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TITLE: Adult fracture patterns in prehistoric Thailand: a biocultural interpretation

SHORT TITLE: Fracture patterns in prehistoric Thailand

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Abstract

The prevalence and distribution patterns of trauma in samples of human skeletal remains can reflect the risks to which the community was exposed in daily activities or as a result of interpersonal violence. This paper describes the patterns of non-vertebral fractures in skeletal samples from four prehistoric Thai sites in terms of long bone fracture rates and individual prevalence rates. The sites range in date from c. 2000 BC (Neolithic) to 400 BC (late Bronze Age) and in environment from coastal estuarine to seasonally dry upland plains. These differences in the natural and cultural environment provided a basis for comparison among the samples representing nearly 300 adult individuals. The types of fractures ranged from simple to severe but most had healed successfully with few limiting complications. The small bones of the hands and feet as well as clavicle and forearm bones were most frequently fractured among all samples. Overall there was an increase in the major long bone fracture rates from the Neolithic (0.3%) to the Bronze Age (3.0%) that may reflect a change in subsistence activities such as land clearance for the intensification of rice agriculture. The prevalence of ulnar fractures is particularly high in the Bronze Age and the analysis of their possible cause, combined with evidence for craniofacial fractures, is suggestive of the presence of interpersonal violence in a small number of individuals.

Introduction

The assessment of trauma can provide information about an individual's relationship with their physical and cultural environment, and observations over an entire skeletal sample can provide information about a population's exposure to risk and provide a basis for comparison among populations (Larsen, 1997; Jurmain, 1999). A number of studies have, in the past decade or so, significantly advanced research on fractures in prehistoric populations (for example Merbs, 1989; Roberts, 1991; Lovell, 1997). The biocultural interpretation and comparison of fracture patterns in prehistoric populations, rather than the analysis of isolated traumatic pathologies, can be particularly informative at the population level (for example Lovejoy & Heiple, 1981; Kelley & Angel, 1987; Grauer & Roberts, 1996; Judd & Roberts, 1998; Alvrus, 1999).

Lovell (1997) recommends classifying fractures according to their predominant characteristics. In this way a single cause is not immediately inferred before all possible evidence is considered. For example, labeling an ulna fracture as a 'parry' fracture immediately implies a violent causation that is not necessarily true of all ulnar fractures. There are many different causes for these, including falls, which are the most frequent cause in modern populations (Rogers, 1992). By systematically analysing the patterns and types of fractures in a skeletal sample significant information may be derived concerning the cause of the fracture and the subsequent effect of the injury on the individuals and the population. Lovell (1997) provides a descriptive protocol for assessing fracture healing success. It includes recording the maximum length of the bone, the apposition of the fracture ends, the degree of rotation, and the degree of angulation of bone at the fracture site (Lovell, 1997). These details assist in the interpretation of such aspects as the quality of healing and complications associated with fractures.

The clinical literature details the extensive array of fractures possible, their cause, and potential complications (Bucholz & Heckman, 2001). Fractures are generally the result of an accident or intentional violence (Roberts & Manchester, 1995). Some individuals may be more predisposed to fracture through an underlying pathological condition such as osteoporosis. This is one of the more common predisposing conditions but infection, developmental abnormalities, and Paget's disease (Springfield & Jennings, 1991; Aufderheide & Rodriquez-Martin, 1998) may also predispose an individual to fracture by weakening the bone.

In this interpretation of the patterns of trauma in Southeast Asian prehistory, adults from four samples from two different regions and three different cultural time periods are studied. This geographic and temporal variation provides an opportunity to examine fracture patterns in relation to both the natural and cultural environment in order to interpret evidence using a biocultural approach. This paper aims to describe the fracture patterns within the samples and compare them between regions and over time. The regions considered are coastal and inland riverine environments. Despite the physical differences in these locations and therefore in lifestyle of the inhabitants, there is no reason to believe either environment was more physically demanding with a higher risk for fracture. Therefore it is hypothesised that there will be no difference in fracture rates between regions, although the patterns of bones affected may differ. The cultural periods considered range from Neolithic through to the Bronze Age. During these periods there were changes in both the natural environment and in social organisation. There was land clearance in association with the agricultural intensification of rice, increasing sedentism, and associated increasing population density (Higham, 2002). These factors may have led to increased competition for resources and possible interpersonal violence either between or within communities. It is hypothesised that fracture rates would increase over time, mainly from accidents but also possibly from competition.

In order to achieve these aims, the characteristics of each fracture are determined first. This involves (1) describing the fracture in the terms defined above following Lovell (1997), (2) detailing possible complications and (3) determining the possible cause of the fracture. The pattern of trauma in each sample is then described, including the distribution within the skeletons and prevalence by sex and through the calculation of fracture rates for bone elements. In order to determine the significance of rates and patterns of fractures, comparisons will be made with other Asian and worldwide samples. The hypotheses are then addressed by comparing the fracture rate data by geographic region and over cultural time periods.

There are some limitations in the analysis of fractures in skeletal remains. These have been reviewed in Roberts (1991) and are outlined briefly here. Firstly, it is not possible to determine the age at which a fracture occurred. Secondly, some fractures, especially in subadults, can heal extremely well, leaving no sign of their occurrence. Small but significant stress fractures may not be easily identified unless every bone is radiographed, but this methodology is frequently limited by financial and logistical constraints. Fractures occurring just before death may be indistinguishable from postmortem damage resulting from post-depositional disturbance.

This analysis of trauma in the Thai skeletal collections includes fractures of the long bones, craniofacial bones, and axial skeleton other than the vertebrae. Evidence of such conditions as spondylolysis in the Thai samples under investigation has been previously considered in Domett (2001).

Materials

The skeletal samples are from four different prehistoric sites in Thailand. The basic information for each site is provided in Table 1 and their location is indicated in the map in Figure 1. Khok Phanom Di and Nong Nor are both in the southeastern region of Thailand and were coastal or close to the coast in prehistory. Ban Lum Khao and Ban Na Di are in inland northeastern Thailand, on tributaries of the Mekong River.

The samples represent two different time periods (Table 1). Khok Phanom Di was occupied by a Neolithic community for up to 500 years beginning approximately 2000 BC (Higham & Bannanurag, 1990). The nearby cemetery of Nong Nor, in use during the Bronze Age (1100-700 BC) (Higham & Hogg, 1998), postdates that of Khok Phanom Di and is approximately contemporary with Ban Lum Khao in the Northeast (1400-500 BC) (Higham, 2002). The sample from Ban Na Di is from the late Bronze Age, approximately 600-400 BC (Higham, 1996). The four skeletal samples have previously been extensively reported on in Tayles (1999) and Domett (2001).

In total, the four samples provide 299 adult skeletons of varying completeness and preservation. The skeletal material from Khok Phanom Di and Ban Lum Khao are the best preserved with many individuals represented by near complete skeletons. The material from Ban Na Di is moderately well preserved but many individuals are represented by incomplete skeletons. The material from Nong Nor provided the largest sample size but is the least well preserved, with many fragmented bones.

Table 2 provides summary data regarding the age at death and sex distribution of each sample. Standard morphological analyses have been carried out in order to determine the sex of each adult individual (Buikstra & Ubelaker, 1994). Morphological features of the pelvis and cranium were given priority. In some cases metric assessment was necessary to estimate sex. Adults were aged using the pubic symphysis when present but in many cases dental wear was employed using the method of seriation (Buikstra & Ubelaker, 1994). In all the samples except Khok Phanom Di a proportion of individuals were unable to have their age at death or sex estimated. Further details are provided in Tayles (1999) and Domett (2001).

Methods

1. Characteristics of the fractures

Every adult bone present was assessed macroscopically for signs of healed antemortem fractures. When identified, the fracture was described in detail in terms of the degree of shortening compared with the contralateral side, apposition of fracture fragments, and angulation and rotation of fracture fragments following healing as detailed in Lovell

(1997). This very detailed information is summarised here and can be found in Domett (2001).

Any possible signs of complications were also noted, such as an association with osteoarthritis in an adjacent joint, or cortical or subperiosteal infection. However, it is recognised that these types of pathologies may not always be directly a result of a fracture and could have been present before the fracture occurred. Long bone length measurements were recorded for both the bone affected and the contralateral bone to determine the degree of shortening.

2. Patterns of fractures

Fracture frequencies were calculated for both adult skeletal elements and for adult individuals. The frequencies in skeletal elements have been defined as 'rates' and were limited to the major long bones of adults. Skeletal elements were counted and the rate, expressed as a percentage, was calculated by dividing the number of bones with fractures by the number of complete bones present in the sample. The fracture rates in smaller bones, such as those of the hands and feet were not calculated because the wide variation in the preservation of these bones precluded sensible analysis of such data. The frequencies in adult individuals have been defined as the 'prevalence', which was calculated from the number of individuals with one or more fractures, including fractures in the small bones, as a proportion of the total number of individuals in the sample. The calculation of fracture rates was deemed more reliable as it removes the bias of preservation to some degree (Jurmain, 1999). An 'individual' in a skeletal sample can sometimes be represented by only a few bones and therefore not correspond to a complete individual, with the potential to lead to underestimation of the prevalence. This problem is analogous to the presentation of dental pathology, where the current practice is to present both sets of data (Hillson, 2001).

The following hypotheses were tested:

Hypothesis 1: That there is no difference in fracture rates between the regions

This first hypothesis was tested by combining the samples from the coastal southeast region (Khok Phanom Di and Nong Nor) and comparing them with the combined samples from the inland northeast region (Ban Lum Khao and Ban Na Di).

Hypothesis 2: That there is an increase in fracture rates over time

The Neolithic sample (Khok Phanom Di) was compared to the combined data for the Bronze Age samples (Ban Lum Khao, Nong Nor and Ban Na Di) to test the second hypothesis.

The statistical analyses in this study have purposely been kept simple. Complex statistics on sometimes inadequate data (for example, small sample sizes and/or missing data) can lead to misleading interpretations. Chi^2 tests (used for comparing three or more samples, or two large samples) and Fisher's exact tests (FET) (used for comparing two samples) were employed to compare samples. A critical level for acceptance or rejection was established at 5%, as is most commonly used (Zar, 1999). FETs are particularly useful when sample sizes are small (Zar, 1999) and when the Chi^2 test cannot be used given the latter's caveat of 80% of cells containing an expected value of greater than five (Zar, 1999).

Results

Over the four samples, 24 bones were identified with healed fractures in 21 individuals (seven females, 12 males, and two of unknown sex).

1. Characteristics of the fractures

Table 3 provides the proportion of adult individuals with one or more fracture for each sample. The results are divided by age and sex and summarised. As with most skeletal samples, not all skeletons are represented by complete remains, therefore the individual prevalences do not take into account missing data.

There are five individuals with healed fractures (three female, two male) in the material from Khok Phanom Di. There is no significant difference in the proportion of males (6.3%) and females (8.3%) with fractures (FET p-value = 1.000). The fractures are restricted to the small bones of the hands (left fifth metacarpal, right fourth metacarpal) and feet (right fifth metatarsal) (for example Figure 2), and to the clavicles (two left clavicles). Healing of the fractures within this sample is generally good with few complications. One of the clavicular fractures has a degree of shortening typical of clavicular fractures (Rogers, 1992), and the other has signs of infection in the form of a cloaca. However, it is not possible to determine if the infection was already present before the fracture and had weakened the bone, or if the infection was post-fracture (Tayles, 1999).

The material from Nong Nor also has five healed fractures (one female, two male, two of unknown sex). There is no significant difference between males (4.5%) and females (2.0%) affected (FET = 0.601) (Table 3). The three long bones affected (two left ulnae and a right clavicle) have all healed well with no significant complications. The thickened and shortened shaft of the clavicular fracture in Burial 47 is typical, where one fragment overrides the other (Rogers, 1992). A further healed fracture is evident in the left mandibular body of a young male (Burial 32) and probably led to the antemortem loss of the first molar in the vicinity of the fracture line. Another adult (Burial 27) also has a healed fracture of a proximal foot phalanx.

The sample from Ban Lum Khao has the most fractures, affecting 12 bones in nine individuals (three females, six males). There is no significant difference between males (21.4%) and females (9.7%) affected (FET = 0.285) despite the predominance of forearm fractures in males; five of seven fractured radii and ulnae are in males. A wide range in the quality of healing, as determined by possibly associated complications, is evident in the fractures from this sample. Complications that may have had significant repercussions on the individual's range of movement include the formation of a new radial head joint on the humerus in the Monteggia fracture of Burial 98 (Figure 3), and a junctional pseudoarthrosis between the shafts of the radius and ulna in Burial 30 (Figure 4). This latter male also has a well-healed fracture in the proximal shaft of the right fibula. An older male with a Colles' fracture also has a relatively low cortical index (as measured from metacarpal radiographs) compared with other individuals from this sample, and multiple vertebral body collapse, all suggesting a diagnosis of osteoporosis. Also of note in this sample is the combination of healed fractures in one adult male's

(Burial 28) right ulna and nasal bones, which may imply a violent causation as discussed later. Another adult male (Burial 48) has evidence of a healed fracture in the left mandibular body (Figure 5). Healed fractures are also observed in a left clavicle of an older female and a left second metatarsal of an adult male.

There are only two fractures in the sample from Ban Na Di, both in males. The absence of fractures in females is not statistically different (FET = 0.495) from those present in males (8.0%). One fracture is that of a third metatarsal, most likely the result of a direct force such as dropping a heavy object on the foot. The other is a fracture of the femoral shaft. Given that the callus is restricted to the posterior shaft and has healed well, this may be a greenstick fracture that had occurred during childhood.

2. Patterns of fractures

A. Fracture prevalence: By individual

The individual data (Table 3) represents those individuals with one or more fracture and includes fractures of the small bones of the hands and feet and mandibular and cranial fractures. When these data are compared among the samples there are a few significant differences, particularly when Ban Lum Khao is compared with the other samples. Overall, Ban Lum Khao has a significantly higher number of individuals with fractures (15.3%) compared with Nong Nor (4.1%) (FET = 0.015) and is close to being significantly higher compared with Ban Na Di (4.0%) (FET = 0.062). When males and females are compared separately among the samples, the only significant difference is between Ban Lum Khao males (21.4%) and Nong Nor males (4.5%) (FET = 0.049). No significant differences have been identified among the female groups where the prevalence ranged from 2.0% to 9.7%.

B. Fracture rates: By bone element

Fracture rates have been calculated for the major long bones for each sample of adults and are presented in Table 4. The total fracture rate over all of these major long bones has also been calculated. However, before this information is presented it must be recognised that the samples have a wide variation in the number of complete or near complete bones observeable for fractures. In particular, both Ban Na Di and Nong Nor have quite low sample sizes for most bone elements.

Khok Phanom Di individuals have very few long bone fractures (0.3%) and this is significantly lower than both Nong Nor (3.4%) (FET = 0.017) and Ban Lum Khao (3.4%) (FET = 0.001). Comparison of fracture rates in individual bones shows that ulnae are fractured significantly more often at Nong Nor (22.2%; FET = 0.011) and at Ban Lum Khao (10.0%; FET = 0.014) than at Khok Phanom Di , where there are no ulnar fractures. Similarly, radii are fractured significantly more often at Ban Lum Khao (6.3%; FET = 0.031) than at Khok Phanom Di where there are again no fractures of this bone.

C. Addressing the hypotheses

Hypothesis 1: That there is no difference in fractures between the regions

The data have been pooled for the two sites in each region and are presented by individual (all fractures) and by bone element (major long bones) (Table 5). Individual fracture data compared between the northeast (10.1%), comprised of the samples from Ban Lum Khao and Ban Na Di, and southeast (5.3%) regions, comprised of Khok Phanom Di and Nong Nor samples, although showing a two-fold difference, are not statistically different (FET = 0.157). There is also no significant difference when males and females are compared separately between the regions although three times as many males have fractures in the northeast (15.1%) compared to the southeast (5.3%) (FET = 0.071). Comparison of fracture rates for major long bones between the two regional samples did show a significantly higher fracture rate in the northeast (2.9%), compared with the southeast (0.7%) (FET = 0.006).

The fracture patterns, that is the bones affected, can also be compared between the northeast and southeast samples. The range of bones affected by fracture in the northeast is slightly more extensive than in the southeast (Table 5). Fractures are restricted to the clavicle, ulna, hands and feet and craniofacial bones in the southeast. The northeast samples included fractures in all of these bones as well as in the lower limb and radius. Of the long bone fracture rates only that for the radius is significantly higher in the northeast (4.5%, all from Ban Lum Khao) compared with the southeast where no radial fractures have been identified. No other statistical differences have been found among the other fracture rates for bone elements.

Hypothesis 2: That there is an increase in fractures over time

The data have been divided into two time periods representing the Neolithic and Bronze Age in Table 6, both by individual (all fractures) and by bone element (major long bones). In the comparison of individual fracture prevalences through time there are no statistically significant differences. When the total fracture rates represented by the major long bones are considered there were statistically significant differences. There is a 10-fold increase in fractures from the Neolithic (0.3%) to the Bronze Age (3.0%) (FET <0.001).

The bone element data in Table 6 also presents fracture rates for each major long bone across the time periods. Of the bones affected, all rates are higher in the Bronze Age with the Neolithic showing very few fractures. Of significance are the forearm fracture rates. The ulnar fracture rate is significantly higher in the Bronze Age (10.2%) compared with the Neolithic (0%) (FET = 0.007); the radial fracture rate is close to being significantly higher (3.8% and 0% respectively) (FET = 0.081).

Discussion

The first hypothesis stated that there would be no difference in fracture rates between the samples from the northeast and southeast of Thailand. The fracture prevalence data for individuals supports this hypothesis, as there are no statistical differences in either the sample as a whole or in the separate sexes. However the fracture rates for bone element (Table 5) do not appear to support this first hypothesis. The Northeast Thai samples had significantly higher total long bone fracture rates and higher ulnar fracture rates. Nevertheless, examination of the evidence shows that these differences are unlikely to reflect regional effects. Rather, the source of the difference appears to lie in the relative sizes of the samples and their contributions to the regional fracture rates. The larger Bronze Age sample in the Northeast, Ban Lum Khao, had high fracture rates whereas the larger sample in the Southeast, Khok Phanom Di, had low rates and is

Neolithic. The apparent regional difference is therefore more likely to reflect diachronic differences than geographic.

The second hypothesis suggests that an increase in fracture rates over time would be identified among the samples. Again the different methods of calculating frequencies produced different results. The prevalence of fractures per individual did not change significantly over time, whereas the fracture rates of the major long bones increased significantly between the Neolithic and the Bronze Age. Cultural changes from the Neolithic to the Bronze Age have been documented, such as an increase in community settlement size, an increasing reliance on cultivated rice (Higham, 2002) but still very little social stratigraphy overall (O'Reilly, 2000). However, significant social and technological change was experienced during the latter half of the first millennium BC as Southeast Asia entered the Iron Age (Higham, 2002). The skeletal evidence from this period is still patchy. The poorly preserved skeletal material from the Iron Age site of Noen U-Loke in northeast Thailand showed no evidence for fractures but this does not necessarily indicate an absence of trauma. Archaeological evidence in the form of bronze weaponry and iron projectile points suggests conflict may have been part of life in the Iron Age (Higham, 2002).

Concentrating on the transition from the Neolithic to the Bronze Age, we need to consider whether an increase in the agricultural contribution to subsistence provided the opportunity for a different fracture risk from a more strongly hunter-gatherer subsistence mode. It is possible that people at Khok Phanom Di undertook different daily tasks from those at the later Bronze Age sites. All communities would have been involved in a proportion of hunting and gathering activities but that proportion may have decreased with the increasing reliance on rice agriculture in the Bronze Age. While it seems logical that there would be less inherent risk in the relatively routine agricultural activities carried out in a familiar environment, our results suggest that this change in subsistence activity may have exposed the Bronze Age people to a higher level of fracture risk than in the Neolithic. In Larsen's (1997) review of accidental injury, there is a predominance of case studies that show a decrease in fracture prevalence from the hunter-gatherer to the agricultural lifestyle. However, earlier reviews of fracture patterns failed to show a consistent pattern, with a decrease in fracture risk in some regions and an increase in others (Cohen & Armelagos, 1984). It is possible that while established agriculturalists may be exposed to less fracture risk, those communities increasing their reliance on agriculture, such as those of the Bronze Age in Southeast Asia, would have been involved in tasks such as land clearance, exposing themselves to an elevated fracture risk.

A question of interest to prehistorians is whether the increase in fracture rates resulted from increasing interpersonal violence consequent on increasing density of settlements and competition for resources between communities. There is currently no archaeological evidence of intercommunity warfare during the Bronze Age of Thai prehistory in the northeast (O'Reilly, 1999; Chetwin, 2001) or the southeast (Higham & Thosarat, 1998). Chetwin (2001) notes that in the Northeast communities were small, the resources abundant, and seasonal mobility would have reduced the need for conflict over resources. Nor is there evidence of mass production of projectiles specialised for warfare. Alternatively, was there more violence *within* Bronze Age communities than in earlier societies? There is no obvious reason why these individuals should have become more aggressive, any more than communities warred with one another.

A number of the Bronze Age fractures do have characteristics that could be evidence for interpersonal violence. Fractures of the forearm, and in particular the ulna, are frequently pre-emptively called ‘parry’ fractures in the archaeological literature and have consequently often been cited as evidence of interpersonal violence when found in skeletal collections (Smith, 1996; Lovell, 1997). In modern clinical texts it is apparent that the causes of fractures are many and varied (Bucholz & Heckman, 2001). Lovell (1997) discusses this at length and it is clear that, regardless of cause, the radius and ulna are the most frequently fractured bones, both in archaeological collections and as reported in the clinical literature. However, by recording details following Lovell’s (1997) protocol a probable cause may be indicated, or at least enable certain causes to be excluded as unlikely. For example, oblique or torsional fractures are more likely to be the result of a fall with forced pronation and twisting of the limb than a direct blow, whereas transverse fractures can have any number of causes including blows and falls (Lovell, 1997; Richards, 2001).

The patterns of fractures in individuals are also relevant to determining the possible cause. If violence was involved there may be multiple fractures and/or fractures to the craniofacial skeleton. Despite the allure of the relationship with violence suggested by the use of the descriptor ‘parry fracture’ for ulnar fractures, fractures of the craniofacial skeleton are in fact more likely to have their origin in violence than fractures of the forearm (Lovell 1997). Walker (1997) notes that in modern populations the most common cause of cranial trauma is interpersonal violence, followed by sports and accidents. The head and neck are favoured in assaults over other parts of the body. Craniofacial injury may therefore support a violent aetiology for long bone midshaft forearm fractures (Smith, 1996; Jurmain, 1999) where these occur in the same individual. With a succession of blows, the individual either successfully protects their face and head from a blow and receives a forearm fracture or, alternatively, unsuccessfully protects their head and face and receives a craniofacial injury or a combination of the two events.

There is evidence of craniofacial injury in Bronze Age males from both Nong Nor and Ban Lum Khao. There are two cases of fractures of the left mandibular body at both sites (for example Figure 5). Both had also lost the first or second molars in the region of the fracture line. These types of fractures are frequently the result of a direct force to the lateral aspect of the mandible (Olson *et al.*, 1982) and are consistent with a right-handed attacker. Reviews of mandibular fractures indicate the mandibular body is the most common site of fracture, particularly that of the left body (Adi *et al.*, 1990; Chidzonga, 1990; Akama *et al.*, 1993). In the clinical literature, fighting is recorded as the most common cause of mandibular fractures (Adi *et al.*, 1990; Chidzonga, 1990; Mwaniki & Guthua, 1990; Akama *et al.*, 1993). However, a direct blow may not necessarily have been from another individual but could also have been from a fall against a hard object or even from a kick from an animal. A variety of wild animals were hunted during the Bronze Age and domesticated cattle and pigs were a significant part of life in these times, more so than during the Neolithic (Higham, 2002). Neither individual with a mandibular fracture had evidence of other injuries. However, at Ban

Lum Khao there was a man with fractured nasal bones who also had a fractured ulna. The combination of injuries in the latter could reflect successfully and unsuccessfully warding off a number of blows to the head and face but as there is no way of knowing whether the two fractures occurred at the same time, this is purely speculative.

In addition to this ulnar fracture, there are three other fractured ulnae in the Ban Lum Khao sample, two in females and one in a male. In the male, the radius is also fractured, which would have required a large force. This could have been a deliberate direct blow by another person but is more likely to have been accidental, a fall from a height, for example. There are also two fractured ulnae at Nong Nor, one in a female and one in an adult of unknown sex. The latter fracture was possibly spiral, which is consistent with a fall rather than a direct blow (Lovell, 1997).

In summary, there are hints of possible interpersonal violence in the fracture patterns in the Bronze Age skeletal samples from Ban Lum Khao and Nong Nor. Why this period would have been particularly violent is unclear. The paucity of evidence for trauma at Khok Phanom Di, given this sample's excellent preservation, strongly suggests that trauma was uncommon for these people.

It is useful to compare these results with other studies including those in Thailand and other parts of Southeast Asia as well as on a worldwide scale. Table 7 presents a summary of results from this study and a selection of others from Thailand, Vietnam, America, Alaska and Sudanese Nubia.

Two other prehistoric northeast Thai skeletal samples have been studied systematically and provide comparable data (Douglas, 1996; Pietrusewsky & Douglas, 2002a). Ban Chiang is a prehistoric site with skeletal material from the Neolithic through to the early Iron Age (Pietrusewsky & Douglas, 2002b). The majority of the Non Nok Tha material was from the Bronze Age but there are some early and later burials also (Douglas, 1996). In comparison with the samples analysed in this present report, there are many similarities in the patterns of fractures at Non Nok Tha and Ban Chiang. Many of the fractures were in bones of small diameter, that is, the hands, feet, clavicle and radius. The main differences were the absence of ulnar fractures, the presence of rib fractures and a few larger bone fractures (tibia, femur, humerus) in Douglas' (1996) analysis. There are cranial fractures in one, possibly two, males, in each case in the vault and in association with fractures of the cervical vertebrae. The actual fracture rates appear quite low in comparison with the other Thai Bronze Age sites (Table 7) with the exception of the clavicle at Non Nok Tha. It was not possible to calculate a total fracture rate for these sites. Pietrusewsky and Douglas (2002a) conclude from the Ban Chiang material that "there are no indications of systematic warfare or other interpersonal violence. The pattern of fracture occurrence reflects a life of heavy physical labor consistent with a rural lifestyle, including agriculture…hunting…lifestock management…" (Pietrusewsky & Douglas, 2002a: 175).

Broadening out to compare Thai prehistoric fracture rates with those in Vietnam it is apparent that individual rates per element are on par with the Thai sites discussed here. However the pattern of bones affected is quite different in the earlier Da But material where it was more common to see larger bones, such as the femur and humerus, fractured (Oxenham *et al.*, 2001). The Metal period material matches that of the Thai Bronze Age with a predominance of forearm fractures, although sample sizes are small (Oxenham *et al.*, 2001). Oxenham *et al*. (2001) conclude from their evidence that interpersonal violence was not common during the Metal period despite other evidence (historical and material culture) for warfare during this time.

In other regions of the world (Table 7) it is evident that the two Bronze Age sites from Thailand stand out with a slightly higher overall long bone fracture rates (3.4% each) than all the other sites mentioned. These Thai Bronze Age sites are closest to the rates in the Libben population of North America (total rate 3.0%) but the patterning of bones affected is much more varied in the large Libben skeletal sample (Lovejoy & Heiple, 1981). The sample of Khok Phanom Di has the lowest overall fracture rate (0.3%) but the rates in Eskimos were a close second (0.4%) (Keenleyside, 1998).

When the pattern of bones affected are compared it is evident that the forearm and the clavicle are the most commonly fractured bones around the world and this is confirmed by other reviews (for example Larsen, 1997; Jurmain, 1999). Of the 13 studies presented here the forearm and clavicle are the most commonly fractured bones in nine instances. This is probably a reflection of the vulnerability to fracture of these bones, along with those of the hands and feet, which are not presented here. They represent the bones of smaller diameter that would require less force to fracture compared with the humerus or femur, for example.

The pattern of fractures has changed considerably in modern times with the invention of the motor vehicle and other machinery (Roberts & Manchester, 1995). More fractures are seen and are frequently caused by a considerably larger force than was possible to experience in prehistory. However, it could be of interest to use fracture patterns in people in the modern rural Thai setting as a comparison to prehistoric patterns, however such evidence was not able to be located; it is suspected that it may exist in Thai publications.

Conclusions

The evidence for trauma among the samples from prehistoric Thailand has provided interesting information regarding patterns of risk over time and between the southeastern and northeastern regions. It appears that the risks of fracture were affected more so by time, and therefore the cultural environment of the community, rather than the region. The Bronze Age stood out as being a particular period of risk for fracture, both in the northeast and southeast. While not distinctive, the most likely explanation for this pattern is a combination of more frequent accidents with a possible contribution from interpersonal violence. Accidents may have increased during this time period as new physical activities were introduced, such as those associated with the clearance of land for rice agriculture and animal husbandry. Fracture rates were low in the Neolithic. Recently, new skeletal samples have been excavated from the Neolithic and Iron Age from northeast Thailand. These may clarify the issues raised by the evidence presented here.

Table 1: The dates and location of the skeletal cemetery samples from prehistoric Thailand analysed in this study

Site	Dates	Period	Region	Environment
Khok Phanom Di	2000-1500 BC[1]	Neolithic	southeast	coastal
Nong Nor	1100-700 BC[2]	Bronze Age	southeast	coastal
Ban Lum Khao	1400-500 BC[3]	Bronze Age	northeast	inland
Ban Na Di	600-400 BC[4]	Late Bronze Age	northeast	inland

1. Higham & Bannanurag (1990); 2. Higham and Hogg (1998); 3. Higham (2002); 4. Higham (1996)

Table 2: Age and sex distribution of the samples

	Khok Phanom Di		Nong Nor			Ban Lum Khao		Ban Na Di		
	M	F	M	F	?sex	M	F	M	F	?sex
Subadults	86		33			51		28		
15-19 y	5	3	0	1	1	3	2	0	0	0
20-29 y	11	12	12	12	2	7	17	9	4	0
30-39 y	14	13	18	20	5	9	7	9	3	1
40+ y	2	8	8	5	1	7	4	4	6	0
?age	0	0	6	11	20	2	1	3	7	4
Total	32	36	44	49	29	28	31	25	20	5
Total (adults)	68		122			59		50		
Total	154		155			110		78		

Table 3: Age and sex distribution of fracture prevalences by individual (percentage of total adult population)

	Khok Phanom Di		Nong Nor		Ban Lum Khao		Ban Na Di	
	A/N	%	A/N	%	A/N	%	A/N	%
Male	2/32	6.3	2/44	4.5	6/28	21.4	2/25	8.0
Female	3/36	8.3	1/49	2.0	3/31	9.7	0/20	0
Total[1]	5/68	7.4	5/122	4.1	9/59	15.3	2/50	4.0

1. Includes those adults with no sex or age estimate; A = number of individuals affected with one or more fracture; N= number of adult individuals.

Table 4: Fracture rates of the major long bones of adults in each prehistoric Thai sample

Bone	Khok Phanom Di		Nong Nor		Ban Lum Khao		Ban Na Di	
	A/N	%	A/N	%	A/N	%	A/N	%
Clavicle	2/106	1.9	1/18	5.6	1/39	2.6	0/15	0
Humerus	0/104	0	0/19	0	0/37	0	0/15	0
Radius	0/102	0	0/13	0	3/48	6.3	0/18	0
Ulna	0/74	0	2/9	22.2	4/40	10.0	0/10	0
Femur	0/85	0	0/17	0	0/37	0	1/13	7.7
Tibia	0/90	0	0/13	0	0/34	0	0/11	0
Fibula	0/48	0	0/0	0	1/29	3.4	0/4	0
Total	2/609	0.3	3/89	3.4	9/264	3.4	1/86	1.2

A= number of bones fractured; N= number of complete adult bones observed.

Table 5: Regional differences in adult fracture prevalence

	Northeast[1]		**Southeast**[2]		Statistical p-value
By individual	A/N[3]	%	A/N[3]	%	
Male	8/53	15.1	4/76	5.3	0.071[7]
Female	3/51	5.9	4/85	4.7	1.000[7]
Total[4]	11/109	10.1	10/190	5.3	0.157[7]
By bone[5]	A/N[6]	%	A/N[6]	%	
Clavicle	1/54	1.9	3/124	2.4	1.000[7]
Humerus	0/52	0	0/123	0	-
Radius	3/66	4.5	0/115	0	0.047[7]
Ulna	4/50	8.0	2/83	2.4	0.197[7]
Femur	1/50	2.0	0/102	0	0.329[7]
Tibia	0/45	0	0/103	0	-
Fibula	1/33	3.0	0/48	0	0.407[7]
Total	10/350	2.9	5/698	0.7	0.006[8]

1. Ban Lum Khao and Ban Na Di samples combined; 2. Khok Phanom Di and Nong Nor samples combined; 3. A = number of individuals with one or more fracture, N = number of adult individuals; 4. Includes individuals with unknown sex/age; 5. Excludes fractures of the small bones of the hands and feet and face; 6. A = number of bones fractured, N = number of assessable bones; 7. FET p-value; 7. Chi^2 p-value.

Table 6: Time differences in adult fracture prevalence

	Neolithic		Bronze[1]		Statistical
By individual	A/N[2]	%	A/N[2]	%	p-value
Male	2/32	6.3	10/97	10.3	0.729[6]
Female	3/36	8.3	4/100	4.0	0.381[6]
Total[3]	5/68	7.4	16/231	6.9	1.000[6]
By bone[4]	A/N[5]	%	A/N[5]	%	
Clavicle	2/106	1.9	2/72	2.8	1.000[6]
Humerus	0/104	0	0/71	0	-
Radius	0/102	0	3/79	3.8	0.081[6]
Ulna	0/74	0	6/59	10.2	0.007[6]
Femur	0/85	0	1/67	1.5	0.441[6]
Tibia	0/90	0	0/58	0	-
Fibula	0/48	0	1/33	3.0	0.407[6]
Total	2/609	0.3	13/439	3.0	<0.001[7]

1. Nong Nor, Ban Lum Khao and Ban Na Di data combined; 2. A = number of individuals with one or more fracture, N = number of adult individuals; 3. Includes individuals with unknown sex/age; 4. Excludes fractures of the small bones of the hands and feet and face; 5. A = number of bones fractured, N = number of assessable bones; 6. FET p-value; 7. Chi^2 p-value.

Table 7: Adult fracture rates among prehistoric populations (% by bone element)

	Southeast Asia													
Bone	Khok Phanom Di	Nong Nor	Ban Lum Khao	Ban Na Di	**This study total**	Ban[1] Chiang	Non Nok Tha[1]	Da But[2]	Vietnam Metal[2]	Nubia[3]	Aleuts[4]	Eskimos[4]	Libben[5]	Mound-ville[6]
Time period	2000-1500 BC	1100-700 BC	1400-500 BC	600-400BC				4000 BC	1300BC - 300AD	400BC-1400 AD	1000 BC-1500 AD	500 - 1850 AD		1050-1550 AD
Clavicle	1.9	5.6	2.6	0	**2.2**	0	4.4	n.d.	n.d.	1.9	0	0	5.8	0.9
Humerus	0	0	0	0	**0**	1.5	1.0	4.4	0	2.1	1.0	0	0.7	0
Radius	0	0	6.3	0	**1.7**	1.6	1.0	0	7.1	1.0	1.2	0.7	5.4	1.5
Ulna	0	22.2	10.0	0	**4.5**	0	0	0	7.7	4.3	0	0	3.1	0.9
Femur	0	0	0	7.7	**0.7**	1.2	0	6.5	0	0.2	1.0	0	2.6	0
Tibia	0	0	0	0	**0**	0	1.6	0	0	1.0	0	1.2	1.4	0
Fibula	0	0	3.4	0	**1.2**	0	1.2	0	0	1.2	1.3	0.7	3.5	0.6
Total	0.3	3.4	3.4	1.2	**1.4**	*	*	2.8	1.9	1.6	0.7	0.4	3.0	0.5

1. Douglas (1996); 2. Oxenham et al (2001); 3. Alvrus (1999); 4. Keenleyside (1998); 5. Lovejoy and Heiple (1981); 6. Powell (1988); n.d. = no data; * unable to be calculated as the denominator data for bone elements with no fractures was not provided.

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Domett Figure 1

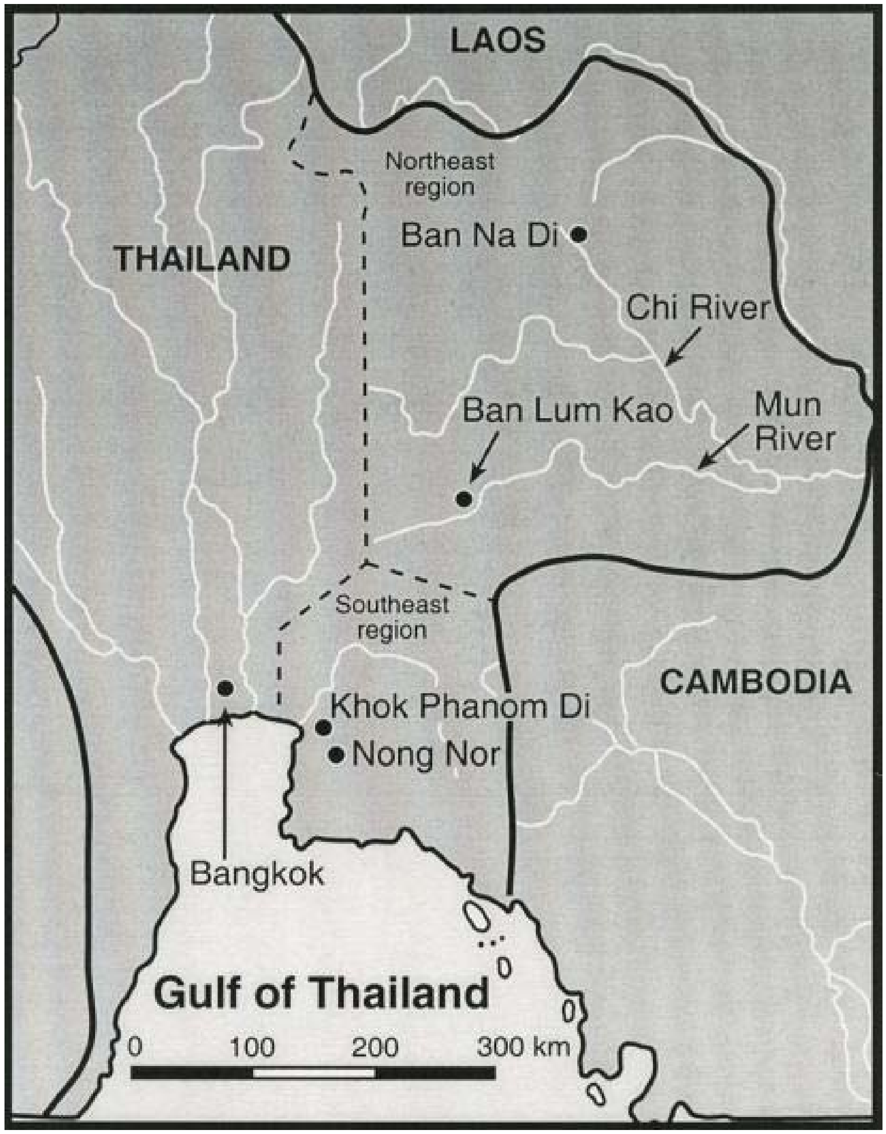

Figure 1: Map of Thailand indicating the location of the sites discussed in this study.

Domett Figure 2

Figure 2: Right metacarpals (lateral view) from Burial 142, Khok Phanom Di, a 31 year old female. The fourth metacarpal shows a healed midshaft fracture.

Domett Figure 3

Figure 3: Left radius and ulna (anterior view) from Burial 30, Ban Lum Khao, a 30-34 year old male. The ulna and radius both have fractures in the proximal third of the shaft; note the junctional pseudoarthrosis. NB. These bones were covered in a postmortem calcareous deposit.

Domett Figure 4

Figure 4: Right humerus, radius and ulna (anterior view) from Burial 98, Ban Lum Khao, a 35-39 year old female. The ulna has a healed Monteggia fracture of the proximal third of the shaft (arrow); note the formation of a new joint for the radial head inferior to the lateral supracondylar ridge of the humerus (arrowhead). NB. These bones were covered in a postmortem calcareous deposit.

Domett Figure 5

Figure 5: Mandible (left lateral view) from Burial 48, Ban Lum Khao, a 40+ year old male. The left mandibular body shows a healed fracture in the line of the second molar which has been lost antemortem possible as a result of the fracture.