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SHORT REPORT

Examining Reactive Arthropathy in Military Skeletal Assemblages: A Pilot Study Using the Mass Grave Assemblage from the Battle of Towton (1461)

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Military personnel are often subjected to physical exertion, sleep deprivation, deficient diets, overcrowding, and stress. All of these influences are capable of compromising the immune system's ability to ward off disease-causing bacteria, thus explaining why the historical narrative of war is frequently accompanied by reports of death and suffering due to epidemics of infectious diseases. Historically some of the most common infections included: diarrhoea, dysentery, typhoid fever, gonorrhoea, and streptococcal tonsillitis. The bacteria which cause these diseases are also capable of triggering arthritis. When an arthritic condition is triggered by an infectious microbe it can broadly be referred to as "reactive arthropathy," of which the spondyloarthritides (SpAs) are of great interest. Since the bacteria associated with these arthritic conditions are responsible for the epidemics which have plagued combatants for centuries, it is reasonable to assume that reactive arthropathy was present in past military populations. This assertion can be tested through a prevalence study of military related skeletal assemblages. To test the methodology and gain preliminary results for this research project, a pilot study was carried out using remains from the 1461 Battle of Towton. The methodology was deemed to be sound and the statistical results, while not significant, were promising.

Introduction

The physical exertion, sleep deprivation, deficient diets, and stress (both environmental and mental) which combatants are subjected to reduces the ability of their immune system to ward off infectious organisms (Ekblom *et al.* 2011). Making matters worse, the various epidemiological backgrounds within a military group create the perfect scenario for epidemic disaster; soldiers are assembled and deployed into disease environments to which their immune systems are not acclimatized, making them more susceptible to unfamiliar pathogens (Smallman-Raynor and Cliff 2004). Further influencing the overall health of military combatants is the fact that wartime leads to overcrowding, unsanitary living conditions, the collapse of social infrastructures like healthcare facilities, and a breakdown of the normal rules of social conduct (Smallman-Raynor and Cliff 2004).

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The connection between the military lifestyle and infectious disease continues in spite of modern medical knowledge, but it can certainly be said that the impact of infectious diseases would have been greater among past combatants due to poor sanitation practices and limited treatment options. Diseases that were commonly found among past combatants included diarrhoeal diseases, venereal diseases, and laryngopharynx infections (Smallman-Raynor and Cliff 2004). These conditions are frequently triggered by bacteria, including: (diarrhoeal) *Salmonella enteritidis*, *Campylobactera jejuni*, *Yersinia enterocolitica*, *Shigella dysenteriae, Shigella flexneri*, *Escherichia coli, Salmonella typhi, Clostridium difficile,* (venereal) *Neisseria gonorrhoeae*, *Chlamydia trachomatis*, (laryngopharynx) *Streptococcus pyogenes*, and *Streptococcus pneumoniae* (Carter 2010; Chandran and Raychaudhuri 2010; Ehrenfeld 2012; Hannu 2011).

These bacteria are known to be arthritogenic, meaning they are capable of triggering an arthritic reaction. When an arthritic reaction occurs as a result of an infectious agent, the condition can be broadly labelled as reactive arthropathy. Of the various forms of reactive arthropathy, the spondyloarthritides (SpAs) are of great in relation to past military populations since they are linked to the bacteria previously mentioned as common among past combatants; Reactive Arthritis (ReA) is associated with the diarrhoeal and venereal bacteria and Psoriatic Arthritis (PsA) with streptococcal bacteria (Barton and Ritchlin 2005; Carter 2010; Chandran and Raychaudhuri 2010).

Since combatants have historically had a higher exposure and susceptibility to arthritogenic bacteria, it is reasonable to assume that the resulting conditions, such as SpAs, could be found in past military populations at a higher frequency than non-military populations. To test this assumption, a project was designed for a palaeoepidemiological prevalence study to be carried out on multiple military assemblages from conflicts of various centuries; these military assemblages would then be compared to control assemblages to identify if disease patterns differed due to contrasting lifestyles (military versus non-military). The first assemblage examined, the Towton assemblage, was utilized as a pilot study intended to: 1) compare a military and non-military assemblage for contrasting and/or consistent patterns in erosive conditions using simple statistics, 2) evaluate the effectiveness of the applied methodology, and 3) identify and modify issue with the designed methodology before applying it to larger assemblages.

Material: The Towton Assemblage

The War of the Roses (1455–1487) was a dynastic dispute between the House of Lancaster (Duke of Somerset) and the House of York (Duke of York). One notable battle occurred in 1461 outside the village of Towton. Chroniclers of the period recorded approximately 28,000 fatalities, but this figure is likely exaggerated based on archaeological research and closer examination of primary resources; a more accurate figure would likely be closer to 3,000 men (Sutherland 2009, 22; Boardman 2007). No matter the true number, the battle was won by the Yorkists and Edward IV became the King of England (Goodwin 2012).

In 1996, not far from the Towton battlefield, construction workers uncovered several sets of human remains in one mass grave (Fiorato 2007). At the end of the excavation, a total of 38 individuals were recovered (Boylston *et al.* 2007). The remains were examined by bioarchaeologists at the University of Bradford and they determined that the individuals were males aged 16–60+ (Boylston *et al.* 2007; Burgess 2007). There was a high prevalence of perimortem trauma (around the time-of-death) in the assemblage that would have been made by blades and blunt force (Novak 2007). The proximity to the battlefield, nature of the burial, biological profile of the remains, and archaeological artifacts all suggested that the skeletal remains were likely casualties of the 1461 Towton engagement (Burgess 2007).

The Men of Towton: Medieval Armies and Military Lifestyle

The early medieval period was the age of "feudal warfare," which means the primary method of enlisting men was through obligatory service. Vassals were obligated to devote 40 days of military service per year, without monetary return (Bentley 1997, 204; Goodwin 2012). This system meant armies were disorganized and made up of men with limited military experience (Goodwin 2012).

By the time the War of the Roses began in the 15th century, problems with military organization had improved greatly. Society was still loosely feudalistic (bastard feudalism), but improvements in "bureaucracy" and "techniques of literate administration" led to a more professional army (Goodwin 2012, 16). Emphasis on the importance of governmental administrations meant that one of the primary means of enlisting men in the late medieval period utilized legal contractual agreements where lords provided land or monetary reimbursement for a vassal's allegiance and military assistance upon request (Goodwin 2012, 124; Gravett 2002, 14). Many of these vassals would have been proficient military men with training, such as knights, mercenaries, and men-at-arms (who were often kept as retainers by nobles or knights) (Bell *et al.* 2013; Goodman 2006; Goodwin 2012). Outside of these contractual agreements, English commoners were also enlisted through active campaigning carried out by influential members of society (magnates, gentlemen, and religious leaders) who had the connections, wealth, and charisma needed to convince people to take up arms (Goodwin 2012, 18–19). In sum, the men who fought in the War of the Roses would have been from mixed social and economic backgrounds, with varied degrees of military experience.

Increased emphasis on contractual agreements amplified the ability to tax subjects on a large scale, which allowed military operations to become larger and more organized (Goodwin 2012, 17). Despite these new advantages, armies were still very expensive and difficult to supply for extended periods of time, so campaigns during the War of the Roses continued to be relatively short endeavors that occurred during the winter when farming was not at its peak (Goodwin 2012). This means that late medieval armies are unique when compared with modern standing armies; standing armies would have been placed under the strenuous conditions of the military lifestyle for extended periods of time, but medieval armies would have been exposed to these condition in short bursts. Though the period of exposure would have been shorter for medieval armies, the struggles would have been much the same: overcrowding, unsanitary/inadequate living conditions, and being undersupplied (Royle 2008). Indeed, fatal diseases did occur among armies during the War of the Roses. For instance in the summer of 1485, a highly fatal infection labeled as the "English sweating sickness" took hold across England. Whether this disease originated within the army is debated, but nearly 50 years after the outbreak of the disease, Polydore Vergil wrote that the disease first appeared in August of 1485 among the French mercenary army of Henry VII (Sadler 2013, 16; Smallman-Raynor and Cliff 2004, 81).

Suitability of the Towton Assemblage for a Pilot Study

Despite the fact that medieval armies do not fit the traditional concept of a standing army, issues such as overcrowding and unsanitary conditions were still recorded among 15th century armies, along with outbreaks of disease (Sadler 2013; Smallman-Raynor and Cliff 2004). For this reason, it was decided that examination of the Towton assemblage would still be appropriate. It was further speculated that this distinction would later prove to be an interesting comparison for the military assemblages obtained from 18th- and 19th-century conflicts. Outside of the historical background of this assemblage, the small number of individuals in the Towton assemblage made it ideal for a pilot study.

Material: Control Assemblage, Medieval All Saint's

Since there was no baseline prevalence of erosive arthropathies in 15th-century England, the medieval cemetery of All Saint's was selected as a control assemblage. The All Saint's church (1091–1539) was located just outside the York city walls and was in use throughout the entirety of the War of the Roses (1455–1487) (McIntyre and Bruce 2010). A total of 550 medieval burials were discovered during the excavation, and it was concluded that these remains represented a normal (non-military) population of the period (McIntyre and Bruce 2010).

No female skeletons were examined from the control assemblage since none were present in the Towton assemblage. The Towton remains were all adults or late adolescents (16–60+), so the pilot sample followed this pattern of age distribution in the selection of skeletal individuals for the study. Reports from previous research carried out by the University of Sheffield were used to create a list of all the male/questionably male skeletons that were estimated to be 16 or older. This list was then used to create a random sample of 35 individuals using Microsoft Excel. If there was disagreement with the reported age or sex once observed, it was excluded and another random number was selected. Pathology was identified and analyzed using the same criteria applied to the Towton assemblage.

Methodology

Identification of Pathology and Applied Statistics

Operational definitions were designed to categorize erosive arthropathies. These definitions and the references used to create them can be found in **Table 1**. Clinical and bioarchaeological research was utilized to create these definitions and the primary categorizations included: erosive arthropathy (EA), rheumatoid arthritis (RA), erosive osteoarthritis (Erosive OA), gout, spondyloarthritides (SpAs), reactive arthritis (ReA), psoriatic arthritis (PsA), and ankylosing spondylitis (AS). Use of these definitions throughout the study insured conformity in the identification of pathology.

Prevalence is the statistical measure of frequency used in this research (Waldron 2007). Prevalence is calculated by taking the number of individuals with the condition of interest and dividing it by the total number of individuals in the defined assemblage. For the purpose of this pilot study, prevalence was used to provide general figures of the total number and types of EA present among skeletal adults of the Towton and All Saint's assemblages that could then be compared. Statistical analysis utilized the Confidence Interval Analysis Software to calculate prevalence and provide 95 percent confidence intervals.

Inclusion in the Study

Identification of EA requires the presence of several skeletal elements for confident diagnosis. The typical method of inclusion into the study dictates that all of the skeletal elements used for diagnosis must be present (Waldron 2007). This method would produce a drastically underestimated prevalence of EA because a large number of skeletons would have to be excluded from the study; archaeological skeletons are rarely complete, meaning it is highly unlikely that all of the key skeletal elements needed for diagnosis of erosive conditions (feet, hands, spine, and pelvis) would be present (Roberts and Manchester 2010; Waldron 2007).

With these details in mind, a method for inclusion and exclusion into the study was developed. Rather than considering every element singularly in each skeleton, a method was designed to measure the preservation of the key elements as a whole. Skeletons were assigned to one of four potential categorizations: poor (the majority of the key elements were unobservable due to absence and/or

	OPERATIONAL DEFINITIONS
SpA	**Spondyloarthritide** The presence of three of the following: 1. Sacroiliitis (inflammatory changes or erosions) 2. Spinal bone formation not characteristic of trauma or conditions such as DISH 3. Enthesopathy (characteristic or in a minimum of 3 locations) 4. Asymmetric peripheral joint erosions
ReA	**Reactive Arthritis** 1. Asymmetric fusion of one or both sacroiliac joints, AND 2. Spinal fusion with skip lesions, AND 3. Asymmetric erosions of the small joints of the foot EXTRA: In addition to the above definition, entheses in the lower limbs and feet support the diagnosis of ReA; calcaneal spurs are particularly common. Clinical data suggests erosions in the large joints of the lower extremities, such as the knee, can also be observed in some clinical cases.
PsA	**Psoriatic Arthritis** 1. Sacroiliitis, AND 2. Spinal fusion with skip lesions, AND 3. Erosions in the distal interphalangeal joints of hands and/or feet, with lysis of distal tufts in hands EXTRA: In addition to the above definition, involvement of the cervical spine has been recorded. Entheses are more likely to occur in the upper extremities. The phalanxes may display a change in shape known as telescoping and the "cup in pencil" deformity is characteristic of PsA.
AS	**Ankylosing Spondylitis** 1. Symmetrical fusion of both sacroiliac joints, AND 2. Continuous spinal fusion; no skip lesions EXTRA: Erosions may be present in the spine. AS is focused in the axial skeleton, but the shoulder and hip are common locations to observe peripheral erosions. Osteoporosis of the spine can be a feature of AS.
EA	**Erosive Arthropathy** 1. Presence of joint erosions, BUT 2. The skeleton lacks the features needed for assignment to a more specific classifications
RA	**Rheumatoid Arthritis** Meets all of the following criteria: 1. Symmetrical marginal erosions of small joints of hands and/or feet, 2. Minimal new bone formation, 3. No involvement of the SIJ 4. Absence of spinal fusion EXTRA: Osteoporosis may be evident in affected joints.
Erosive OA	**Erosive Osteoarthritis** 1. Presence of eburnation in any of the joints of the hand, AND 2. Asymmetrical central erosions of the proximal-interphalangeal or distal-interpalangeal joint(s) of the hands. 3. No SIJ involvement 4. No spinal fusion

Contd.

OPERATIONAL DEFINITIONS	
Gout	Meets all of the following criteria: 1. Asymmetric erosions in articular or para-articular tissues, 2. Absence of osteoporosis in the affected joint(s) 3. Erosions are often accompanied by a Martel hook (overhanging margin) EXTRA: Ankylosis is not a characteristic feature of gout. Erosions are usually round and may have sclerotic edges. Common locations include the feet, ankle, knee, hands, and wrists.

Table 1: This table provides the operational definitions used within this research project. The organization of the definitions are based on Waldron 2009, but the content includes information from an extensive examination of clinical (Carter 2010; Chandran and Raychaudhuri 2010; Dhir and Aggarwal 2013; Ehrenfeld 2012; Ezzat *et al.* 2013; Hannu 2006; Hannu 2011; Jacobson *et al.* 2008; Kleinert *et al.* 2007; Toivanen 2007; Van Tubergen and Weber 2012) and bioarchaeological literature (Aceves-Avila *et al.* 2001; Arriaza 1993; Blondiaux *et al.* 1997; Hacking *et al.* 1994; Inoue *et al.* 2005; Inoue *et al.* 1999; Martin-Dupont *et al.* 2006; Mckinnon *et al.* 2013; Rogers *et al.* 1991; Rothschild *et al.* 1999; Rothschild *et al.* 1990; Rothschild and Heathcote, 1995; Rothschild and Woods 1991; Šlaus *et al.* 2012; Tersigni-Tarrant and Zachow 2010; Waldron 2009; Waldron *et al.* 1994; Waldron and Rogers 1990; Zias and Mitchell 1996). Source: created by author.

poor preservation, elements present <45 percent); moderate (approximately half of the key elements were observable, but absence and/or poor preservation was still considerable, key elements present 46–65 percent), good (the majority of the key elements were observable, elements present 66–85 percent), and excellent (a near complete skeleton, key elements present >86 percent).

Assigning skeletons to these categories allows the data to be analyzed in levels. A "comprehensive" prevalence would consider all of the skeletal material in the defined population (adult males/males?) regardless of their completeness; this measure certainly underestimates the true prevalence since it assumes all of the missing elements did not have evidence of erosive pathology. Critical analysis would exempt skeletons without relevant erosive pathology assigned to the "poor" or "poor" and "moderate" categories. This analysis accepts that there is an increased probability of underestimating the prevalence when skeletons with a low percentage of observable elements are included in the study, but decreases the probability of underestimating the prevalence if only categories with a high percentage of observable elements are allowed into the study. This method of dealing with missing elements does not eliminate the issue of prevalence underestimation, but it is a critical method that is more inclusive than the alternative and is capable of providing comparable results.

Age Estimation

Currently the best method of ageing adult skeletal material is to have a multifactorial approach which uses several methods to determine a likely age range (Bedford *et al.* 1993). The key features examined for age estimation in this study were: epiphyseal fusion (only an option in young adults, based on McKern and Stewart 1957), dental attrition (compared to Brothwell 1981), changes to the pubic symphysis (using Brooks and Suchey 1990), and changes to the auricular surface of the pelvis (using Lovejoy *et al.* 1985). After comparing the ages assigned by the various methods, individuals were placed into one of four potential categorizations based on ten year increments, which were: Young Adult (16–25), Lower Middle Adult

(26–35), Upper Middle Adult (36–45), and Mature Adult (46+).

Sex Estimation

As with age estimation, sex estimation was done with a multifactorial approach. Both morphological and metric data was utilized. The human skull and pelvis express the largest amount of sexual dimorphism, so these morphological features were accessed using Buikstra and Ubelaker (1994). Sex was also determined through consideration of metric measurements. The primary measurements taken were the maximum diameter of the femur head (FHD1) and the maximum diameter of the humeral head (HuD1) (Bass 1971). Measurements >46.5 mm were considered to be male, unknown between 43.5–46.5 mm, and female in measurements <43.5 mm.

Findings in the Towton Assemblage

Overall, 6 skeletons had EA (3 unspecifiable EA, 3 SpAs). The skeletons assigned to the SpA categorization were of particular interest. The SpA skeletons shared characteristics commonly observed in ReA, but not to the extent that they fulfilled all of the criteria needed to meet the ReA operational definition. Nevertheless, they provided enough evidence to strongly suggest the pattern of the condition's course had it been able to continue its development. Though they cannot be categorized as ReA, the amount of supporting evidence indicated that some informal categorization beyond the general SpA classification should be used. These cases were thus identified as "Early ReA", which simply delineates that these skeletal individuals seem to follow the patterning of ReA more than the alternative SpAs. The following sections provide a brief description of all the EA observed in the Towton assemblage.

Unspecifiable EA: Towton 25, 41, and 50

Towton 25 had two erosions. The first erosion was on the right first metatarsal on the distal end, medial surface. This erosion was para-articular, round, and deep. The walls were made of thickened and smooth trabecular bone. The second erosion was on the right scaphoid. This erosion was round and marginal, with uneven scalloped margins. The interior surface of this erosion exposed irregular and dense trabecular bone. These characteristics were not enough to clearly understand the nature of these erosions.

The skeleton of Towton 41 had erosions on the distal end of the right fifth proximal phalanx. These erosions were marginal and made of irregular bone on the para-articular lateral surface. This was the only location where erosions were observed, but the erosive changes were extensive and eroded enough bone to distort the natural shape of the joint margin. Once again, these erosions were not characteristic enough to be categorized beyond the EA categorization.

Towton 50 was the last skeleton to have unspecifiable EA. Two of the erosions were suspect since they were not characteristic of what is normally observed in EA or pressure lesions such as bunions. These lesions occurred on the distal end of the right and left first metatarsals on the medial surface. The holes were deep and round in shape with the interior walls being made of dense trabecular bone. The lesion on the left metatarsal had an overhanging bridge of bone around the margin, but it did not appear to be a Martel hook as would be seen in gout. Though these mystery lesions could not be easily identified as true erosions, clearly defined erosions were also present. The first true erosion was observed on the superior surface of the right navicular. Finally, erosions were observed on the distal end of the left second proximal phalanx and affected the margins of both the medial and lateral surface and was accompanied by subcortical resorption on the joint surface.

SpAs: Towton 8, 9, and 13

The first skeleton fitting with the SpA classification was Towton 8 (see **Fig. 1**), which had several foot erosions, characteristic bone formation in the feet, and sacroiliac joint involvement. The focus of the erosions and bone formation in the feet is suggestive of

Figure 1: Pictured and labeled above are examples of the erosions, bone formation, and sacroiliitis observed in Towton 8 which led to the diagnosis of "SpA" and "Early ReA". Entheses can be seen in the fifth metatarsal and erosions were observed in the right navicular, left fifth proximal phalanx, left fourth intermediate phalanx, and right sacrum. The sacrum images show marginal erosions (above) and subcortical erosions (below). Source: photos taken courtesy of BARC, arranged by author.

ReA, but minimal spinal involvement and lack of sacroiliac joint fusion prevented confident diagnosis based on the operational definition. Two vertebrae (L1 and S1) both had para-vertebral bone formation that seemed more characteristic of ossification of ligamentous tissue than the marginal osteophytes observed in spinal degeneration; the surface of the vertebral body did not show pitting and the bone growth originated inferior to the joint's true margin. The foot erosions affected numerous elements, including: the distal end of the left fifth proximal phalanx (also associated with ankylosis of the distal interphalangeal joint), the distal end of the left fourth intermediate phalanx, the distal end of the left first proximal phalanx, and the inferior margin of the right navicular. In addition to these erosions, both the right and left shaft of the fifth metatarsals had ReA-characteristic entheses associated with the plantar interossei muscle. Lastly, there was unilateral sacroiliitis of the right sacroiliac joint, which was defined by: marginal erosions on the sacrum (superior), an area of subcortical resorption on the joint surface, and lipping suggestive of early ossification of the anterior sacroiliac ligament.

Towton 9 also fit the SpA classification (see **Fig. 2**) and was characterized by: extensive lower limb enthesopathy, asymmetric fusion of three consecutive thoracic vertebrae (T6-T8), ligamentous ossification in T9 –T12, sacroiliitis, and small erosions in the feet. The lower limb enthesopathy and small erosions in the feet are characteristic of ReA, but the spinal fusion did not have observable skip lesions (unfused vertebrae separating segments of fused vertebrae). Though there were no skip lesions, the pattern of ligamentous ossification in several other vertebrae suggested that further fusion may have eventually occurred. Though sacroiliac joint fusion was not observed in Towton 9, bilateral sacroiliitis was present and defined by enthesopathy of the anterior sacroiliac ligament and a thin layer of porous bone growth on the joint surface.

The final SpA identified was Towton 13 (see **Fig. 3**). The features used to categorize Towton 13 were: enthesopathy (primarily in the lower limbs), left and right para-vertebral

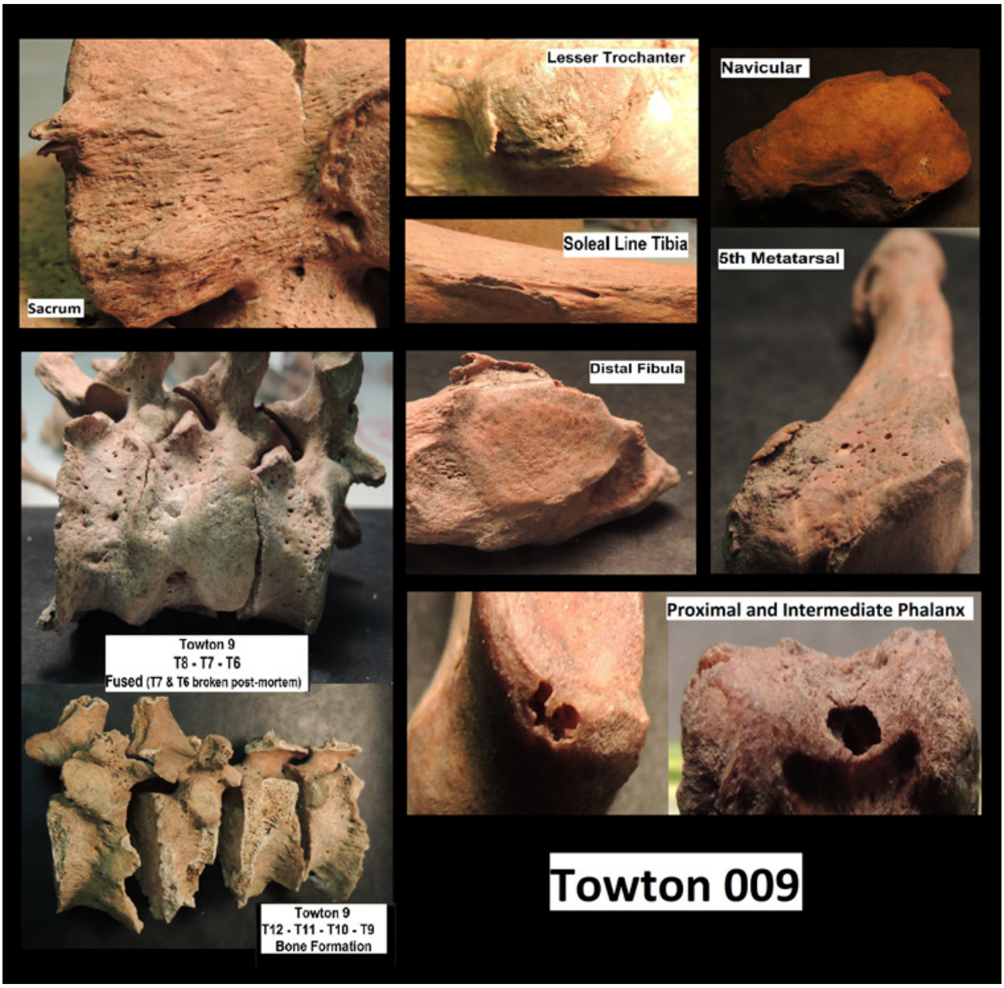

Figure 2: Pictured and labeled above are examples of the erosions, spinal fusion, bone formation, and sacroiliitis of Towton 9 which led to the diagnosis of "SpA" and "Early ReA". Enthesopathy shown in this image includes the anterior sacroiliac ligament in the left sacrum, the lesser trochanter of the femur, soleal line of the tibia, the distal fibula, tubercle of the fifth metatarsal, and the navicular. Erosions affected a proximal and intermediate phalanx of the right foot. Fusion in T6-T8 vertebrae and ligamentous growth in the T9-T12 vertebrae was also observed. Source: photos taken courtesy of BARC, arranged by author.

ligamentous ossification in several thoracic vertebrae (T7 –T12) suggestive of eventual fusion, sacroiliitis, and small erosions in the feet. Once again, lower limb enthesopathy and erosions are a distribution pattern seen in ReA. This pattern was observed in Towton 13 apart from entheses on the humeri. The erosions observed in Towton 13 occurred in the left foot, including the distal end of the first metatarsal and the distal end of the second proximal phalanx. Though there was no spinal fusion in Towton 13, ligamentous growth was observed in the left and right para-vertebral position and was suggestive of eventual fusion most characteristic of ReA or PsA; the position of the bone growth observed in the spine is not characteristic of the anterior fusion seen in cases of AS and was

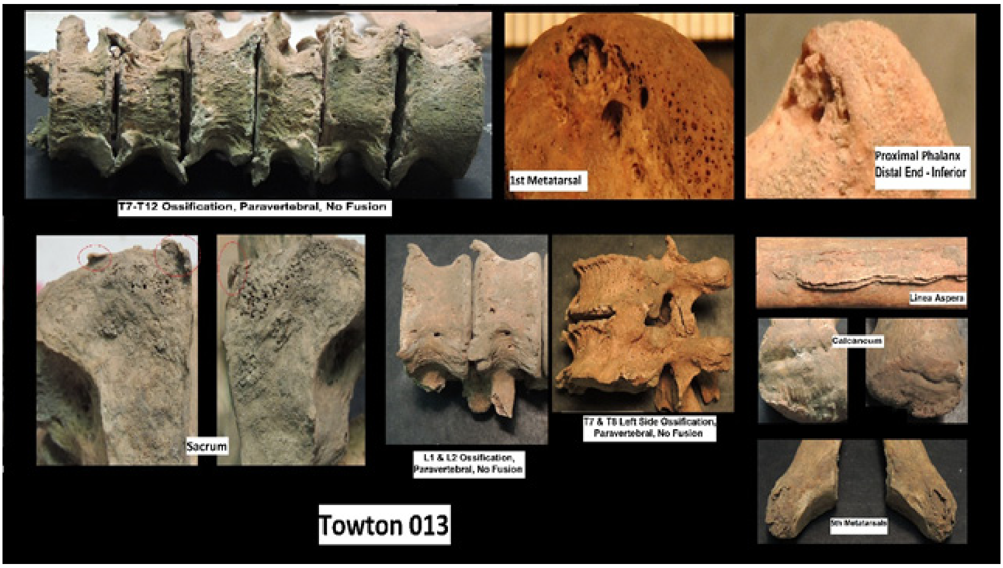

Figure 3: Pictured and labeled above are examples of the erosions, bone formation, and sacroiliitis of Towton 13 which lead to the diagnosis of "SpA" and "Early ReA". Though there was no spinal fusion, there was well developed ligamentous growth observed in the thoracic and lumbar spine. Sacroiliitis was also present in both the left and right sacroiliac joint. Enthesopathy was observed in numerous locations, including the linea aspera in the femur, calcaneum, and tubercles of the left and right fifth metatarsals. Erosions were observed in the left first metatarsal and the left second proximal phalanx. Source: photos taken courtesy of BARC, arranged by author.

not characteristic of the bone growth seen in Diffuse Idiopathic Skeletal Hyperostosis (DISH), which is confined to the right side in the thoracic region of the vertebral column (Waldron 2009). The sacroiliac joint was not fused in Towton 13, but sacroiliitis was present and defined by bilateral growth in the anterior sacroiliac ligament and pitting on the joint surfaces.

Findings in the Control Assemblage

Two of the control skeletons had spinal fusion (2705 and 3114), but one of them (2705) lacked any other pathology. The second skeleton did have evidence of being an EA, possibly SpA.

Skeleton 2705

The spinal fusion observed in 2705 was uncharacteristic of DISH because skip lesions were present; thoracic vertebrae T6-T8 were fused in the right paravertebral position, T9-T10 were unfused, and T11-L1 were fused in the right and left paravertebral position. A SpA would explain the observed pathology of the spine in skeleton 2705, but erosions, enthesopathy, and sacroiliac joint involvement were all absent. Since no pathology was observed outside of the spinal involvement, skeleton 2705 could not be classified as any form of EA.

Skeleton 3114

The problem of a SpA diagnosis in skeleton 3114 is a mix of contradicting characteristics, post-mortem damage to the spine, and moderate preservation (the majority of the left hand and all off the left foot were absent). Skeleton 3114 exhibited extensive spinal fusion, one foot erosion, upper and lower limb enthesopathy, and extensive sacroiliitis.

The observed spinal fusion was confined to the right side and involved T5-L1. The fusion in the thoracic and lumbar vertebrae

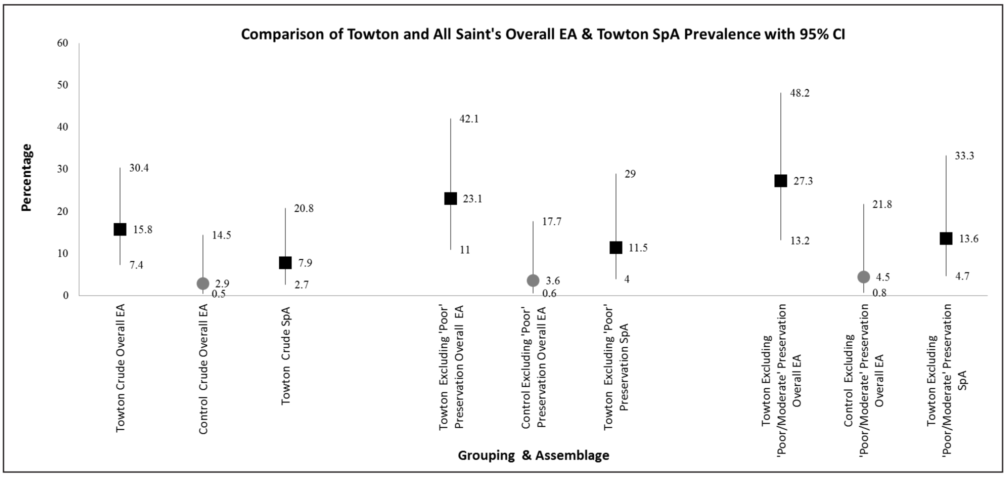

Figure 4: This table compares the data from the Towton (black squares) and All Saint's (gray triangles) assemblages. Towton had more examples of overall EA; 6 skeletons, 3 of which were classified as SpAs. The control assemblage had 1 skeleton with EA which could possibly represent a SpA. The confidence intervals overlap, meaning the results are not statistically significant, but this may be due to the small number of individuals.

appeared to have been continuous, but post-mortem fragmentation made it impossable to determine if this was truly the case. If continuous para-vertebral fusion could be confirmed, then DISH would be considered a reasonable explanation for the observed spinal pathology, but there are other features of the spinal bone growth that are uncharacteristic of DISH as well. The spinal bone growth of skeleton 3114 was not limited to the ligament, but had spread onto the joint surface in some of the vertebral bodies, which is not a feature of bone formation in DISH (Resnick 1996), but can be a feature of SpAs (Waldron 2009). Though sacroiliac joint fusion has been reported in DISH (Waldron and Rogers 1990), inflammatory changes (sacroiliitis) are not normally linked to the condition (Resnick 1996). The presence of sacroiliitis in skeleton 3114 in addition to the questions of the spinal fusion made DISH a questionable diagnosis and suggested that SpA may be a more satisfactory explanation for the observed pathology, but there is also the question of the erosions located on the distal end of the right fifth metatarsal. These erosions had clear undercut edges with exposed trabecular bone, but they were not marginal. The erosions occurred on the articular surface, which is a characteristic feature of gout. The presence of erosions in combination with the other pathology seems suspiciously in favor of a SpA, but it is not impossible for the individual to have had DISH and gout simultaneously, making the arthropathy of skeleton 3114 highly complicated. Though an argument could be made for a SpA categorization (spinal fusion of a questionable nature, enthesopathy, sacroiliitis, and erosions), skeleton 3114 was classified as unclassifiable EA since this would account for both gout and SpA.

Prevalence Analysis and Discussion

The results of the prevalence analysis for both assemblages can be seen in **Table 2** and **Fig 4**. In **Table 2** it should be noted that any conditions not mentioned were absent (prevalence 0 percent). Since the pathology observed in control skeleton 3114 was debatable, if one chose to analyse it as a SpA instead of EA, the prevalence would be the same as currently presented in **Table 2**; both n and N would be the same. For this same reason, **Fig 4** not only compares the overall EA statistics for Towton and the control, but

Prevalence of Erosive Arthropathy in the Towton Assemblage

Broad Classifications	Grouping	n	N	Prevalence (95% CI)
Overall EA (including SpA)	"Comprehensive Prevalence"	6	38	15.8% (7.4–30.4)
	Excluding "Poor" Preservation	6	26	23.1% (11.0–42.1)
	Excluding "Poor/Moderate" Preservation	6	22	27.3% (13.2–48.2)
EA (excluding SpA)	"Comprehensive Prevalence"	3	38	7.9% (2.7–20.8)
	Excluding "Poor" Preservation	3	26	11.5% (4.0–29.0)
	Excluding "Poor/Moderate" Preservation	3	22	13.6% (4.7–33.3)
SpA	"Comprehensive Prevalence"	3	38	7.9% (2.7–20.8)
	Excluding "Poor" Preservation	3	26	11.5% (4.0–29.0)
	Excluding "Poor/Moderate" Preservation	3	22	13.6% (4.7–33.3)
Specific Classifications	**Grouping**	**n**	**N**	**Prevalence (95% CI)**
"Early" ReA	"Comprehensive Prevalence"	3	38	7.9% (2.7–20.8)
	Excluding "Poor" Preservation	3	26	11.5% (4.0–29.0)
	Excluding "Poor/Moderate" Preservation	3	22	13.6% (4.7–33.3)

Prevalence of Erosive Arthropathy in the Control Assemblage

Broad Classifications	Grouping	n	N	Prevalence (95% CI)
Overall EA	"Comprehensive Prevalence"	1	35	2.9% (0.5–4.5)
	Excluding "Poor" Preservation	1	28	3.6% (0.6–17.7)
	Excluding "Poor/Moderate" Preservation	1	22	4.5% (0.8–21.8)

Table 2: This table shows the prevalence of erosive conditions in the Towton and All Saint's assemblages.

also the data for the SpAs identified in the Towton assemblage.

The confidence intervals overlap in **Fig 4**, meaning the results are not statistically significant, but the small sample size has expanded the 95 percent confidence intervals making the table a bit deceiving. Though not significant, the prevalence is still notably higher in the Towton assemblage; over five times that of the control sample. The presence of six skeletal individuals (15.8 percent prevalence) fitting the criteria for an "overall

EA" classification in the Towton assemblage is a striking figure compared to the control which had only one skeleton (2.9 percent prevalence) fitting the defined criteria.

As mentioned in the methodology section, preservation was considered as a means of including and excluding skeletons from the study. These figures are also presented in **Table 2**. Considering the "overall EA" figures for Towton and the control group, Towton's lowest possible accounting of individuals has a prevalence of 27.3 percent and the highest accounting would be 15.8 percent. The control's lowest possible accounting of individuals would be a prevalence of 4.5 percent and the highest possible accounting would be 2.9 percent. This equals a difference of 12.9–22.8 percent between the two assemblages.

The Towton assemblage had three skeletons fitting the criteria for a SpA classification with the lowest possible accounting of individuals being 13.6 percent, and the highest possible accounting being 7.6 percent. This is also a prominent figure when compared to the control. Even if we entertain the idea that the EA found in the control sample was indeed a SpA (not gout combined with DISH), the comparative prevalence would be 4.5 percent with the lowest possible accounting and 2.9 percent with the highest accounting. This equals a difference of 4.7–9.1 percent for the "SpA" classification of the two assemblages. Of comparative interest, Arriaza 1993 reported a similar SpA prevalence of 4.4–7.4 percent in a skeletal assemblage from Chile; Arriaza noted that this was a high prevalence which could indicate that the population was prone to outbreaks of infectious diseases.

Of the three skeletons with unspecifiable EA in the Towton assemblage, none appeared characteristic of gout or erosive OA, which are the only forms of EA that are not reactive suspects; therefore, all of the EA observed in the Towton assemblage may have been reactive to bacterial triggers. Being more cautious, the skeletons classified as having SpAs can certainly be considered as reactive based on modern clinical research (Carter 2010; Chandran and Raychaudhuri 2010; Ehrenfeld 2012; Hannu 2011). Taking this a step further, the spinal fusion, pattern of erosions, and distribution of enthesopathy in the Towton SpAs appeared to be most characteristic of ReA. If these instances were indeed underdeveloped ReA, a list of potential bacterial triggers could be provided, which would include bacteria of the Urogenital (*Chlamydia* and *N. gonorrhea)* and Gastrointestinal (*Salmonella enteritidis, Campylobactera jejuni, Yersinia enterocolitica, Shigella dysenteriae, Shigella flexneri, Escherichia coli* and *Clostridium difficile*) variety (Carter 2010); therefore, the presence of such pathology provides an idea of the potential diseases this group of combatants potentially encountered at some point during their military service. This is an interesting line of reasoning since these bacterial diseases do not cause direct skeletal changes and are infrequently discussed by bioarchaeologists for this reason (Roberts and Manchester 2010; Waldron 2009), but SpAs provide an indirect method of discussing these infections in skeletal material. For instance, the results from the Towton assemblage supports what was already suspected according to clinical research and historical documentation, that at least some of the bacterial agents which trigger SpAs were present in military populations as far back as the 15th century.

An interesting pattern which emerged from this pilot study was a bias for individuals with EA to fall into the "Upper Middle Adult" category. Towton 50 was unable to be assigned an age beyond "Adult", but of the remaining skeletons with relevant pathology, 4 were Upper Middle Adults and 1 was a Lower Middle Adult. In the control assemblage, the 1 confirmed EA was also an Upper Middle Adult. This pattern may or may not continue in collections yet to be examined, but the pattern is markedly established in the Towton assemblage. A potential explanation for this pattern is that the older individuals may have contracted a bacterial agent earlier in life, which would mean the disease had more time to cause observable changes to the skeleton.

Conclusions: Methodology and Statistics

The operational definitions fulfilled their intended purpose of providing both general data about EA (the EA and SpA categorizations) and specific data (the RA, ReA, PsA, and AS categorizations). This pilot study has shown that the use of general categorizations are necessary for thorough analysis of erosive arthropathy, as most skeletons will not have the exact criteria needed for confident diagnosis of specific erosive conditions; in some instances, this is due to poor preservation, but another explanation could be a matter of how long the individual was affected by the erosive condition. Though the operational definitions designed for this research were efficient, one addition was made. Some of the cases which could not be assigned to specific categorizations still expressed enough distinctive characteristics to suggest their potential pattern of progression, so informal descriptions such as "Early ReA" were added to the vocabulary used within this project.

Age categorizations satisfactorily identified patterns in disease distribution (preference towards the "Upper Middle Adult" categorization), so no changes were made. The method of inclusion into the study designed for this research project was also satisfactory; it is more inclusive than traditional methods but it still provided comparable figures. Overall, the designed methodology utilized for this pilot study proved to be an efficient way of collecting and analyzing data about EA in the past.

Comparing the data of Towton with other military and non-military assemblages will be the ultimate path to identifying reliable patterns in disease behavior and presentation. For instance, medieval warfare did not utilize the large standing armies that became the norm in later history, so this may prove to be an interesting comparison with the assemblages being examined from the 17th and 19th centuries; does the prevalence increase over time? Though these comparisons are promised after further analysis, the pilot study using the Towton assemblage has already provided some interesting results. While the prevalence of the Towton assemblage was not statistically significant when compared to the control assemblage, a general inspection of the results showed that the prevalence of the Towton assemblage was five times higher than that of the control. Despite the lack of statistical significance, the higher prevalence of the Towton assemblage indicated that further investigation should be carried out on larger assemblages where the results would not be skewed by a small denominator. Further investigation of larger military assemblages is currently underway.

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