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CASE REPORT

ANTHROPOLOGY

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Radiographic Comparison of a Fractured Clavicle Exhibiting a Pseudo-Arthrosis*

ABSTRACT: Bone remodeling is a natural process that is potentially problematic for radiographic comparisons because it can occur after antemortem (AM) imaging, thus interfering with the comparability of AM and postmortem (PM) radiographs from the same individual. While the effects of age-related remodeling have been studied, limited attention has been given to trauma-related remodeling with respect to radiographic comparisons. This report adds to the latter topic by presenting a case of AM clavicle fracture that developed into a pseudo-arthrosis over a 12-month period prior to the individual's death. Even though remodeling was discernable along the fracture margins, adjacent skeletal features on the PM radiograph remained unaltered and constituted compelling evidence for the identification. This case illustrates the potential of using both normal and pathological anatomy concurrently to maximize the surety of findings from radiographic comparisons.

KEYWORDS: forensic science, forensic anthropology, antemortem, postmortem, X-ray, overlay, concordance, identification, nonunion, bone remodeling

The radiographic comparison of cranial and infracranial skeletal elements is a common technique used to identify decedents (1–12). In performing these analyses, the bone morphology that is visible on the postmortem (PM) radiograph(s) is compared to that on the antemortem (AM) radiograph(s). For an identification to be established, the morphology observed on the PM and AM images must match. However, it is known that bone remodeling has the potential to alter bone structure over the period between the acquisition of the AM and PM radiographs and, therefore, is a concern when conducting comparisons (2).

This concern has resulted in a number of research studies and case reports focused on determining the stability of radiographic bone morphology. In general, these studies suggest that age-related bone remodeling, over periods of 10–20 years, has little effect on the radiographic morphology of bones (2,13–15). However, trauma and altered biomechanical function may produce morphological changes at an accelerated rate (2), but their effects on radiographic comparisons are not fully understood.

While a trauma incident may itself provide some evidence in favor of a radiographic match (i.e., fracture type or location), certainty can be maximized if normal anatomical features specific to the bone (or bones) being compared can also be matched. Therefore, it is useful to know to what extent the body's response to trauma influences the shape of the bone, especially for those parts that are distant from the fracture site. While multiple factors such as fracture type, body region, medical treatment, sex, age, general health, preexisting medical conditions, and lifestyle interact in complex ways to determine individual healing rates and treatment outcomes; few investigations have examined the feasibility of using "normal" anatomy adjacent to trauma sites for radiographic comparison. To the authors' knowledge, the effect of trauma on radiographic comparisons has only been investigated on the feet where pre- and postsurgical radiographs were compared over an interval of 2–48 months, with few morphological differences being noted (16). This case study contributes additional information to this topic by describing a radiographic comparison performed on an individual who developed a pseudo-arthrosis of a right clavicle fracture in the time between AM radiography of the break and the individual's death.

Case Background

On August 1, 2008, the Honolulu Police Department (HPD) contacted the Joint POW/MIA Accounting Command-Central Identification Laboratory (JPAC-CIL) requesting recovery support and assistance in their ongoing investigation of a possible human remains discovery. A JPAC-CIL team responded, conducting an on-site survey and subsequent surface recovery of an articulated human skeleton. All recovered materials were turned over to representatives from the Department of the Medical Examiner, City and County of Honolulu, who transported them to the Medical Examiner's office.

Examination of the remains by the Medical Examiner revealed an almost completely skeletonized body with skull, upper extremities, thorax, pelvis, and lower extremities clothed in a t-shirt and floral patterned dress. Severely decayed internal organs, which were of little diagnostic value, were found on examination of the torso. No obvious evidence of perimortem injury was apparent, although portions of several bones were missing, possibly due to animal depredation. These findings suggested to investigators that the remains

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corresponded to a missing person's report of a woman last seen in January 2008 wearing a t-shirt and floral print dress. Lacking avenues to obtained further information, the remains were transferred to the JPAC-CIL for a more detailed skeletal analysis.

At the JPAC-CIL, the skeletal elements were found to be in excellent condition, although lighter in weight than is typical for adults. Subsequent radiograph examination revealed general long bone cortical thinning consistent with osteopenia (17). Most skeletal elements retained a greasy texture, and the right leg was entirely encased in dried soft tissue. Sun bleaching was noted on the left side of the cranium and anterior portions of the left upper and lower extremities, indicating that exposure had been in a supine position. Several phalanges from the hands and feet were missing, and their preserved ends exhibited evidence of carnivore gnawing.

Physical examination of the skeletal remains yielded a minimum number of individuals of one and the following biological profile: an adult Asian female aged ≥50 years, with an estimated living stature of 58.0 ± 1.7 inches (point estimate ± 95% confidence interval using the Raxter et al. [18] method). AM trauma included a simple oblique right clavicle mid-shaft fracture exhibiting nonunion and pseudoarthrosis, healed compression fractures of T6 and T7 with ankylosis and kyphosis, L5 spondylolysis with nonunion of the pars interarticularis, healed fractures along the bodies of the right eighth and ninth ribs, and a healed fracture of the sternal end of the seventh left rib. Osteoarthritis was suggested by osteophytic lipping of the C1-C2 and the articulations of several thoracic and lumbar vertebrae.

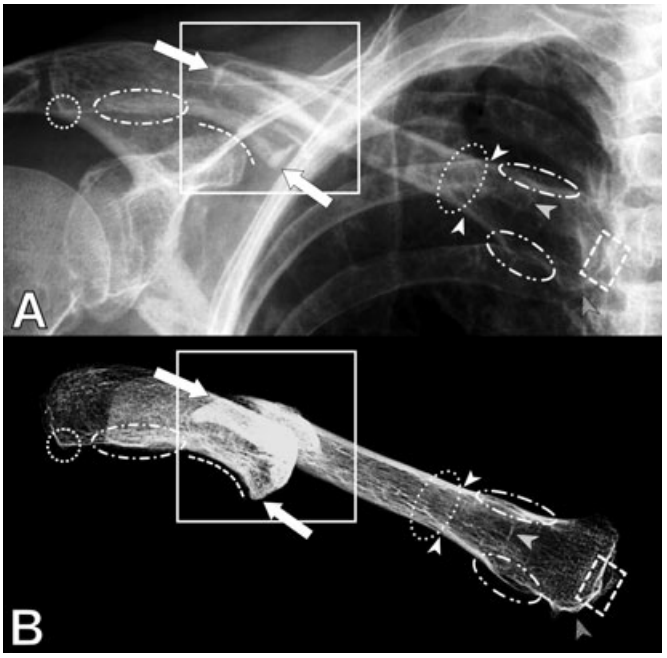

FIG. 1—*Right clavicle antemortem radiograph (A) and postmortem radiograph (B). Large white box shows alignment at fracture location, large white arrows identify change in bone shape at fracture margins. Highlighted points of concordance are presented in Table 1.*

Radiographic Comparison

After the physical examination was completed, six AM radiographs from the suspected missing person were made available for analysis. The radiographs, dated to February 2007, showed an individual's right shoulder, specifically focusing on a fracture of the right clavicle. Although varying in quality and clarity, the radiographs appeared to document the nonoperative steps taken to reduce the fracture.

The AM radiographs were initially converted to a digital format using a Sierra Advantage VIDAR radiograph scanner (VIDAR Systems Corporation, Herndon, VA). Then, the radiograph exhibiting the clearest clavicle morphology was selected for comparison. Next, a series of PM radiographs of the recovered right clavicle were taken using a Hologic® Radex™ digital X-ray machine (Hologic Inc., Bedford, MA) to obtain an image with the clavicle orientated as shown in the AM radiograph. Once a radiograph was obtained that closely matched the AM radiograph, both images were transferred to Adobe® Photoshop® CS3 (Adobe Systems Incorporated, San Jose, CA) where the analysis was performed.

Comparisons were conducted using a procedure similar to that of Adams and Maves (12). This method involves a combination of matching the morphology (size, shape, and orientation) between the AM and PM radiographs and then evaluating them for anatomical concordances.

Results

Remodeling associated with attempted repair from the complete shaft fracture, and altered biomechanical function resulting from pseudo-arthrosis development in the *c.* 12 months following fracture, did not preclude the successful application of radiographic comparison methods on osseous regions removed from the fracture site in this case.

Macroscopically, the change in bone shape (remodeling) was limited to the fracture margins on the PM radiograph (white arrows in Fig. 1), thus preserving numerous individuating characteristics in other regions of the clavicle. Included among these characters was the general shape of the clavicle (Figs 1 and 2), and nine other anatomic features listed in Table 1. Overlays of the PM images on the AM images (Fig. 2) demonstrated the strong correspondence in the fracture location and type in addition to the specific features listed in Table 1.

In summary, the clavicles depicted in the AM and PM radiographs exhibit at least 10 points of concordance reflecting similarities in size and orientation, fracture position, and eight additional morphological similarities. This number of features exceeds Mann's (7) minimum criterion of four points of concordance to establish identity. No discrepancy other than the remodeling along the fracture margins was observed. After reviewing the concordances outlined above and data available for biological comparisons (Table 2), the Medical Examiner of the City and County of Honolulu identified the skeletal remains as the woman in the HPD missing person's report.

Discussion and Conclusion

The rate and degree of fracture healing depends on multiple factors all of which apply to the clavicle (see, e.g., [19]). Consequently, the degree and rate of bone remodeling, and its effect on bone shape and morphology subsequent to the fracture, will likely vary between individuals and should be evaluated on a case-by-case basis. Nevertheless, as demonstrated in this case, remodeling associated with bone fracture healing does not necessarily preclude the comparison of osseous regions adjacent to the fracture site. These findings are consistent with those of Rich et al. (16) who found that radiographic anatomy, captured on postoperative foot and ankle radiographs, continued to be comparable to preoperative radiographs over periods ranging from 2 to 48 months.

While some authors have emphasized the use of either abnormal (see, e.g., [1,20]) or normal anatomic features (see, e.g., [2,21]) in radiographic comparisons, this case highlights the utility of

TABLE 1—*Concordances between antemortem and postmortem radiographs.*

	Label in Fig. 1	Concordance
1	Dotted circle	L-shaped radiopacity along the anteroinferior border of the Cortex near the acromioclavicular joint surface
2	Short dash-dot oval	A broad U-shaped cortical radiopacity along the anterior edge of the deltoid origin
3	Dotted oval and small white arrows	C-shaped radiolucency in the trabecular bone that is opaque inferiorly and translucent superiorly
4	Long dash-dot oval	The two lines of radiopacity separated by a line of radiolucency along the superior clavicle border near the region of sternocleidomastoid muscle attachment
5	Long dash-two dot oval	A broad U-shaped radiopacity on the inferior edge of the clavicle near the region of costoclavicular ligament attachment
6	White dashed rectangle	Y-shaped radiolucency on the sternal edge of the clavicle
7	Gridded hatch filled arrow	Strong linear radiopacity that crosses approximately half the width of the clavicle slightly inferior to the featured noted for the sternocleidomastoid
8	Angled hatch filled arrow	Rounded radiopacity (inverted U-shape) of cortical bone on the medial and inferior edge of the clavicle
9	White dashed line	Form and extent of lateral clavicle fragment inferior curve

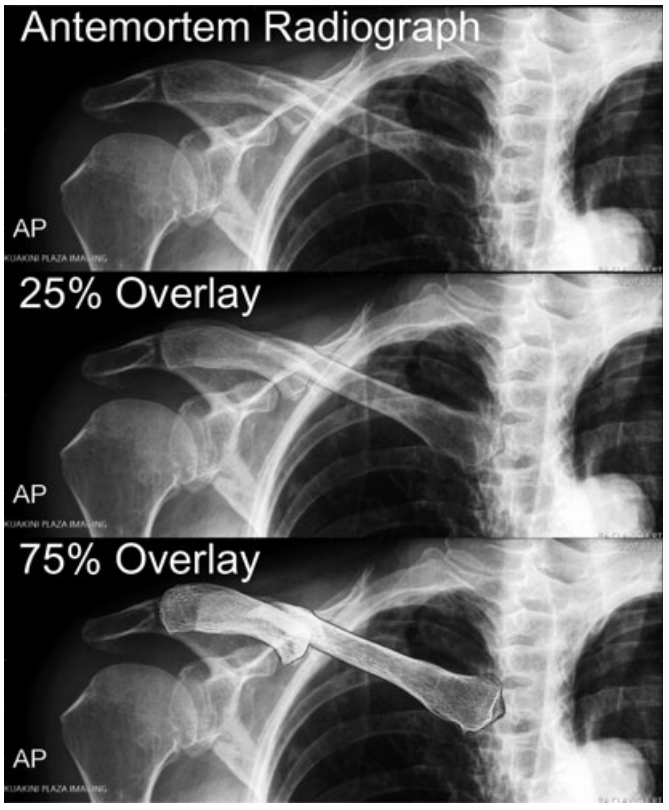

FIG. 2—*Antemortem radiograph, 25%, and 75% postmortem radiograph overlays.*

TABLE 2—*Biological profile comparison between data collected from recovered skeletal remains and information available on suspected missing person.*

	Recovered Remains	Suspected Missing Person
Sex	Female	Female
Age	≥50 years	79 years
Race	Asian	Filipino
Stature	58.0 ± 1.7 inches (point estimate ± 95% confidence interval)	62 inches (driver's license)
Trauma	Healed antemortem vertebral and rib fracture and recent nonunion of right clavicle fracture	History of traumatic falls, one in the 1980s and another in early 2007 that resulted in right clavicle fracture

concurrently using both types of features when abnormal anatomy is present. In those cases where trauma is present, the comparison of both the normal and abnormal anatomy should be undertaken to maximize the surety of the case findings, rather than relying upon congruence in fracture type and site alone.

In the future, it would be useful to establish the point at which, if any, trauma-induced remodeling removes the "preinjury" bony anatomy. In our view, the complete removal of the "preinjury" anatomy will be unlikely except, perhaps, with extremely comminuted fractures and in cases with gross pathological changes. This matter could be definitively elucidated by tracking osseous features before and after extensive trauma incidents.

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