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SHORT COMMUNICATION

# Distinguishing between perimortem and postmortem fractures: are osteons of any help?

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**Abstract** The distinction between perimortem and postmortem fractures in forensic anthropology is still a frequently unsolved issue. In the present study, we try to verify if there are differences in the pattern of osteon fracturing between fresh and dry bone which could be used for such a diagnosis. Fresh and dry long bones were fractured by a hammer at the mid-shaft perpendicularly to the long axis of the bone and the fracture margins examined under a light microscope as undecalcified sections. Examination of 982 osteons (505 fresh, 477 dry) showed that twice as often the fracture line crosses the osteons as opposed to travelling around them, independently of whether the bone is fresh or dry. Statistical analysis confirmed that there was no significant difference between fresh and dry bone. This seems to imply that osteon fracture pattern cannot help in the diagnosis of perimortem versus postmortem bone fractures. Further research however must be performed concerning fast and slow energy dispersal which may have an influence on the type of fracture inflicted.

**Keywords** Forensic science · Forensic anthropology · Perimortem · Osteons · Fracture · Bone microstructure · Microscopy

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Forensic pathologists can usually provide information on the timing of injuries on fresh skin [1–3]; doing the same for the skeleton however may be more problematic. Bone fractures result from the application of repeated forces of low magnitude over a certain period of time (stress or fatigue fractures) or from a single impact of a force with the capacity to overcome the elasticity of the bone tissue [4, 5]. It is critical to know whether the injury occurred prior to, around the time of or after death, in other words antemortem, perimortem or postmortem—a difficult task since perimortem fractures that are "green" and elastic with bent spicules at their margins are not always fresh, nor postmortem fractures are always "dry" and lighter in colour compared to the surrounding bone, particularly when the environment is damp and wet [6–11]. Is it possible to find an answer to the question "peri or postmortem" by simple bone microscopy? If the assumption is that an elastic bone breaks differently from a dry one, then it may be that this difference can be assessed microscopically.

Collagen gives bone its elasticity and ability to dissipate energy under mechanical deformation. Mineralized collagen fibres are arranged into randomly oriented bundles which are organized into a lamellar structure. The concentric arrangement of lamellar rings produces cylindrical secondary osteons (Haversian systems) externally bound by a cement line [12] (from this point onwards the term osteon will be used with reference to secondary osteons). The mechanical properties of a single osteon are still not well-known; however, Rho et al. [13] examined the variations in the individual thick lamellar properties within completed secondary osteons as a function of distance from the osteonal center (Haversian canal). Concerning bone strength, the morphology of the cement line and its roles in the fatigue and fracture properties of bone has been investigated but are not clear. Dong et al. [14] experimen-

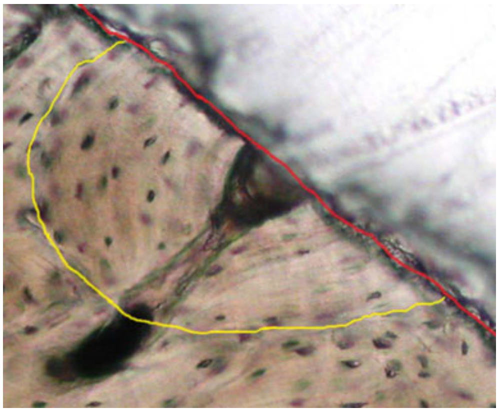

**Fig. 1** Break going through the central canal (*straight line* = break, *curved line* = cement line); type A

tally determined the interfacial strength of cement lines in human cortical bone by performing osteon pushout tests. Egerer et al. [15] quantified the length of the osteonal cement line in human tibias with respect to overall tibial mechanical properties. Their data reveal a direct relationship between cement line length per area and the maximum load necessary to completely fracture the bone. According to the results of Schaffler et al. [16], cement lines contain significantly less calcium and phosphorus, but significantly more sulphur, than the surrounding bone matrix and the Ca/P ratio of cement lines is significantly greater than that of lamellar bone, suggesting that the mineral in cement lines may not be in the form of mature hydroxyapatite. Skedros et al. [17] reject the hypothesis of Schaffler et al. [16] or Burr et al. [18], which states that the secondary osteon cement line is poorly mineralized with respect to immediately surrounding osteonal bone. Their data suggest that cement lines of secondary osteons are relatively highly mineralized or collagen deficient (according to backscattered electron imagining) or according to energy dispersive X-ray similarly mineralized when compared to surrounding osteonal bone.

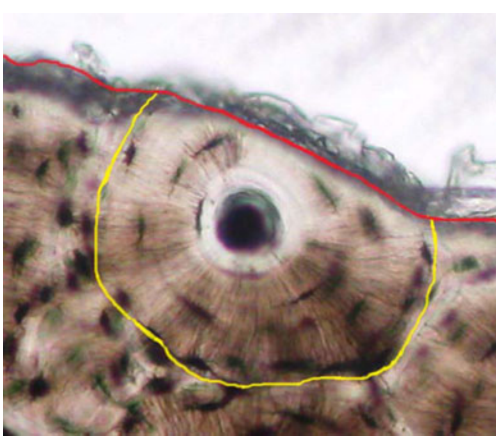

**Fig. 2** Break passing straight through the lamellae (*straight line* = break, *curved line* = cement line); type A

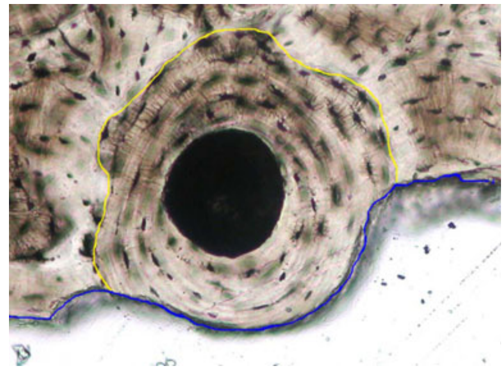

**Fig. 3** Fracture line running around the inner lamella (*lower line* = break, *upper curved line* = cement line); type B

On the basis of these different theories, we decided to investigate if the cement line and/or the lamellar structure of secondary osteons plays a role during the fracture process. The main question was if the fracture line in fresh elastic bone respects the structure of secondary osteons and passes around them (through the cement line or between the lamellae) which may be a point of least resistance of adult bone microstructure. The aim of this study was therefore to verify at the microscopic level if there exists a difference in direction and pattern of fracture line in fresh and dry bone which could be used for distinguishing perimortem and postmortem fractures.

## Materials and methods

Twenty-six fresh and dry fragments of human long bones were used in this study which had been taken from cadavers for judicial purposes. Fragments from three fresh femurs, two tibias, two radii and to two fibulae fractured by blunt

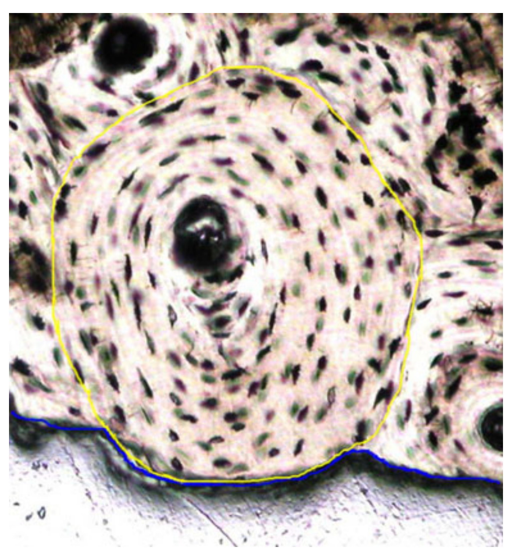

**Fig. 4** The disruption in the area of cement line (*lower line* = break, *curved line* = cement line); type B

**Table 1** The relationship between the fracture line and secondary osteons: numbers of osteons with fracture line crossing the Haversian canal or lamellae (type A) and osteons with fracture line running around/along the cement line or inner lamellae (type B)

| Type | Bone | No. | Total osteons | Type A | Type B | Type A (%) | Type B (%) |
|---|---|---|---|---|---|---|---|
| Fresh | Femur | 3 | 260 | 142 | 118 | 54.37 | 45.63 |
| Fresh | Tibia | 2 | 100 | 68 | 32 | 68.45 | 31.55 |
| Fresh | Fibula | 2 | 74 | 49 | 25 | 66.45 | 33.55 |
| Fresh | Radius | 2 | 71 | 46 | 25 | 65.45 | 34.55 |
| Fresh | Total | 9 | 505 | 305 | 200 | 63.68 | 36.32 |
| Dry | Femur | 3 | 159 | 97 | 62 | 60.33 | 39.67 |
| Dry | Tibia | 5 | 157 | 121 | 36 | 77.12 | 22.92 |
| Dry | Radius | 4 | 91 | 61 | 30 | 67.23 | 32.8 |
| Dry | Fibula | 5 | 70 | 44 | 26 | 62.82 | 37.18 |
| Dry | Total | 17 | 477 | 323 | 154 | 66.88 | 33.14 |

force injury on a transverse plane with respect to the major axis of the bone were collected from two autopsy cases according to juridical and national mortuary regulation laws. These will be referred to as the fresh bone samples. Then, dry bone samples were prepared from historical human bones (16th century) in the same manner, by the application of blunt force injury so as to create a transverse fracture of the diaphysis. Small pieces bordering the transverse fracture were then sampled and mounted perpendicularly to the fracture surface onto a glass slide with Pertex, ground and polished on a Struers DAP-7 (grades 320, 600, 1200, 2400 and 4000) in order to create a thin undecalcified section (150 μm) which could be read in light microscopy.

The fracture patterns of 982 osteons (505 from the fresh samples, 477 from the dry) along the fracture line were then examined. The number of osteons with a fracture line crossing the Haversian canal (Fig. 1) or the lamellae (Fig. 2) (which we will call "type A") were counted, as well as cases where the fracture line ran along the osteon structure (Fig. 3), either following an inner lamella (Fig. 3) or the cement line (Fig. 4) (which we will call type B). The *T* test was used for basic statistical analysis on MS Excel 2003.

## Results

Results are shown in Table 1. The fracture line in fresh bone specimens passed through the osteons (pattern A) in 63.7% cases on average. The highest percentage was found in tibia (68.5%), then fibula and radius and less than 60% in femur samples. Pattern B was found in 36.3% cases, with a highest value in femur samples (45.6%).

In dry bone, the fracture went through osteons (pattern A) in 66.9% cases on average. The tibias showed higher values (77%) followed by radius, fibula and femur (above 60%). The fracture line respecting the Haversian structure was observed on average in 33.1% cases. The contrast between the fracture lines going through or around osteons was most significant in the tibia for both fresh and dry bones (Table 2).

The results showed that the fracture line crosses the osteons twice as often with pattern A, in fresh as well as in dry bone. Statistical analysis confirmed that there is no statistically significant difference in pattern A frequency between fresh and dry bones (*T* test, $p=0.156$) or in pattern B frequency (*T* test, $p=0.157$).

## Discussion

The distinction between perimortem and postmortem bone fractures is still problematic. Several recent studies show that some osseous characteristics associated with perimortem trauma can be seen also in postmortem fractures on dry bone [6, 10]. As mentioned by Wieberg and Wescott [7], bone may regain its "fresh" qualities in damp environments long after the bone has become dry. Ultimately, distinguish-

**Table 2** The relationship between the fracture line and secondary osteons: comparison for each bone type (fresh or dry)

| Type | Bone | No. | Total osteons | Type A | Type B | Type A (%) | Type B (%) |
|---|---|---|---|---|---|---|---|
| Fresh | Femur | 3 | 260 | 142 | 118 | 54.37 | 45.63 |
| Dry | Femur | 3 | 159 | 97 | 62 | 60.33 | 39.67 |
| Fresh | Tibia | 2 | 100 | 68 | 32 | 68.45 | 31.55 |
| Dry | Tibia | 5 | 157 | 121 | 36 | 77.12 | 22.92 |
| Fresh | Radius | 2 | 71 | 46 | 25 | 65.45 | 34.55 |
| Dry | Radius | 4 | 91 | 61 | 30 | 67.23 | 32.8 |
| Fresh | Fibula | 2 | 74 | 49 | 25 | 66.45 | 33.55 |
| Dry | Fibula | 5 | 70 | 44 | 26 | 62.82 | 37.18 |

ing a fracture either produced on dry or fresh bone is not easy at times.

For the reasons mentioned above, we tried to verify whether it was possible to distinguish between a fracture produced on fresh and dry bone microscopically, in other words by observing how the fracture line respects bone structure. Up to now, there has been only one similar study on the relationship between the fracture line and the Haversian lamellae [19]. In this study, the authors performed sagittal splitting osteotomy of two fresh human mandibles. The histological observation showed that the fracture line tends to run along the curve of the lamellar structures. The incidence of the fracture line running along the lamellar structure was approximately 65% (21 cases) and the incidence of fracture lines cutting across the Haversian canal was approximately 35% (11 cases). These results drastically differ from ours (64% in pattern A and 36% in pattern B). The different type of bone used and the type of trauma may explain such inconsistencies, but more research needs to be done.

Piekarski [5] found that at slow velocities of propagation, a crack follows the weak interface of the Haversian lamellae or travels through interstitial bone but with high velocity rates, fractures propagate indiscriminately through all microstructures. This would mean that fractures require more energy to travel through entire bone structures as opposed to around them. Rho et al. [13] studied variations in the individual thick lamellar properties as a function of distance from the osteonal centre. They found that elasticity and hardness of completed secondary osteons are significantly lower than those of interstitial bone. Furthermore, the elasticity and hardness of the individual thick lamellae of completed secondary osteons decrease with increasing distance from the centre of the osteon; in other words, lamellar properties near the centre of the osteon are greater than those at the outermost osteonal lamellae. These support our observations that the fractures two times as often cross the osteons at all distances from the central canal. When the cracks infrequently respected the Haversian structure and followed the lamellae, it was always in correspondence with outer osteonal lamellae or the cement line. Dong et al. [14], who studied cement line properties, also suggested that the cement line interface between osteon and interstitial bone tissue is weaker than that between bone tissue lamellae. Even if we did not study the strength of lamellae and cement lines, the high ratio (8:1) between the cracks going around the cement line (179 cases in fresh bone) and those which pass between outer lamellae (21 cases) indicates that the cement line could be weaker than the interface between lamellae within the concentric organization.

Results of our study disclaim the initial hypothesis that in fresh elastic bone, the fracture line will respect the structure of the Haversian system and pass around it (as opposed to through it) compared with dry bone. Furthermore, the cement line does not act as the weakest interface for crack progression in cortical bone; most fractures travel irregularly across the lamellae. No statistically significant difference between fresh and dry bone values was found using the *T* test. The values for fresh bones seem to be more uniform, whereas the dry ones showed a greater dispersion. The difference in frequency of A and B patterns differed only by 3%. This high conformity between fresh and dry bone specimens seems to exclude the possibility of using microscopic fracture patterns for distinguishing between perimortem and postmortem fractures. Further investigations however need to be performed since this may also be due to the type of bone, impact and energy applied.

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