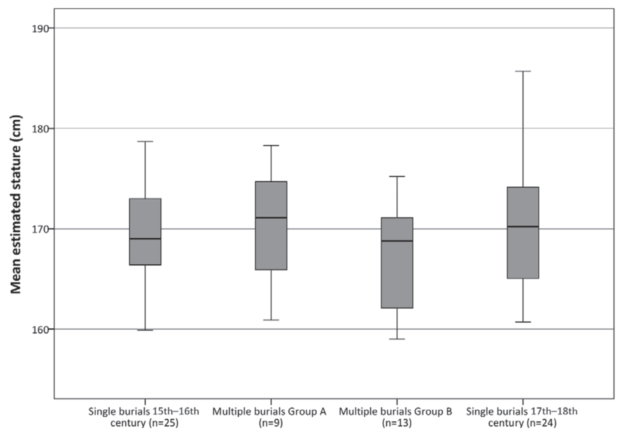

Figure 7. Graph illustrating the differences in estimated stature for males in the single depositions from the different periods and groups A and B.

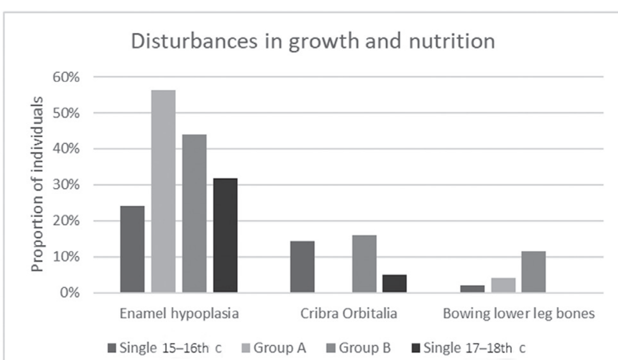

Figure 8. Histogram illustrating the prevalence of growth disturbances among groups.

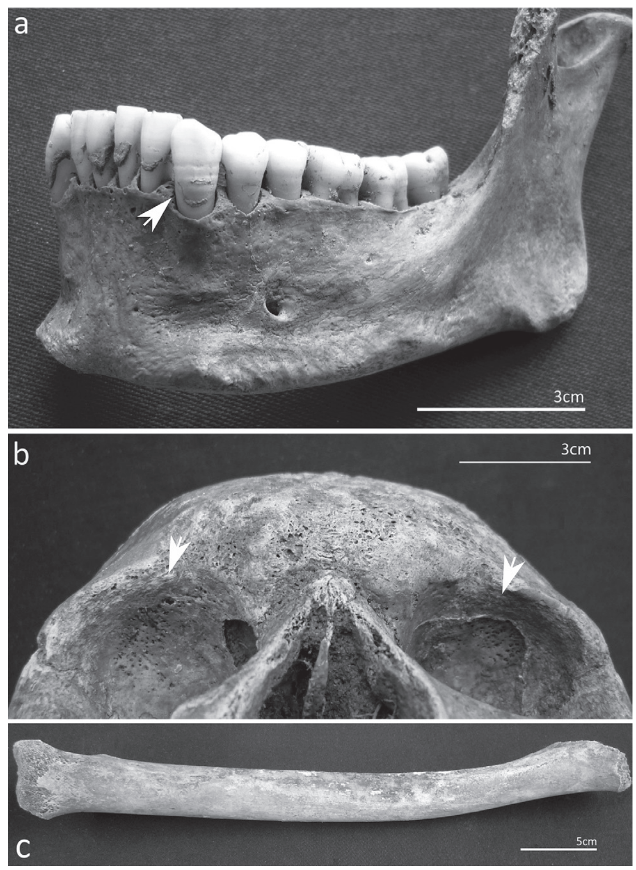

Figure 9. Illustration of pathological lesions related to growth disturbances and nutritional stress: (a) dental enamel hypoplasia (GR287-10); (b) cribra orbitalia (GR275-13); (c) bowing of lower leg bones (GR203-3).

between 12 and 25 years, it was not significant. Nor was the higher prevalence in group A compared to group B, overall and between 18 and 50 years, significant.

Cribra orbitalia was observed in 12 individuals (Table 3; Figs. 8 and 9b) and was overall more common in males and non-adults in all groups except the seventeenth–eighteenth-century single depositions. The association with non-adults was significant for the fifteenth–sixteenth-century single depositions ($\chi^2 = 5.523$, df = 1, Fisher's exact test: $p = 0.029$). It can be caused by varied conditions, including anaemia, hemorrhaging, infection, inflammation, or neoplasms (Ortner 2003:102–105; Waldron 2009:136–137). Cribra orbitalia was not recorded in group A, and prevalence was higher in group B than contemporaneous single depositions, overall and for all age categories, without significant differences.

Mild bowing of lower leg bones was recorded in five individuals (Table 3; Figs. 8 and 9c). Bowing may be due to rickets in non-adults or healed rickets or osteomalacia in adults. The changes are related to vitamin D deficiency, which is derived through exposure to ultraviolet light and in a lesser degree from nutrition (Brickley 2000:187–190; Ortner 2003:393–403). Bowing was observed in one individual from a fifteenth–sixteenth-century single deposition, one from group A, and three from group B. The difference between group B and contemporaneous single depositions was significant according to Fisher's exact test ($\chi^2 = 6.357$, df = 1, $p = 0.012$), although differences within age categories were not significant. There were no significant patterns between multiple burials. Only non-adults were affected in group B, and only male adults in group A and the single deposition were affected.

Physical stress and activity

Only healed traumatic lesions were observed. Fractures were recorded in 77 individuals, with multiple fractures in 30 (Table 3; Fig. 10). Fracture prevalences were significantly higher in males ($\chi^2 = 4.458$, df = 1, $p = 0.035$), and generally increased with age in the single depositions and group A, although only significantly for males in fifteenth–sixteenth-century single depositions ($\chi^2 = 6.099$, df = 2, $p = 0.047$). In group B, the highest prevalence was observed between 18 and 25 years, followed by the 12–17-year category, but this difference was not significant. There were no significant differences among burial types. The fifteenth–sixteenth-century single depositions showed a generally higher prevalence than group A, except for males between 18 and 25 years old, but without significant differences. Group B displayed an overall higher prevalence than single depositions, although males and individuals over 25 years presented higher prevalences in single depositions, but differences were not significant. Group B showed an overall higher prevalence than group A, mainly due to the 12–25-year categories; for males, prevalence was higher in group A. Multiple fractures showed a higher prevalence between 12 and 25 years in group A, although the fifteenth–sixteenth-century single depositions showed an overall higher prevalence. Group B showed generally higher prevalences in all age categories compared to single depositions, and higher prevalences than group A for males except for the 18–25 year category, although this difference was not significant.

Fractures in limb bones were listed in 36 different bones (observed bones = 3,853, 0.9%), of which 22 were long bones (observed bones = 2,284, 1.0%). Fractures included complete transverse or oblique fractures, incomplete or crush fractures, and avulsion fractures, related to direct and indirect trauma (Lovell 1997). The most commonly affected bones were the right and left ulna and right fibula. In 14 joints, mainly the wrist, ankle, hand, and foot, a fracture was recorded on the articular surface. Twelve individuals over 12 years old presented bowing of a long bone diaphysis, in eight ulnae, two radii, two fibulae, and one hand phalanx. Three individuals with traumatic bowing lesions were recorded in group A and four in group B. All were young adults except one middle adult from group B. Three individuals with bowed long bones were recorded

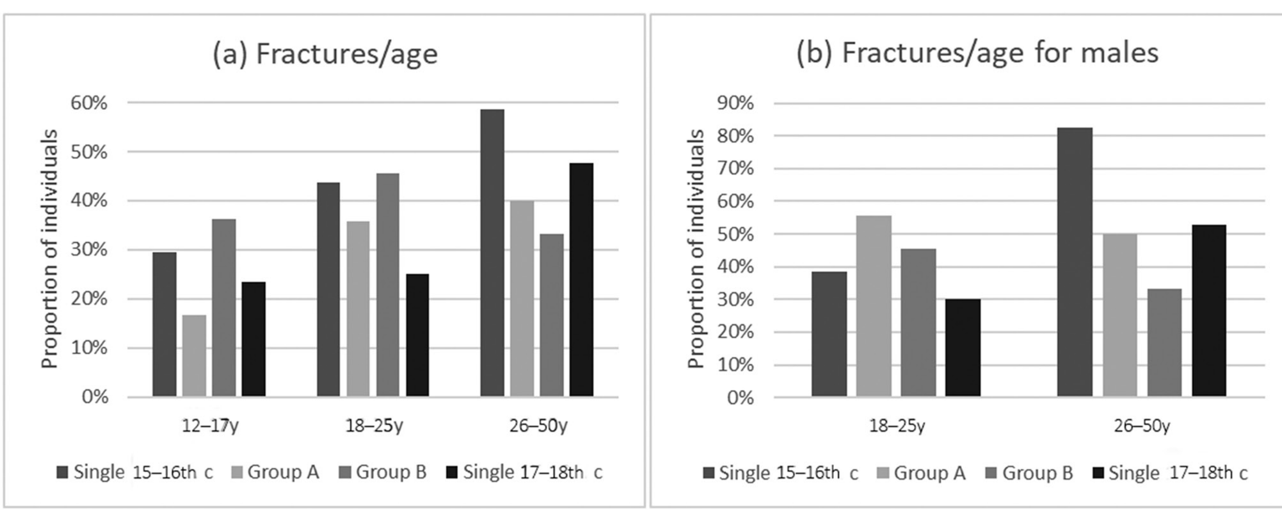

Figure 10. Histograms illustrating the prevalence of fractures among groups within age categories: (a) overall; (b) for males.

in fifteenth–sixteenth-century single depositions and two from the seventeenth–eighteenth-century layer, one adolescent and four middle adults. Traumatic bowing is associated with injury during growth (Lewis 2018). Most fracture types were found in all groups, and the low prevalences hindered the observation of relevant differences. Fractures were often relatively minor and in an advanced stage of remodeling.

Healed fractures of the upper limb were observed in 20 individuals (Table 3). Prevalence was higher in older age categories for all groups, but without significant patterns. There was a higher prevalence in group A between 18 and 50 years old than the fifteenth–sixteenth-century single depositions, which was significant for the 18–25-year category ($\chi^2=5.367$, df = 1, Fisher's exact test: $p=0.047$) and males ($\chi^2=8.155$, df = 1, Fisher's exact test: $p=0.012$). Group B also showed higher prevalences between 18 and 50 years old than contemporaneous single depositions, but not significantly. There were no significant differences among multiple burials, with higher prevalences in group A. Healed lower-limb fractures were recorded in 19 individuals (Table 3). Prevalences were higher between 12 and 25 years, except for the seventeenth–eighteenth-century single depositions, but there were no significant patterns. Prevalence was higher in the fifteenth–sixteenth-century single depositions than in group A, except for the 12–17-year category, but without significant differences. Prevalences were higher in all age categories in group B than in contemporaneous single depositions and group A, but again not significantly.

Rib fractures, due to direct trauma (Lovell 1997:159), were observed in eight individuals, all from single depositions (Table 3). They were recorded on a single rib in four individuals and in up to five ribs in others. Prevalence increased with age and was higher in males, but without significant differences. Differences with multiple burials were not significant. Injuries of vertebral bodies, of one to seven vertebrae, were noted in 21 individuals (Table 3). The fractures indicate indirect trauma and mechanical stress, with wedge-shaped bodies and impression, burst, or avulsion fractures (Lovell 1997; Maat and Mastwijk 2000). They occurred more often in males and only from 12 years onward. In the single depositions, prevalences were higher between 18 and 50 years. In the multiple burials, lesions were only observed between 12 and 17 years old. These patterns were not significant. Frequencies were generally higher in single depositions, but not significantly. Between 12 and 17 years, prevalence was higher in multiple burials.

Schmorl's nodes were observed in 75 individuals (Table 3; Figs. 6c and 11). These are indentations in vertebral bodies due to mechanical stress or injuries

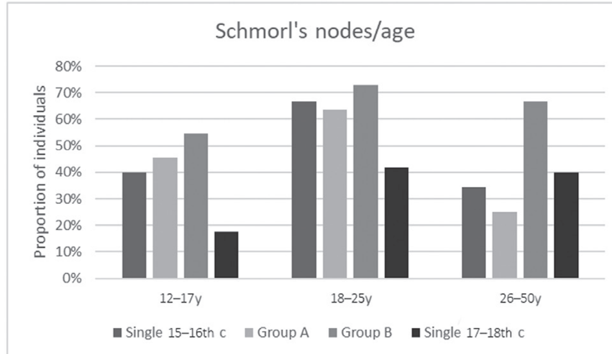

Figure 11. Histogram illustrating the prevalence of Schmorl's nodes among groups within age categories.

as well as age (Aufderheide and Rodríguez-Martín 1998:97). In young individuals, they indicate physical stress (Knüsel 2007:112). Schmorl's nodes showed a significantly higher prevalence in males ($\chi^2=4.981$, df = 1, $p=0.026$) and were significantly associated with age ($\chi^2=18.214$, df = 5, $p=0.006$), with the highest prevalence between 18 and 25 years old. This pattern was observed in all groups but was no longer significant. Lesions were more common in multiple burials, particularly group B. Prevalence was higher in group A than in the fifteenth–sixteenth-century single depositions overall and between 12 and 17 years, but not for the 18–50-year categories. Differences were not significant. The prevalence in group B is significantly higher than in contemporaneous single depositions ($\chi^2=10.666$, df = 1, $p=0.001$), which remained significant for males ($\chi^2=5.421$, df = 1, $p=0.020$). It was observed in all age categories, but differences were no longer significant. The common odds ratio for the comparison between the group B and the single depositions was 4.09, a substantial deviation from unity, suggesting the difference was unrelated to the differences in age structure. There were no significant variations among multiple burials, with a generally higher prevalence in group B.

Entheseal lesions were recorded in 129 individuals (Table 3). They represent pathological changes of muscle and ligament attachments, which may be osteophytic or osteolytic. Injury or physical stress is often proposed as etiology (Jurmain et al. 2012; Knüsel 2007). Fibrocartilaginous entheses are more often associated with injury or stress than fibrous entheses, although both are affected by age as well as sex, body size, and disease (Villotte et al. 2010). All lesions were analyzed to observe patterns, but age was considered when comparing groups. Enthesopathy was more common in males and showed a significant increase with age ($\chi^2=21.028$, df = 7, $p=0.002$), which remained significant for the seventeenth–eighteenth-century single depositions ($\chi^2=17.554$, df = 5, $p=0.004$). This increase was also observed in the fifteenth–sixteenth-century single depositions and group A. Group B, however, showed higher prevalences between 12 and 25 years, although without significant differences. There was a higher prevalence in the fifteenth–sixteenth-century single depositions than group A, in all age categories, but not significantly. Group B displayed the highest prevalence, which was significantly higher than contemporaneous single depositions ($\chi^2 = 4.318$, df = 1, $p = 0.038$). This difference remained significant between 12 and 17 years ($\chi^2 = 5.812$, df = 1, $p = 0.016$) and was observed between 18 and 25 years. Over 25 years old, however, enthesopathy occurred more often in single depositions, although not significantly. The common odds ratio was 3.36, deviating substantially from unity, suggesting the higher prevalence in group B was not related to the different age structure. The difference between group A and group B was also significant ($\chi^2 = 6.782$, df = 1, $p = 0.009$), was observed in all age categories, and remained significant between 18 and 25 years old ($\chi^2 = 4.738$, df = 1, Fisher's exact test: $p = 0.042$). Here, too, the common odds ratio (0.16) deviated considerably.

Enthesopathy in the upper limbs was observed in 100 individuals (Table 3; Figs. 6b and 12). Prevalence was higher in older age categories in the single depositions, although not significantly. In group A, prevalence was lowest between 18 and 25 years. In group B, prevalence decreased with age. These patterns were not significant. Prevalence was higher in the fifteenth-sixteenth-century single depositions than group A; however, between 12 and 17 and 26 and 50 years old, prevalence was higher in group A. Differences were not significant. Group B showed a higher prevalence than contemporaneous single depositions between 12 and 25 years, which was significant between 12 and 17 years ($\chi^2 = 5.531$, df = 1, Fisher's exact test: $p = 0.033$). The common odds ratio was 3.45, deviating considerably from unity, even though the difference between group B and the single depositions was not significant. Over 25 years old, prevalence was higher in single depositions, but not significantly. Group A and B showed a significant difference ($\chi^2 = 5.275$, df = 1, $p = 0.022$), with a strong deviation of the common odds ratio (0.19) and a higher overall prevalence in group B, although prevalence was higher in group A for the 26–50 year category.

Patterns varied for the different joints (Table 4). Group A showed a higher prevalence of entheseal lesions for the right shoulder than contemporaneous single depositions but a lower prevalence for the left. The single depositions also displayed a higher prevalence in the elbows. Group B showed a significantly higher prevalence than the seventeenth–eighteenth-century single depositions in the shoulders ($\chi^2 = 5.740$, df = 1, $p = 0.017$), while single depositions presented a higher prevalence for the right but a similar prevalence for the left elbow. The higher prevalence in group B compared to group A for the left shoulder was significant ($\chi^2 = 3.955$, df = 1, $p = 0.047$). Entheseal lesions around the right elbow were more common in group A but were more common around the left elbow in group B. Overall, the shoulders showed higher prevalences in multiple burials, particularly group B, and the elbows showed higher prevalences in single depositions.

Males displayed similar patterns. Group A showed higher prevalences in the right and left shoulder than single depositions for the 12–17 and 26–50-year categories, which was significant for the right shoulder in adolescents ($\chi^2 = 5.885$, df = 1, Fisher's exact test: $p = 0.029$). The higher prevalences in group B compared to single depositions remained significant for the 12–17 ($\chi^2 = 8.110$, df = 1, Fisher's exact test: $p = 0.008$) and 18–25-year categories ($\chi^2 = 5.402$, df = 1, Fisher's exact test: $p = 0.041$). For the right shoulder, however, single depositions presented a higher prevalence between 26 and 50 years old. The right shoulder showed a higher prevalence in group A compared to group B between 12 and 17 and 26 and 50 years old and a

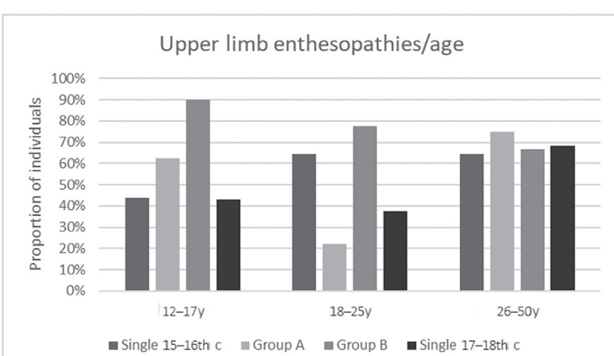

Figure 12. Histogram illustrating the prevalence of upper-limb enthesopathy among groups within age categories.

Table 4. Overview of the prevalence of entheseal lesions for different joints of the upper limb. Significant differences are indicated in bold.

Joint	Single 15–16th Century	Group A	Group B	Single 17–18th Century
Shoulder right	21/49 (42.8%)	8/13 (61.5%)	**15/23 (65.2%)**	**14/41 (34.1%)**
Shoulder left	18/49 (36.7%)	**4/13 (30.7%)**	**15/23 (65.2%)**	**14/41 (34.1%)**
Elbow right	13/49 (26.5%)	2/13 (15.4%)	0/23 (0.0%)	5/41 (12.2%)
Elbow left	12/49 (24.5%)	1/13 (7.7%)	3/23 (13.0%)	5/41 (12.2%)

higher prevalence in group B between 18 and 25 years. Prevalence for the left shoulder remained significantly higher in group B between 18 and 25 years ($\chi^2 = 5.833$, df = 1, Fisher's exact test: $p = 0.031$), while group A showed a higher prevalence between 26 and 50 years old.

Enthesopathy in the lower limb was noted in 50 individuals (Table 3). Prevalence significantly increased with age in the single depositions from the fifteenth–sixteenth century (χ^2=12.782, df=4, $p = 0.012$) and seventeenth–eighteenth century ($\chi^2 = 11.723$, df = 5, $p = 0.059$). In group A, prevalence was highest between 18 and 25 years, while in group B, the 18–25-year category showed the lowest prevalence, but there were no significant patterns. Prevalences were significantly higher in fifteenth–sixteenth-century single depositions than in group A ($\chi^2 = 5.007$, df = 1, $p = 0.025$) and remained significant for males ($\chi^2 = 8.239$, df = 1, Fisher's exact test: $p = 0.010$). Prevalence in group B was higher than in contemporaneous single burials, which was significant between 12 and 17 years ($\chi^2 = 6.295$, df = 1, Fisher's exact test: $p = 0.024$). Enthesopathy in the lower limb was more common in group B than in group A except for the 18–25-year category.

Joint changes related to osteoarthritis were observed in 59 individuals (Table 3). They are influenced by age, sex, and genetic background and may result from activity, obesity, and injury (Jurmain et al. 2012; Rogers and Waldron 1995:32–45). Osteoarthritis was significantly more common in females ($\chi^2 = 4.775$, df = 1, $p = 0.029$) and significantly increased with age ($\chi^2 = 90.893$, df = 6, $p \leq 0.001$), which was observed in all groups, with significant associations for the single depositions and group B. Lesions were not observed under 18 years old in this sample. There was a significantly higher prevalence in fifteenth–sixteenth-century single depositions than in group A ($\chi^2 = 11.457$; df = 1, $p = 0.001$), also for males ($\chi^2 = 9.777$, df = 1, Fisher's exact test: $p = 0.002$). While prevalence was generally higher in seventeenth–eighteenth-century single depositions than in group B, the 18–25-year category displayed a higher prevalence in group B, although differences were not significant. The higher prevalence in group B compared to group A was significant for males ($\chi^2 = 6.147$, df = 1, Fisher's exact test: $p = 0.020$).

Osteoarthritis in the appendicular skeleton was recorded in 38 individuals (Table 3). Prevalence increased significantly with age for single depositions from the fifteenth–sixteenth century ($\chi^2 = 25.274$, df = 5, $p \leq 0.001$) and the seventeenth–eighteenth century ($\chi^2 = 24.406$, df = 5, $p \leq 0.001$). Patterns could not be observed for the multiple burials. Prevalence was significantly higher in fifteenth–sixteenth-century single depositions than in group A ($\chi^2 = 6.276$; df = 1, $p = 0.012$), remained significant for males ($\chi^2 = 4.692$, df = 12, Fisher's exact test: $p = 0.044$), and was observed for all age categories. A similar lower prevalence was observed for group B compared to contemporaneous single depositions ($\chi^2 = 5.669$, df = 1, $p = 0.017$), although the 18–25-year category showed a higher prevalence in group B, which was not significant. Groups A and B showed the same frequency. Osteoarthritis in the facet joints of the spine was noted in 22 individuals (Table 3), without significant differences. It increased significantly with age ($\chi^2 = 31.326$, df = 6, $p \leq 0.001$), which remained significant for the single depositions and group B. There were no affected individuals in group A, and prevalence in group B was lower than the seventeenth–eighteenth-century single depositions, but not significantly, with a similar prevalence in the 18–25-year category and a lower prevalence between 26 and 50 years.

Lesions related to disease

Periosteal new bone formation was observed for 113 individuals (Table 3). Infection and trauma are the most common explanations. Periosteal new bone, however, also can be associated with chronic skin ulcers, hemorrhage, metabolic disease, hypertrophic osteoarthropathy, and joint, vascular, or neoplastic disease (Aufderheide and Rodríguez-Martín 1998:179; Waldron 2009:115–117; Weston 2012). The new bone had a woven appearance in 42 individuals, which implies active lesions, was lamellar in 23, which implies healing, and was a mixture of woven and lamellar bone in 48 individuals (Waldron 2009:116; Weston 2012). Periosteal new bone formation was significantly associated with age ($\chi^2 = 16.336$, df = 6, $p = 0.012$). It was more common between 12 and 25 years old in the single depositions and group B, which was significant for the fifteenth–sixteenth-century single depositions ($\chi^2 = 8.040$, df = 5, $p = 0.003$), while group A showed the lowest prevalence between 18 and 25 years and the highest between 26 and 50 years. It was recorded more often in group A than fifteenth–sixteenth-century single depositions, although not significantly. Both females in the multiple burials displayed lesions. The 12–25-year categories showed higher prevalences in the single depositions, while those over 25 years showed a significantly higher prevalence in group A ($\chi^2 = 8.374$, df = 1, Fisher's exact test: $p = 0.007$). It was more common in group B than contemporaneous single depositions for individuals under 26 years old, but without significant differences. Group B showed a generally higher prevalence than group A, although individuals over 25 years showed a higher prevalence in group A (Fig. 13), but there were no significant differences. There were no significant differences in the presence of woven or lamellar bone, although group B more commonly displayed woven bone (94.7%) compared

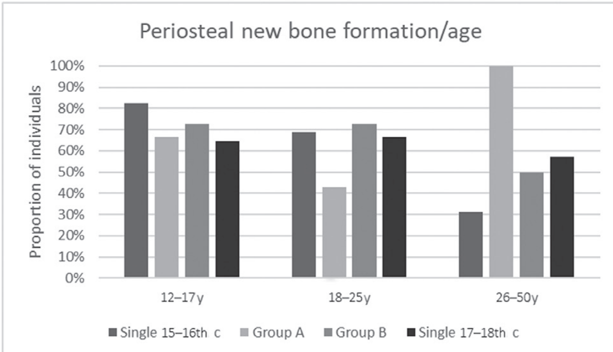

Figure 13. Histogram illustrating the prevalence of periosteal new bone formation among groups within age categories.

to group A (65.0%) and the single depositions from the seventeenth–eighteenth century (72.9%) and fifteenth–sixteenth century (86.5%). It was mostly related to age, with higher proportions of woven bone in younger categories. To observe wider patterns but still make suggestions for etiology, lesions were divided into localized lesions, diffuse lesions spread across different limbs, and visceral rib lesions. Lesions were localized in 26 individuals and were most common on the tibia and femur.

A diffuse spread of periosteal new bone, with lesions on several limb bones, was recorded for 40 individuals (Table 3; Figs. 14 and 15a) and was more common between 12 and 25 years in each group, but without significant associations. Long bones, particularly of the lower limbs, were more commonly affected. Diffuse periosteal new bone showed no significant patterns among groups. It was more common in group A than in fifteenth–sixteenth-century single depositions between 12 and 17 years and was more common in single depositions in older categories. It occurred more often in seventeenth–eighteenth-century single depositions than in group B, for all age categories.

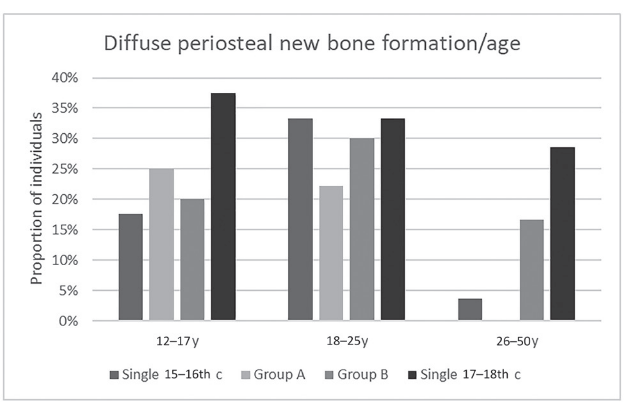

Figure 14. Histogram illustrating the prevalence of diffuse periosteal new bone formation among groups within age categories.

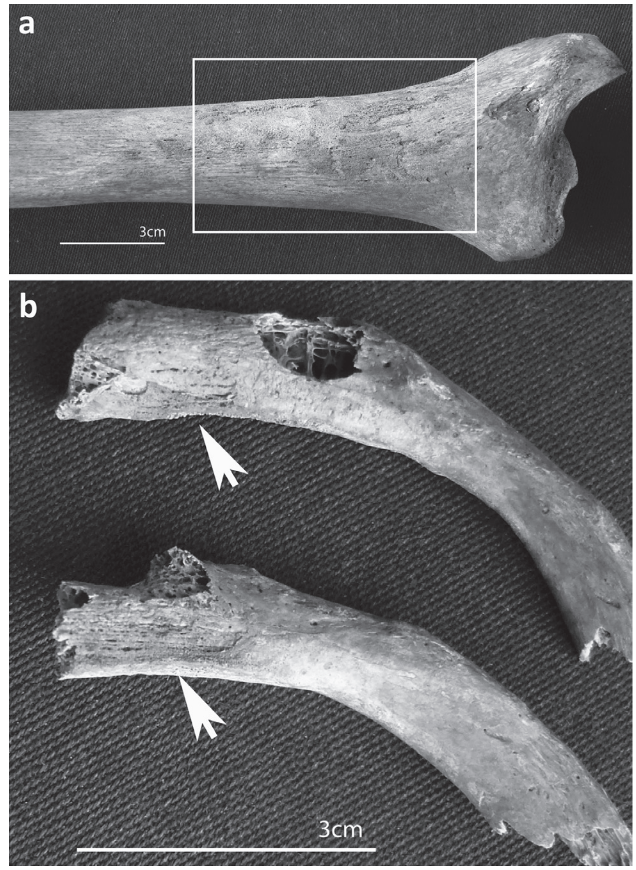

Figure 15. Illustration of pathological lesions that may be associated with disease: (a) periosteal new bone formation on the tibia (GR261-13); (b) periosteal new bone formation and necrosis on the visceral surface of ribs (GR145-4).

Prevalence was higher in group B than in group A overall and between 18 and 50 years old. Eighteen individuals also showed visceral rib lesions. This was significant for single depositions ($\chi^2 = 15.995$, df = 1, $p \leq 0.001$) and was observed in the multiple burials. Diffuse periosteal new bone was accompanied by new bone on the mandible in one individual, bowed long bones in one individual, and cribra orbitalia in five individuals. Four individuals showed a fracture, but not directly associated with periosteal new bone.

Periosteal new bone formation on the visceral rib surface was observed in 52 individuals (Table 3; Figs. 15b and 16) and consisted of woven bone or a mixture in 50 and lamellar bone in two single depositions. Visceral rib lesions are often related to pulmonary infections (Mays et al. 2002; Roberts 2000:151; Waldron 2009:117). The lesions were more common in males and between 12 and 25 years old. The fifteenth–sixteenth-century single depositions showed a higher prevalence between 12 and 25 years, which was significant ($\chi^2 = 20.993$, df = 5, $p = 0.001$). The other groups showed no clear age-related patterns; group A and

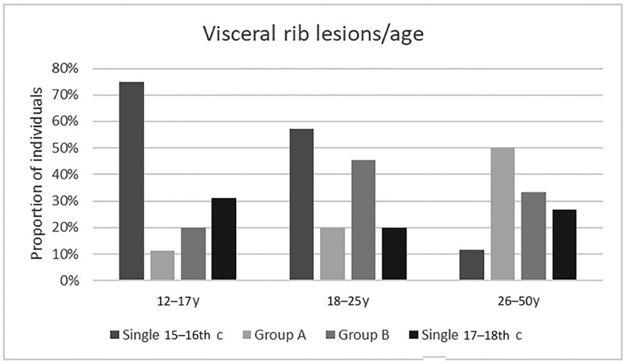

Figure 16. Histogram depicting the prevalence of visceral rib lesions among groups within age categories.

the seventeenth–eighteenth-century single depositions showed lower prevalences between 18 and 25 years, and group B showed an increase with age. Prevalence was higher in fifteenth–sixteenth-century single depositions than in group A, which was significant for the 12–17-year category ($\chi^2 = 9.420$, df = 1, Fisher's exact test: $p = 0.004$) and observed between 18 and 25 years, but a higher prevalence was observed in group A between 26 and 50 years old. Lesions were more common in group B than in contemporaneous single burials between 18 and 50 years old, and single depositions showed a higher prevalence between 12 and 17 years, without significant differences. Group B showed a higher prevalence than group A for males overall and between 12 and 25 years old, while the 26–50-year category showed a higher prevalence in group A.

Ten individuals showed lesions related to osteomyelitis, a bacterial infection of bone and bone marrow (Aufderheide and Rodríguez-Martín 1998:172–176; Ortner 2003:181–189; Waldron 2009:84–87). Periosteal new bone formation was associated with bone destruction or pus-draining cloacae in six individuals in the limbs or mandible and in four on the visceral rib surface. Three were observed in fifteenth–sixteenth-century single depositions and four in seventeenth–eighteenth-century single depositions. Three individuals were recorded in group B. There were no significant differences.

Discussion

Why were the multiple burials used?

The simultaneous burial of up to 12 individuals implies they died around the same time, indicating an elevated and possibly unusual mortality. Group A was dated to the second half of the fifteenth–early seventeenth century and showed a regular orientation of bodies, deposited in one phase. Group B was dated after A.D. 1640 and showed several phases of deposition and deviant orientations. The differences suggest different circumstances of death and burial. While group A reflects more abrupt episodes of elevated mortality, the phases in group B suggest extended periods of unusual mortality.

St. Rombout's cemetery could not be fully excavated, showed later disturbances, and not all individuals were buried here. The multiple burials were also interspersed among the traditional single burials, and it was not possible to identify all graves related to a particular episode. Since the assemblage was not representative, mortality quotients cannot provide a specific cause of death. Broad suggestions nevertheless can be made using mortality patterns, historical background, and pathological lesions.

The mortality profiles of both groups of multiple burials deviated from model life tables and contemporaneous single depositions (Fig. 5; Table 2). The mortality curves of the multiple burials of both groups presented a lack of individuals under 10 years old and a strong over-representation between 15 and 29 years. This pattern does not correspond with catastrophic mortality patterns. Nevertheless, the overrepresentation of adolescents and young adults deviated from an expected natural pattern of deaths, which denotes an unusual mortality. Comparison with a contemporaneous plague site and a hospital showed no similarities, which indicates different circumstances of death. Differences in the background and composition of these assemblages may also have influenced comparisons, although these factors could not be compared to historical documentation. The multiple burials from Mechelen demonstrated the greatest similarities with St. Benedict's parish cemetery. Both sites showed a main increase in probability of death in the multiple burials after 14 years, and group B displayed a similar strong rise for the 20–29-year interval. The overrepresentation of males observed in Mechelen was also present in St. Benedict's cemetery, where it may be related to its use as a burial ground for a monastery or military hospital. Multiple burials from the St. Petri-Kirchhof in Berlin also included mostly young individuals, but also children (Melisch and Sewell 2011).

The mortality profiles showed no indication for cause of death and deviate from known patterns. The absence of perimortem traumatic lesions implies that violence was not the cause, but famine or disease may have been responsible. Historical sources offer suggestions, with various famines and epidemics, including plague, smallpox, whooping cough, sweating sickness, and dysentery from the fourteenth century onward (Delafaille 1874). The years 1315 and 1316 were catastrophic, with a great famine and indications for a high death toll in Mechelen and the establishment of a subsidiary cemetery. The Black Death (1346–1351) had less impact, although later outbreaks apparently necessitated the establishment of a plague house outside the city in the fifteenth century (Depuydt et al. 2013).

The registers for St. Rombout's parish (1506–1796) do not mention multiple graves, but they do show occasional peaks in the number of burials. This pattern may be related to episodes of disease and famine or the tumultuous sixteenth century, which saw the Iconoclastic Fury (1566), the Spanish Fury (1572) and the English Fury (1580). The mean number of burials was around 80 per year in the sixteenth century, with peaks of 200–300. By the early eighteenth century, burials increased to 200 per year and later decreased to 160, while peaks continued to occur (Van de Vijver et al. 2018). These rates do not represent an overwhelming amount of deaths and indicate that multiple graves were likely not a common solution. Unfortunately, the broad dates of the burials do not allow associations with written sources.

Skeletal lesions showed no indications for cause of death. For the fifteenth–sixteenth century, periosteal new bone formation in general and a diffuse spread, which indicates disease, occurred more often in group A overall, in middle adults for general presence, and in adolescents for a diffuse spread. New bone formation on the visceral rib surface, suggesting infection, was more common in single depositions, although middle adults showed a higher prevalence in group A. For the seventeenth–eighteenth century, a diffuse spread of periosteal new bone presented a higher prevalence in single burials, while visceral rib lesions in adults were more common in group B. Group A showed no lesions associated with infection, while group B displayed the highest prevalence. Overall, adults and mainly middle adults showed higher prevalences of disease in multiple burials. The lesions showed no clear association with disease, and differences were mostly non-significant. The lesions represent long-standing illness and may be due to varied etiology (Roberts 2000:145).

A specific diagnosis can be difficult for periosteal new bone formation, which constitutes a reaction to varied conditions. The localized lesions may be due to trauma or a skin ulcer (Ortner and Putschar 1981:129–132; Weston 2008). When lesions are spread across different limbs, trauma is unlikely. The association of diffuse periosteal new bone and visceral rib lesions suggests infection or hypertrophic osteoarthropathy, a condition that results in symmetrical periosteal new bone formation, which can arise from any severe illness (Assis et al. 2011:155–157; Ortner 2003:354). Bowing of lower limb bones in one individual from group A indicates rickets, and accompanying periosteal new bone on the mandible suggests scurvy. Cribra orbitalia in five individuals suggests metabolic disease or infection. In four individuals, fractures could indicate secondary infection, although lesions were not directly associated. In most individuals, diffuse periosteal new bone formation could be associated with varied etiology, including inflammation, infection, scurvy, or hypertrophic osteoarthropathy. The observation of lime in burial 131 from group A suggests infection. Unfortunately, most acute epidemic diseases leave little or no osteological evidence. In most cases, death or recovery occurs before skeletal lesions can be observed. Not all infections affect the skeleton, and even when lesions are present they may not allow diagnosis (Cox 1993; Ortner 2007; Roberts 2000:145). These factors hinder the study of a cause of death.

Both groups showed an overrepresentation of adolescents and young adults, a lack of children, and a strong male overrepresentation. This profile implies a selection based on social roles, influenced by age and sex, in addition to the unusual mortality. The mortality curves of groups A and B also displayed differences. Group A presented a peak in the 15–19-year interval, and one multiple burial also contained two females. Group B presented a peak in the 20–29-year interval, a higher proportion of middle adults, and only males. The differences in age and sex composition between groups A and B highlight the different characteristics of the burials, with one or more phases and differences in orientation, which suggest different circumstances of death and a different background of individuals.

Aside from a large group of young males in the living population, the overrepresentation of males and young adults also suggests a military background. The similarities with St. Benedict's cemetery, particularly for group B, point to an association with the Spanish military hospital (1585–1715) located near St. Rombout's cemetery. It is possible that patients were buried in the churchyard, although historical studies have not confirmed this and pathological profiles do not indicate soldiers. There were no trauma patterns that might suggest an association with violence for one of the groups. Group A displayed a higher prevalence of cranial vault fractures, but group B showed the lowest overall prevalence. While radiocarbon dates indicate that both groups may overlap with the period of use of the hospital, group B showed the largest overlap in time. The burial characteristics, with several phases, are reminiscent of longer and recurring episodes of elevated mortality, which may be related to a hospital. The lack of females and slightly higher number of adults and more frequent evidence for infection, albeit non-significant, also suggest the military hospital could be a possible explanation for group B. Their deviant orientation also highlights these burials as a separate group and indicates a particular background or circumstances of death (Alexandre-Bidon 1993:190–191; Gilchrist and Sloane 2005:152–153). While an association with a hospital implies a group with a similar background and circumstances of death and burial, such as soldiers and dependent individuals, the coincident death of individuals would not necessarily be due to the same cause. Rather than trying to determine the exact cause of death, the study of differential funerary practices and socioeconomic background provides more information to interpret these burials. Group A, on the other hand, seems associated with more abrupt mortality crises and may be related to episodes of disease and famine among the parish population, for which there is ample historical evidence.

While a specific cause of death cannot be ascertained, the differences in construction, mortality patterns, and paleopathological profiles provide information to interpret the different circumstances in which these burials were created. They also indicate that the background of individuals may have influenced the choice of burial in both groups.

Socioeconomic background of the individuals in the multiple burials

The peak between 15 and 19 years observed in the single and multiple burials can also be linked to documentary evidence for a high proportion of young people in the living population. The economic migration of young people into towns during the medieval and post-medieval periods is a well-known trend, and it may have affected urban mortality profiles (Connell et al. 2012:10–11; Dyer 1998:192; Gilchrist 2012:53). A census from 1796 in Mechelen recorded an increase after 12–14 years, peaking between 25 and 29 years. The census further listed 32.8% of adults as immigrants (Piessens 2014). The higher proportion of adolescents and young adults and lack of children in the multiple burials, which was significant for group A, indicates both an unusual mortality and a selection based on age. The strong male overrepresentation implies that gender was also a factor. The differences between groups A and B, moreover, suggest a different *recrutement*, although they were not significant.

The life course in the medieval and post-medieval periods depended on social position and cultural patterns (Connell et al. 2012:169–170; Gilchrist 2012:1–4, 38-42; Shahar 1990). At the start of adolescence, between 12 and 14 years old, many people moved into other households to start work, often into towns as apprentices or servants (Alexandre-Bidon and Lett 1997; Hanawalt 1993; Heywood 2001). Adolescence could last up to 21–28 years old (Alexandre-Bidon and Lett 1997; Shahar 1990). An "extended adolescence" into biological adulthood has been proposed for medieval males (Gilchrist 2012:41–42; Hanawalt 1993:111). According to common law in Mechelen, based on a document from 1530, adulthood was reached at age 25 (Installé 1993:73). Osteological studies suggest this pattern could have been both social and biological, with a prolonged physical development (Gilchrist 2012; Lewis et al. 2015).

There was a generally high prevalence of injuries and lesions related to mechanical stress that appeared from a young age, indicating that this part of the population was exposed to physical stress and accidental injury. Group A showed higher prevalences of upper-limb fractures between 18 and 50 years old, and Schmorl's nodes and upper-limb enthesopathy between 12 and 17 years, compared to single depositions, although only upper-limb fractures showed a significant difference for the 18–25-year category. Other age categories showed higher prevalences in the single depositions. Group B displayed higher prevalences of upper- and lower-limb fractures in all age categories, vertebral fractures between 12 and 17 years and significantly more Schmorl's nodes and enthesopathy for individuals between 12 and 25 years compared to the single depositions, although older age categories showed higher prevalences in the single depositions.

Fractures are often more common in older age categories, related to the concept of an increased period of exposure and thus risk of fracture (Glencross and Sawchuk 2003). The development of entheseal lesions and Schmorl's nodes is also often associated with increasing age. A higher prevalence in young individuals, therefore, may be related to an increased risk and mechanical stress. Fractures showed an increase with age in the single depositions and group A, while group B showed higher prevalences in the younger categories, although these differences were not significant. A similar pattern was observed for enthesopathy, with higher prevalences in young categories in group B as opposed to an increase with age in the other groups. For enthesopathy of the upper limbs, group A showed a high prevalence between 12 and 17 years, while the highest prevalence was observed in the oldest category. In group B, upper-limb enthesopathy decreased with age. The different patterns suggest that young individuals in group B may have been more subjected to mechanical stress. Schmorl's nodes showed the highest prevalences in the 18–25-year category in single and multiple burials, suggesting mechanical stress from a young age in all groups. Although group A showed an increase with age for several types of lesions of physical stress, similar to the single depositions, the younger categories in group A did show some higher prevalences than the single depositions, although differences were only significant for upper-limb fractures. Group B showed more pronounced differences, both in the distribution over age categories and with higher prevalences for fractures of the limbs and significantly higher prevalences of Schmorl's nodes and enthesopathy. Considering the overall younger age distribution of group B, this pattern also suggests higher levels of mechanical stress. Significant differences were corroborated by strong deviations in the common odds ratios, indicating they were likely not related to differences in the age structure. Since the age distribution of group A was significantly younger than the single depositions, higher prevalences of Schmorl's nodes and upper-limb fractures may be related to mechanical stress.

Group B showed more indications for physical stress and injury than group A, with higher levels of lower-limb fractures, vertebral fractures, and Schmorl's nodes, but only significantly higher prevalences of enthesopathy between 12 and 25 years, although group A showed a higher prevalence of upper-limb fractures. The age distributions between the two groups of multiple burials showed no significant differences, despite slightly more older individuals in group B. While most differences were not significant, the recurring patterns may suggest higher levels of mechanical stress for group B.

The variations in enthesopathy for different joints suggests different activity patterns. Osteoarthritis, rib and vertebral fractures, and enthesopathy in middle adults showed a higher prevalence in single depositions, although only osteoarthritis showed significant differences. The association of trauma and osteoarthritis with age suggests that increased years of exposure could have been more important (Glencross and Sawchuk 2003). Most injuries were relatively minor and associated with accidents. The higher male prevalence is common for medieval and post-medieval urban populations (Connell et al. 2012; Grauer and Roberts 1996). The lesions suggest that individuals from group B, in particular, may have suffered higher levels of physical stress. However, while there are indications for physical stress from a young age in the multiple burials, and different activity patterns, there are no clear-cut differences between individuals from the multiple burials compared to the single depositions, particularly for group A. This result may be partly related to the fact that circumstances of death also influenced burial type and inclusion in multiple burials.

Group B showed a lower stature, which may be due to stress during growth, and a higher prevalence of enamel hypoplasia and cribra orbitalia than contemporaneous single depositions, but no significant patterns. Group A presented a significantly higher prevalence of enamel hypoplasia that the common odds ratio indicated was not related to differences in age structure, but had a lower prevalence of cribra orbitalia than single depositions. Bowing of lower leg bones was also more common in multiple burials, particularly in group B, which may be due to lifestyle and environment. Group B further showed a shorter stature and a higher prevalence of cribra orbitalia and bowed lower leg bones than group A, while group A displayed a higher prevalence of enamel hypoplasia, but without significant differences.

The mass graves in St. Mary Spital in London also showed a higher proportion of subadults compared to attritional graves. Individuals in the mass graves between A.D. 1120 and 1200 showed higher prevalences of stress indicators, including dental enamel hypoplasia, cribra orbitalia, and non-specific infection. Between A.D. 1200 and 1400 high rates were recorded in both attritional and mass graves. It is considered that the individuals in the mass graves from the first period were more susceptible to mortality crises because their health was affected by childhood stresses, which also may be relevant for Mechelen. In later periods, the entire population had suffered similar degrees of malnutrition and disease. The cemetery of St. Mary Spital was related to a priory and hospital that looked after the poor and sick. They could be buried in the cemetery, which included both clergy and lay people, rich and poor, and was also a subsidiary cemetery for St. Botolph's parish (Connell et al. 2012). This difference in background likely affects comparisons with Mechelen.

The differences between groups A and B in the prevalence of lesions do not resemble the chronological differences between the fifteenth–sixteenth-century and seventeenth–eighteenth-century single depositions. The higher levels of growth disturbances in groups A and B suggest stress during childhood and adolescence and appear more severe for group B, but differences are not clear. Group A also showed a higher prevalence of diffuse periosteal new bone than the single depositions overall and between 12 and 17 years old, which may be related to stress. The higher levels of growth disturbances for the multiple burials can be associated with lower age at death. This observation suggests that the individuals in multiple burials experienced increased morbidity and frailty, which may have made them more susceptible to epidemics or famine. Combined with evidence for physical stress, particularly for group B, a lower or different socioeconomic background than the single depositions is implied. The higher rates of mortality, along with some lesions related to disease and physical stress for individuals between 12 and 25 years old, particularly in the multiple burials, may reflect the hazards of employment and the vulnerability to disease of servants, apprentices, and immigrants (Lewis 2002). Age and sex composition and pathological profiles suggest that socioeconomic background may have influenced who was included in a multiple grave. Perhaps simultaneous burial was also related to motives to save money and therefore included individuals with a poorer and more dependent background.

The differences between the two groups of multiple burials, with a lower stature, higher levels of metabolic disease, physical stress, diffuse periosteal new bone formation, and infection in group B and higher levels of enamel hypoplasia and upper-limb fractures in group A, as well as different patterns when they were compared with the single depositions, suggest a different background and emphasize the different organization of the burials. To summarize, for group B, the differences in pathological profiles may reflect the different background of patients of the Spanish military hospital. For group A, the different funerary treatment of males between 12 and 25 years old may reflect the "extended male adolescence," with mostly young and dependent individuals.

Conclusion

While simultaneous burial indicates an elevated or unusual mortality, the patterns observed in the multiple burials from St. Rombout's cemetery indicate that considerations beyond a large number of dead influenced multiple burial. The demographic composition in both groups deviated from natural mortality patterns and contemporaneous single depositions, indicating both an unusual mortality and a social selection. Since it was not possible to identify all graves related to an episode of unusual mortality, mortality profiles could not be used to determine a specific cause of death. Paleopathological profiles showed that violence was probably not the cause of death, although disease or famine may have been responsible.

Paleopathological profiles showed higher levels of growth disturbances, physical stress from a young age, particularly for group B, and some lesions related to disease than the single depositions, associated with a lower age at death. Although differences were mostly non-significant and sample sizes were often very small, which hindered the observation of meaningful patterns, the recurrence of some patterns may reflect differences in socioeconomic background, with a lower and more dependent social position for the individuals included in multiple burials. Differences were more pronounced for group B, particularly for physical stress. Multiple burial was avoided if possible, and perhaps the burials are related to motives to save money and space during episodes of elevated mortality.

Differences between the two defined groups indicate different circumstances of death and burial. Group B, dated after A.D. 1640, may be related to the Spanish military hospital based on the characteristics of the graves, the demographic composition, and differences in pathological profiles. Unfortunately, historical studies have not confirmed the burial of patients in the churchyard, although this study suggests it may have occurred, although it was not possible to distinguish soldiers. Group A, dated to the late fifteenth–early seventeenth century, may be related to more abrupt episodes of disease or famine in the parish, comprising mostly young, dependent inhabitants such as servants and apprentices. Socioeconomic background and lifestyle may have resulted in a higher number of deaths among these individuals, as frailty may have made them more susceptible. Unfortunately, the difficulties in observing acute infections in skeletal remains and associating documentary sources make it impossible to identify specific crises.

The study shows that the multidisciplinary analysis of differential funerary practices associated with demographic and palaeopathological patterns provides important information for the interpretation of circumstances of death and burial and how socioeconomic factors influenced the choice of burial beyond the elevated mortality.

Acknowledgments

The research was funded by the Center for Archaeological Sciences at the University of Leuven (Program Financing of "Center for Archaeological Sciences 2"), and the analysis of the remains was carried out at the Royal Belgian Institute of Natural Sciences. The archaeology department of the city council of Mechelen carried out the excavation and offered important support. Wim Van Neer, Ronny Decorte, Caroline Polet, Dominique Castex, Frank Kinnaer, Brigitte Meijns, George Maat, Anton Ervynck, and Marc Lodewijckx offered helpful feedback. Dominique Castex and Hélène Réveillas kindly provided comparative data. I would also like to thank the reviewers for their suggestions to improve this article.

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