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Skeletal Evidence for Child Abuse: A Physical Anthropological Perspective

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ABSTRACT: Analysis of the skeletal remains of abused children can prove challenging for forensic pathologists and radiographers who are inexperienced in the direct examination of bones. In such cases, radiographically invisible skeletal lesions that document a history of trauma can often be identified by a physical anthropologist with appropriate osteological experience. This is illustrated by cases in which skeletal remains of four murdered children and a mentally handicapped adult produced evidence of antemortem trauma and perimortem injuries that was critical in developing murder cases against the assailants. In these cases, well-healed areas of subperiosteal new bone formation were identified that were below the threshold of radiographic detection. Such injuries provide strong evidence for a history of physical abuse.

KEYWORDS: forensic science, forensic anthropology, child abuse, physical anthropology, skeletal trauma, radiography, homicide, periostitis, fractures

Very little attention has been paid to the problems of identifying child abuse in the skeletal remains of children. For example, Kerley's (1) review of forensic anthropology and juvenile remains includes little discussion of the topic. This lack of published information is unfortunate because cases involving skeletal remains of chronically abused children are common. When abusive parents kill a child, they may surreptitiously dispose of the body and then claim that the child was kidnapped. Under these circumstances, months can elapse before the body is discovered and often a fragmentary skeleton is all that remains.

Cases such as these can prove challenging for forensic pathologists and radiographers, who typically have little experience in the identification and analysis of skeletal remains. The picture of the battered child syndrome seen radiographically is very different from the one that physical anthropologists confront when they examine skeletal material. As we will show, lesions that are radiographically invisible are often apparent when bones are examined directly. On the other hand, signs of recent soft tissue trauma that would have been readily apparent at the time of death are often obscured or lost during skeletonization.

To illustrate these points, we will describe a series of cases in which our analysis of the skeletal remains of murdered children produced evidence of previous trauma and perimortem injuries not apparent to pathologists and radiologists lacking training in skeletal analysis. We will then discuss the diagnostic principles we have developed through working on such cases.

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Case Reports

Case 1

An eleven-month-old child was reported missing by his family. Ten days later, the police found cranial vault bones, femoral diaphyses, and rib fragments of a young child in a rural area near the missing boy's home. Physical anthropological analysis showed that the bones were consistent with a child of the missing boy's age. The mother and stepfather were eventually charged with murdering the child. The mother was convicted of second degree murder. The step-father was convicted of being an accessory to murder, felony child endangerment, and felony child abuse.

Although carnivores had reduced the skeleton to a few bones, the material that remained provided substantial evidence for chronic physical abuse. Three episodes of cranial trauma are suggested by lesions on the right parietal. A 15 mm long, y-shaped fracture on the posterior part of this bone has sharp edges that bevel internally with no evidence of healing (Fig. 1). The shape of the defect suggests that the object that produced it concentrated a considerable amount of force just above the fracture line. Although it is conceivable that this is a postmortem fracture caused by the body being dropped on a pointed object, this is unlikely. Studies of cranial injuries in children show that short distance falls seldom produce cranial injuries such as this (2,3). The injury does not show the conical indentations characteristic of carnivore damage (4). Evidence presented in the trial revealed that this fracture resulted from the boy's head being beaten against the corner of his crib. This injury appears to have been the cause of death.

In addition to the fracture, the external surface of the parietal has two roughly circular, 1–2 cm in diameter areas of subperiosteal (pericranial) new bone formation (Fig. 1). These lesions are responses to two episodes of blunt force trauma. Their stage of healing suggests that the injuries occurred several weeks or more before death. One lesion is just above the fracture. It is well-healed, with new bone beginning to smooth its edges and fill in the vascular porosities in its surface. The possibility was considered that the fracture and this lesion resulted from a single blow. The difference in healing between the two lesions (none versus considerable), however, makes it clear that their juxtaposition is fortuitous.

The second area of new bone formation is located a few centimeters anterior to the fracture (Fig. 1). Its edges are sharply delimited

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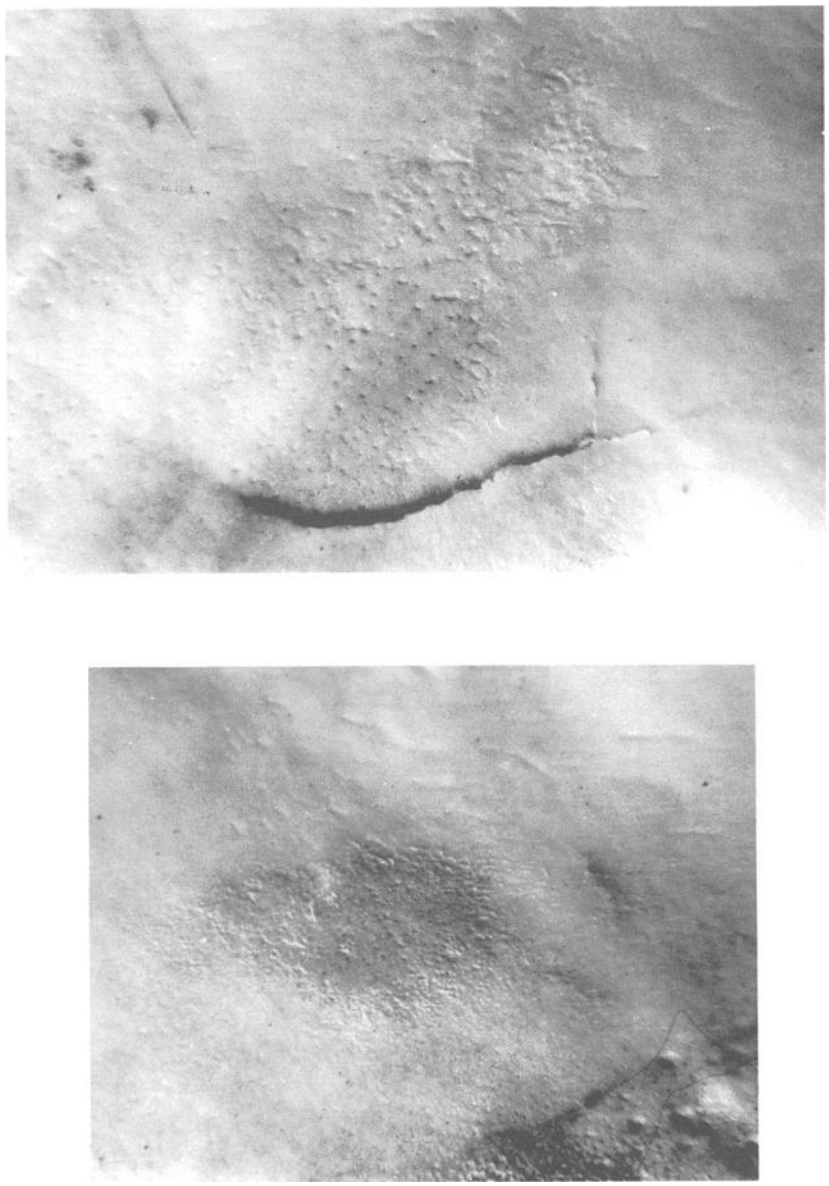

FIG. 1—*(Top) A 15-mm long, y-shaped fracture on the right parietal of Case 1. The fracture has sharp edges that bevel internally with no evidence of healing. Above the fracture is an area of subperiosteal new bone formation from an earlier cranial injury that shows considerable evidence of healing. (Bottom) A 21-mm wide area of area subperiosteal new bone formation located a few centimeters anterior to the first lesion. This injury shows much less remodeling than the lesion associated with the fracture in the top of this figure and probably resulted from a different assault.*

and porosities in its surface show little remodeling. This suggests that it is more recent than the well-healed lesion. Neither of the healed cranial injuries were associated with macroscopic pathological changes on the internal surface of the skull.

Both femoral fragments have areas of subperiosteal new bone formation on their anterior surfaces that are consistent with severe premortem trauma to the thighs. The lesion of the right femur is on the proximal end of its shaft and is 0.5 cm wide and 2 cm long. The lesion on the left side is on the distal end of the fragment and is larger than that on the right femur. Although both injuries show considerable healing, the right side has progressed further than the left. It is possible, therefore, that they reflect two different traumatic episodes.

Testimony given at the trial of the parents verified that this child was beaten on the legs. The mother told a witness who came to the aid of the crying child that she slapped his legs "because he wouldn't take a nap." Although rib fractures are a common finding in child abuse (5,6), careful examination of the 18 ribs and rib fragments retrieved from the burial site revealed no evidence of antemortem trauma.

Case 2

Police investigating a report of a boy who had been missing for five years discovered the partially skeletonized remains of the three-year-old child in the trunk of his parents' car. The parents

initially told investigators that they buried the boy after he died while taking a bath. It soon became clear that they had carried his body in their car for five years. The initial autopsy was inconclusive regarding cause of death, and the parents were charged with illegal disposal of a body. A subsequent analysis of the remains by one of us produced evidence of perimortem injuries and severe physical abuse over a prolonged period. Because of these findings, the parents were charged with second-degree murder and eventually pled guilty.

Dental development and long bone dimensions suggest an age of 3–4 years at the time of death. Age estimates based on Retzius line and cross striation counts in histological sections of the child's teeth are consistent with evidence that he was 3 years, 7 months old when he died.

Cleaning the cranial bones of desiccated soft tissue revealed a linear fracture of the left occipital bone extending from the foramen magnum to the lambdoid suture. There is evidence that the child survived for several weeks or more after sustaining this injury. A 3.5 cm^2 area of subperiosteal new bone formation is evident below the lambdoid suture on the left side. It is confined to the occipital bone and extends to the fracture line (Fig. 2).

Gross examination and histological analysis show that the area of new bone formation records at least two stages of healing. Most of the affected area lacks large porosities, is comparatively dense, and is beginning to reintegrate with the external surface of the occipital. This suggests a month or more intervened between the injury that produced this lesion and death. Along the borders of the fracture, the well-healed bone is overlaid by bone from a second, more recent, episode of new bone formation. Although this bone is more porous than the underlying bone, it would require more than a week to form. In some areas, the edges of the fracture are beginning to remodel.

There are several possible interpretations of these superimposed areas of bone in different stages of healing. It is conceivable that the well-healed area is associated with an old injury unrelated to the cranial fracture, as was found in Case 1. Alternatively, the well-healed area may be associated with a hematoma that formed at the time of the fracture. After an interval of healing, a second episode of trauma could have occurred. Bleeding associated with a second injury to the healing fracture, could thus account for the less well-healed lesion along the fracture's margins.

Disruption of the healing process in this way by multiple traumatic episodes is common in child abuse cases. Parents who chronically beat their children are reluctant to seek medical treatment because they fear their abusive behavior will be discovered. This lack of treatment in combination with repeated trauma makes precise conclusions about the timing of specific injuries difficult.

An upper and a lower incisor of this child have antemortem fractures of their occlusal surfaces with evidence of subsequent wear. Although fractures of this type are common in children and would otherwise be unremarkable, their presence here is consistent with the high frequency of such injuries in abused children (7) and reinforces the conclusion that this child was injured repeatedly.

The sternal end of the child's right clavicle has a healed fracture, and the left radius and the ulna exhibit areas of subperiosteal new bone formation suggesting antemortem forearm trauma. The ulna has an area of subperiosteal new bone on its distal half that nearly encircles the shaft (Fig. 3). The radial lesion is located on the proximal half of the bone and is confined to the anterior and lateral surfaces. No other long bones showed evidence of subperiosteal new bone formation. A traumatic origin is suggested by the asymmetrical distribution of these subperiosteal injuries in vulnerable areas where bones are close to the surface of the body. The borders of the lesions are beginning to become integrated into the cortical bone of the radius and ulna. This healing suggests that a month or more elapsed between the injury that caused them and death. None of these long bone lesions were visible on high resolution radiographs taken with no-screen film.

Radiographs reveal many Harris lines in the long bones. Harris lines are produced when a child's growth resumes after a period of disruption caused by conditions such as injury, infection, and psychological stress (8,9,10). Analysis of radiographs using an image analysis system revealed 15 Harris lines in the distal 18 mm of the radii that occurred at the same positions in the bones of the right and left sides. Although some Harris lines are normally present in children of this age, and do not by themselves constitute evidence of abuse or neglect, this number is unusual. Fewer than 5% of children between the ages of 2.5 and 4 years have as many Harris lines in the distal 1 cm of the radius as does this child (10).

Additional evidence on the timing and frequency of growth disruption was obtained through the analysis of tooth histology. Because of the incremental nature of tooth development, tooth histology preserves a precise chronological record of a person's development (10). This child's teeth contained several accentuated lines of Retzius, indicating disrupted dental development. The last of these dates to about two months before death and may coincide with the assault that caused his cranial injury.

Case 3

The skeleton of a child was found near the house of parents who were eventually prosecuted for murdering their three-year-old girl. The parents claimed that they had abandoned their baby in another city and that the remains were thus not those of their child. They were convicted of murder, but the judge overturned the jury's ruling.

The skeleton of this child is well preserved and nearly complete. Dental development and long bone dimensions suggest an age of 2–3 years that is consistent with the missing girl's age. An apical bone in the skull and in radiographs of the missing girl adds further credence to the identification of this skeleton as hers.

This child's long bones have areas of subperiosteal new bone formation in different stages of healing like those described in Cases 1 and 2. One lesion is on the anterior side of the left fibula near the middle of the shaft. It has raised margins and is just beginning to heal (Fig. 4). The left radius has an older, 12 by 6 mm lesion on the dorsal side of its distal end. The remodeling process has progressed to the point that the lesion's center is beginning to become smooth and its edges blend into the bone's surface (Fig. 5). The left and right ulnae also have similar lesions on the dorsal sides of their distal ends.

This child's subperiosteal lesions suggest that she suffered several severe antemortem traumas. The asymmetrical distribution and different stages of healing of the lesions are consistent with the interpretation that this child suffered from chronic physical abuse.

Case 4

An especially severe example of child abuse is provided by the case of a seven-year-old girl whose body was exhumed for autopsy $19^1/_2$ years after her death. The exhumation was precipitated by the statements of siblings who had witnessed their sister's death. Although the skeletal evidence resulted in the child's mother being charged with murder, she died during the pretrial discovery period.

FIG. 2—*A close-up ectocranial view of the left occipital fracture in Case 2. The raised area of bone in the lower half of the photo is part of a well-healed of subperiosteal lesion possibly dating from earlier trauma. Superimposed upon this is a layer of less well consolidated new bone formation along the margins of the fracture. Bridging of the fracture suggests that it occurred more than a week before death.*

The exhumed skeleton was essentially complete and mostly in good condition. Some bones were soft and had exfoliated on their dorsal side where they contacted the coffin's floor. A black mass on the anterior alveolar bone of the mandible appeared to be a hematoma.

Dental development is consistent with the known age of seven years. Long bone lengths are at the 10th (femur, tibia, fibula, humerus) or 25th (radius, ulna) percentile of the Maresh (12) growth standards for seven-year-old, middle class Colorado girls.

The skeleton showed evidence of repeated trauma over a prolonged period. Among the skeletal lesions are healed fractures of the nasal bones, tibia, radius, ulna, and hand. The ribs and ischium had more recent healing fractures. Layered areas of subperiosteal bone formation on the cranial vault, nasal bones, and mandible are asymmetrically distributed and show mixed stages of healing. These injuries point to a chronic pattern of physical abuse.

Medical records show that the child underwent cranial surgery for a subdural hematoma three months before death. This procedure is evidenced by a surgical scar on the left parietal and frontal including five trephine holes and an ununited roundel (Fig. 6). These lesions are of interest because they provide information on the rate of bone repair in this child. There is fine, partially consolidated new bone on the margins of the trephine holes and dense, ivory-like bone under the metal clips used to stabilize the roundel. Although there is no bridging across the lesions, the repair tissue surrounding the trephine holes is well consolidated (Fig. 6). Fine, partially consolidated, new bone extends across the area of the surgery and presumably corresponds to the flap used to expose the skull.

Besides the evidence of surgery, there are areas of irregular, healed subperiosteal new bone formation on the right frontal and parietal. These lesions are more consolidated and, therefore, older than the surgical scar. Patches of fibrous new bone formation are also present on the right zygomatic process of the frontal and right parietal above the temporal lines. These lesions are poorly consolidated and therefore more recent than the surgical scar.

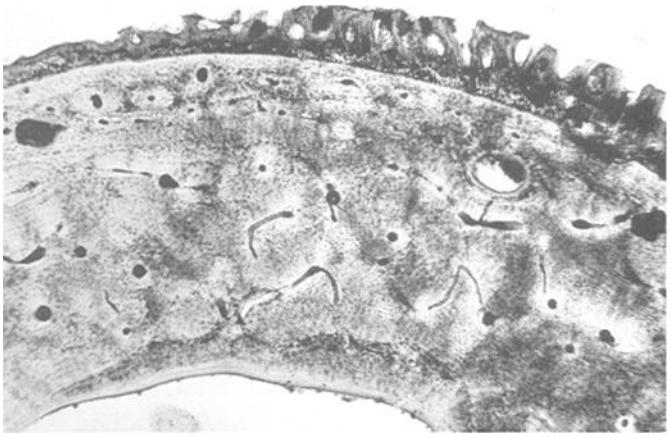

FIG. 3—*Cross-section of radius in Case 2 showing the histological appearance of subperiosteal new bone formation in response to trauma. Compare the normal subperiosteal bone at the margin of the lesion (upper left) with the thickened layer of highly vascularized bone near the center of the lesion (upper right).*

There are also healed fractures of both nasal bones and the right nasal process of the maxilla with depressed bone fragments and a thick, consolidated fracture callus. These fractures appear to be older than the surgical scars. This is consistent with medical records that show the child suffered from a nasal septum fracture when she was three.

Additional evidence of repeated facial trauma consists of subperiosteal new bone formation on the facial and inferior surface of mandible extending forward on either side from the level of the deciduous second molar. This area is composed of three layers. All of them are less consolidated and probably more recent than the surgical scars. Radiographs show fairly extensive reorganization of the underlying cortex. The new bone at the chin shows some consolidation.

There is fine, porous new bone from the level of the second incisors laterally, and there are patchy, coarser elevations on the surface of this new bone that are less consolidated and therefore more recent. Between the second incisor roots there is a large area of necrotic bone surrounded by fibrous new bone that does not adhere to the necrotic bone underneath it. This area is 3 to 4 mm thick and probably began to develop several weeks before death. The overall appearance of the lesions is consistent with repeated blows to the chin over a prolonged period. The lack of similar injuries on the maxillae suggests that these lesions are from purposefully inflicted blows and not the result of falls or other accidental trauma.

There are also many post cranial injuries. Old, healed fractures are present in the left distal radius and ulna, right distal humerus, both clavicles, and the left tibia. The tibial, radial, and ulnar fractures are well consolidated and probably older than the others. The radial and ulnar fractures passed through the metaphysis and disrupted the joint. The directions of the breaks are longitudinal and suggest a twisting or crushing force. The orientation of the tibial fracture also suggests a twisting force. The clavicular fractures are greenstick fractures. Their location at the midshaft and the conoid tubercle suggests that they were produced by blows.

Areas of active subperiosteal new bone formation are present on the anteromedial sides of the tibial shafts, the posterior sides of the ulnar shafts, and supinator crest areas of the radial shafts. Additional lesions, apparently of traumatic origin, are present in the distal humerus and the hands.

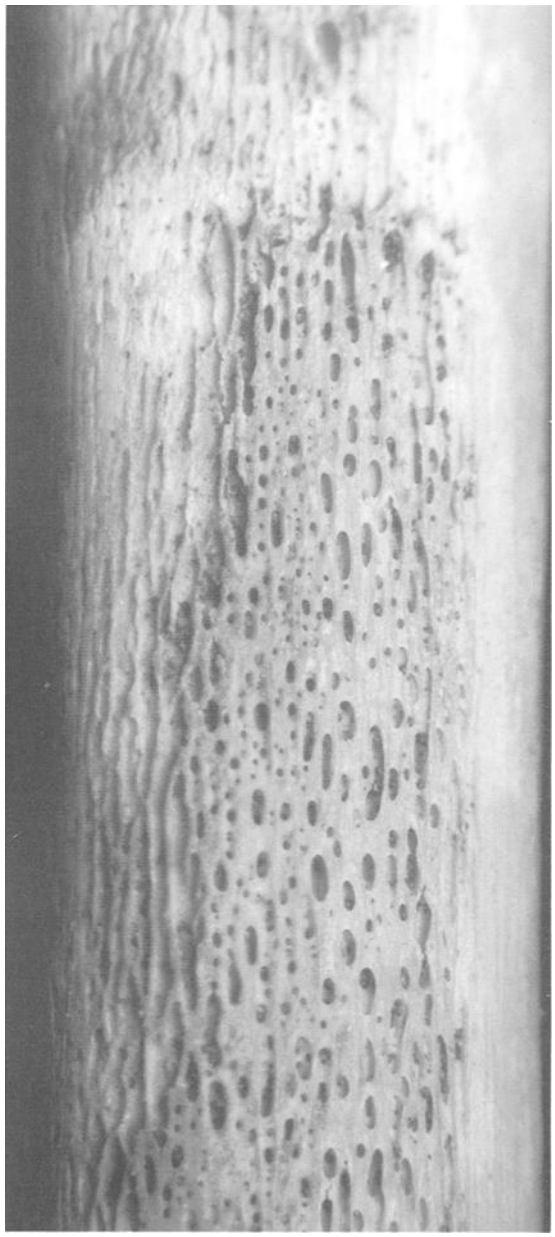

FIG. 4—*Area of subperiosteal new bone formation on the fibula of Case 3 showing porosities and sharp margins indicative of recent healing. Some of the lesion at the top of the photo has been lost through postmortem damage.*

The girl has many rib fractures in different stages of healing. Old healed fractures are present in two left ribs and four right ribs near their angles. The head of right rib 11 has a recent incomplete fracture with a callus formation that is perhaps 2 to 3 weeks old. Loose subperiosteal new bone is also present on three additional ribs.

Finally, there is a hairline fracture on the lateral aspect of the left ischium with a partially consolidated callus. An area of recent subperiosteal new bone formation from a bone bruise or periosteal tear is also present anterior to the left auricular surface of the os coxae. A similar lesion on the right side is less extensive.

This girl's injuries clearly show that she suffered from repeated episodes of severe physical abuse. It is difficult to see how this pattern of injuries could be produced other than by repeated blows

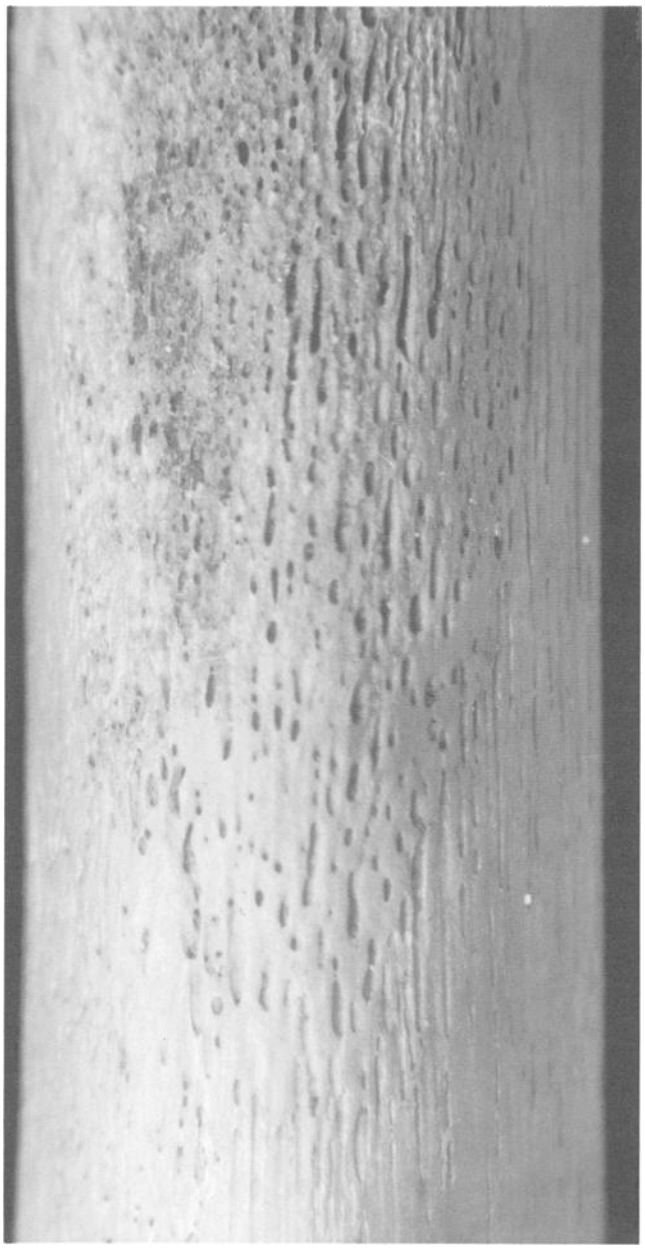

FIG. 5—*Area of subperiosteal new bone formation in the radius of Case 3 showing smoothing and the integration of the margins of the lesion into the cortex indicative of advanced healing.*

over a prolonged period. The pelvic and rib fractures are particularly difficult to explain any other way in a small child. Lesions on the mandible, vault, ribs, and pelvis are both older and more recent than the surgical scar. This suggests a pattern of chronic abuse in which the assailant concentrated on these areas.

It is worth noting that this child had very poor dental health with rampant caries. The poor dental health and absence of evidence for dental care is consistent with the findings of Greene, Chisick, and Aaron (13). These researchers compared the oral health status of abused and nonabused children and found, after controlling for other variables, that abused children are eight times more likely to have untreated, decayed permanent teeth than nonabused children.

Case 5

Our final case is unusual because it involves physical abuse that continued into adulthood. A 35-year-old mentally retarded man was reported missing by his aunt. It was generally assumed that he had wandered away. His mother and her boyfriend with whom he had resided did not seem concerned about his whereabouts. A neighbor observed that the missing man had some serious injuries a few days before he was reported missing. A concrete mason, who knew of the disappearance, became suspicious and called the police when the mother's boyfriend asked him to pour a concrete floor in the family's barn. As a result, the missing man's partially decomposed body was discovered buried in the floor of a barn stall 11 months after his death. Autopsy revealed that severe blunt force and chopping wounds of the face, neck and back had caused his death. The mother's boyfriend was eventually convicted of murder.

At the autopsy, the skeleton was cleaned of soft tissue. This revealed many skeletal injuries. Differences in healing show that these occurred during at least four episodes. Injuries inflicted at the time of death include neural arch or transverse process fractures of 13 vertebrae and many ribs, a cut in the right mandible, and fractures of the left maxilla and zygomatic. Hematomas related to these injuries were still visible in soft tissue remains.

Injuries occurring within two weeks of death, showing surface resorption of margins but no periosteal bone formation, include many rib fractures, fractures of the nasal area, alveolar fractures, avulsion of three upper incisors, and a fracture of the right sphenoid.

Injuries occurring within two weeks to a few months of death with evidence of fibrous new bone formation include many rib fractures (Fig. 7), a fracture of the transverse process of the second lumbar vertebra, multiple scapular fractures, a fracture of the right zygomatic arch and posterior wall of maxilla, a healing bone bruise of the left ascending ramus of mandible (Fig. 8), and bone bruises of the femora and left tibia.

Well-healed injuries at least six months old include many rib fractures and transverse process fractures of thoracic vertebrae 10 and 12. There are also well-healed areas of subperiosteal new bone formation on the 11th and 12th ribs, gladiolus, right femoral shaft, left zygomatic process of the frontal, and the dorsal surfaces of the metacarpals of both hands.

These injuries are consistent with a pattern of repeated abuse in which the head and torso were beaten. The injuries causing death show the same distribution, and are merely more severe than the healed injuries.

We include this case to illustrate that skeletal evidence on the timing of injuries can contribute to discovering abuse of adult dependents as well as of children. The boyfriend was tried and convicted. During the trial, the defense attempted to attribute the healed injuries to a fall from a tree.

Discussion

These cases highlight several types of evidence physical anthropologists can provide that are often crucial in the prosecution of child abuse cases based on skeletal evidence. This includes information on age at death, manner of death, and evidence suggesting that the child was the victim of chronic, patterned physical abuse.

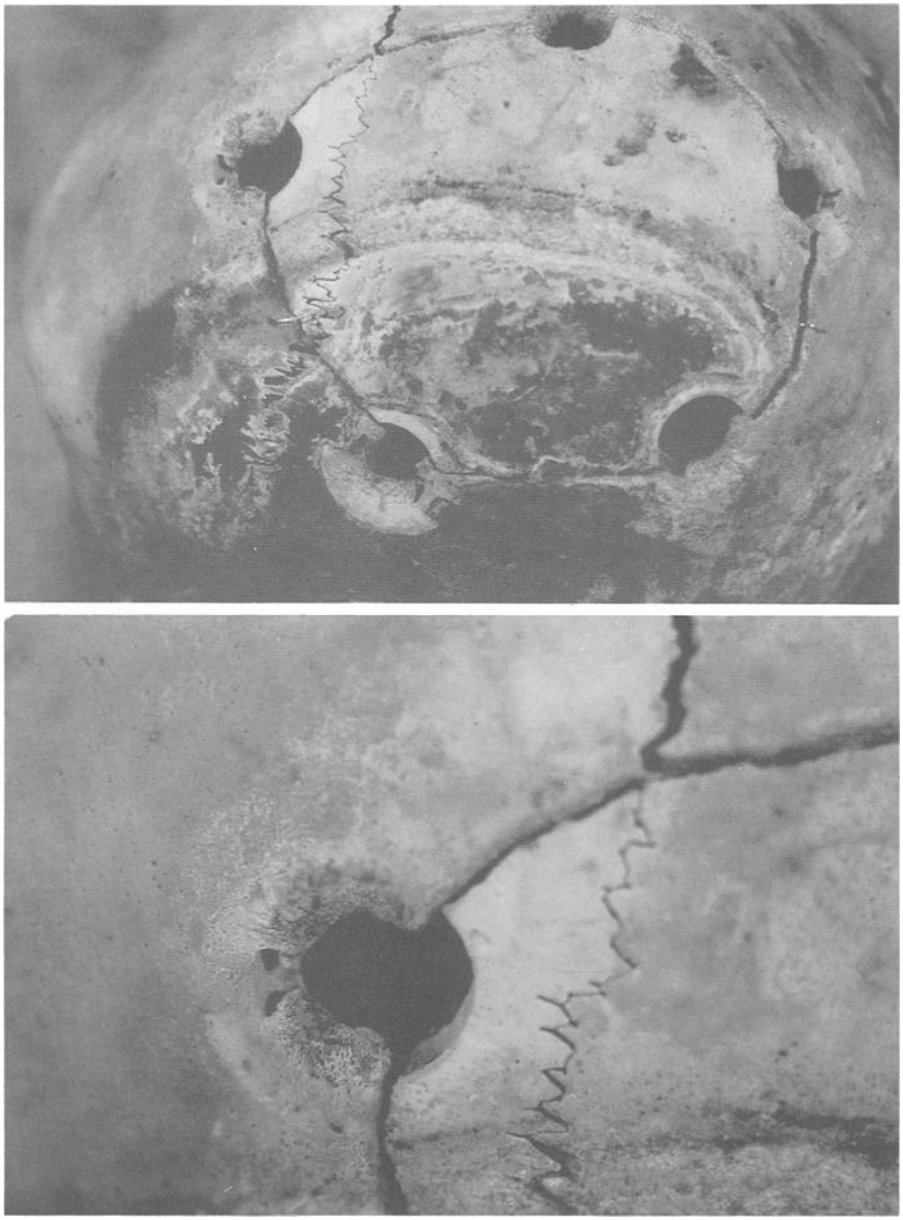

FIG. 6—*(Top) A surgical scar on left parietal and frontal including five trephine holes and an ununited roundel associated with the treatment of premortem cranial trauma in Case 4. This surgery occurred three months before death. Fine, partially consolidated, new bone extends across the area of the surgery. (Bottom) Close-up view of the trephine hole in the frontal bone near the coronal suture. There is fine, partially consolidated new bone on the margins of the trephine. Although there is no bridging across the lesions, the repair tissue surrounding the trephine holes is well consolidated.*

Age Determination

The anthropological literature on determining age at death from the skeletal remains of children is well summarized in standard texts (14,15,16,17). A few important points, however, are worth considering. Fragmentary skeletons of children are often difficult to age because the features used in conventional aging methods have been lost. In such cases, it may be necessary to improvise an aging technique. For example, in Case 1, the absence of standard aging criteria (teeth, long bone lengths, etc.) required some improvisation. An estimate of the circumference of the child's head was obtained by reassembling the cranial vault bones. After correcting for soft tissue thickness, this measurement was compared with cranial circumference growth standards (18). A second set of age estimates was obtained based on the transverse diameters of the femoral diaphyses using equations derived from the regression of these dimensions against long bone lengths of children from archaeological sites (19).

Age and Abuse

Injury patterns in child abuse are closely related to the victim's age. For example, fractures in children under the age of three are much more likely to be from abuse than are fractures in older children (20). The average age of the battered children with fractures surveyed by Loder and Bookout (21) was 16 months. Children in this age group are also more likely than older children to have multiple fractures and bruising of the head and neck. One child

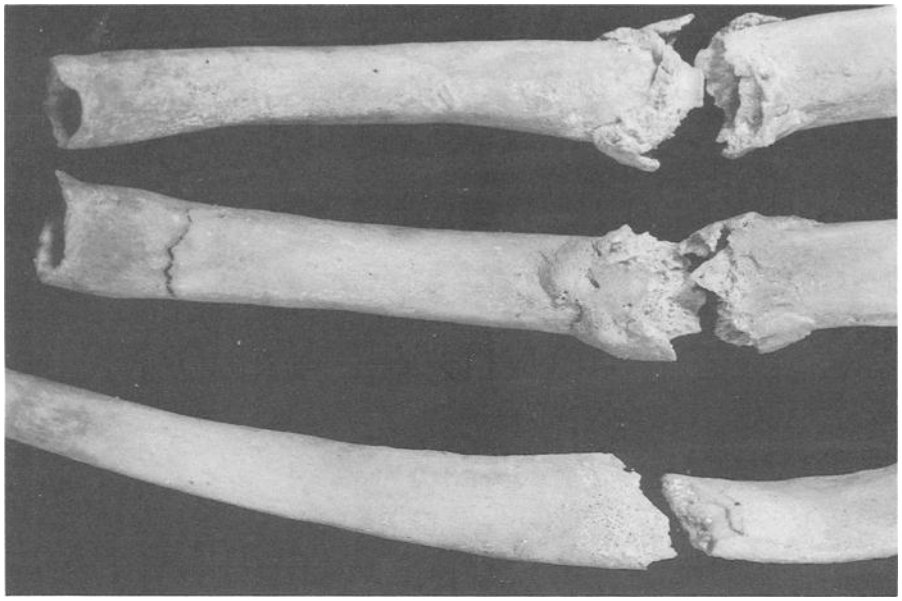

FIG. 7—*Rib fractures in Case 5 with fibrous new bone formation indicating that they occurred within a few months of death. The rib in the middle of the photo has a perimortem fracture near its sternal end.*

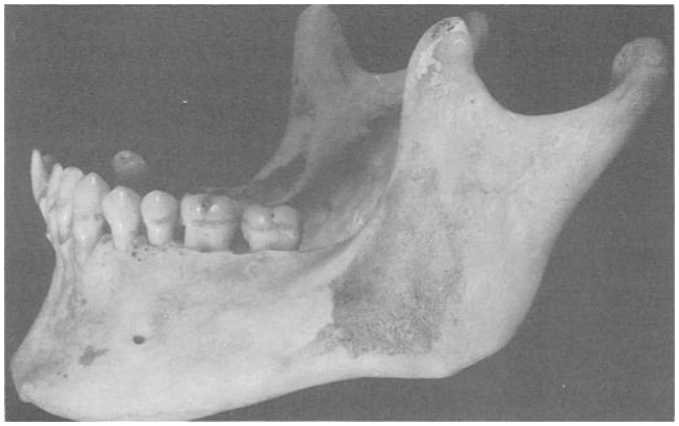

FIG. 8—*A healing bone bruise of the left ascending ramus of mandible in Case 5. The consolidation of the new bone suggests that the injury occurred several weeks before death.*

in eight aged under 18 months who suffers a fracture is likely to be an abuse victim (22).

The frequency of fractures produced by severe physical abuse decreases rapidly with increasing age. This age effect undoubtedly is related to the ease with which small children can be held by their arms, legs and so on and beaten. Such abuse becomes more difficult to inflict as children become older because of their greater size and capacity to resist abuse.

That older children sometimes do sustain fractures is illustrated by two of our cases. The seven-year-old girl (Case 4) had several healed fractures. However, some of these may have been sustained earlier in her childhood. The 35-year-old mentally retarded man (Case 5), on the other hand, experienced fractures from severe physical abuse over a period of about a year. This points out the importance of being especially vigilant in cases involving handicapped individuals because of their vulnerability to abuse. In one study of mentally handicapped children and adolescents, over 11% were found to suffer from some form of maltreatment (23).

Types of Fractures

Skeletal injuries from child abuse have some distinctive features rarely seen in other circumstances. Rib fractures without major chest trauma, for example, are a strong indication of abuse (23). Child abuse tends to result in bilateral, multiple rib fractures close to the spine such as some of those we described in Case 4. In infants, this kind of fracture typically results when an adult assailant grasps the victim's chest with both hands and shakes or squeezes it. Compression of the chest in this way fractures ribs near their vertebral ends (24,25).

Spiral fractures and metaphyseal injuries are commonly seen in the long bones of abused infants (22). These fractures are often produced when an arm or leg is grasped and forcefully twisted. Metaphyseal injuries such as chip fractures are also common in child abuse. These injuries are frequently multiple and often occur when an infant is held by the trunk or extremities and violently shaken (26). High risk metaphyses for this kind of injury include the proximal humerus, knee, and distal tibia.

Diaphyseal fractures are usually easily identified in skeletal remains through radiography and gross examination. We have found, however, that gross examination sometimes reveals surface irregularities from old, well-healed injuries that are not apparent in radiographs. Metaphyseal injuries and fractures, in contrast, are often very difficult to identify in skeletal material because of postmortem damage.

Although cranial fractures associated with abuse are similar to those produced accidentally, multiple fractures, bilateral fractures, and fractures crossing sutures occur more often in abused children than in accident victims (27). In child abuse cases, cranial fractures tend to be simple linear fractures; depressed and comminuted fractures are rare.

Multiple Injuries

Although identifying child abuse based upon skeletal remains poses special problems, the basic principals developed in the radio graphic literature on the "battered child syndrome" apply (20). Of greatest significance is the presence of traumatic injuries in several

locations in different stages of healing (28). This is an indication of repeated episodes of abuse. An accidental explanation becomes increasingly unlikely as the number of traumatic episodes increases.

Our cases illustrate many features that have become recognized as diagnostic of the battered child syndrome. Multiple injuries in different stages of healing were present in all of these individuals. For example, in Case 1, a fatal cranial injury was superimposed upon an earlier one, and in Case 4, the layering of periosteal new bone suggested multiple traumatic episodes.

Subperiosteal Lesions

Much of the evidence of chronic abuse in our cases comes from the identification of localized, asymmetrically distributed subperiosteal lesions in different stages of healing. These are thin layers of new bone that form beneath the periosteum in response to trauma and subperiosteal bleeding.

The subperiosteal lesions we have encountered fall into two groups. Some of them are a result of the stripping of the periosteum from the bone that occurs when an arm or leg is used as a "handle" to punish the child violently (29). The forces applied by the adult hand in such circumstances are predominantly traction and torsion. They are likely to result in epiphyseal separations and periosteal shearing, especially in the metaphyseal area (30). Infants are especially susceptible to this kind of injury because their periosteum is loosely attached to the cortex (31).

A different type of subperiosteal lesion results when the child is hit with a hand or hand-held object, or when the child is lifted and beaten against an object. Lesions produced in this way are likely to be in areas with little overlying soft tissue, such as the cranial vault, where the bone is especially vulnerable to this kind of trauma (Fig. 1). These injuries are primarily a result of tissue damage and bleeding owing to localized compressive forces. To some extent, the shape of such lesions will conform to the shape of the object that produced them.

Lesions of both types are found more frequently in the skeletal remains of abused children than might be expected based on the radiographic literature. The reason for this is clear; many bone scars from earlier abuse have healed enough to be below the threshold of radiographic detection. In the initial stages of the healing process, such injuries can be clearly seen in radiographs because of the elevation of the periosteum and the low density of the repair bone that forms within the associated hematoma. If death occurs at this point, there may be no skeletal evidence of the child's antemortem injury because the underlying cortical bone has not yet been affected and the unconsolidated repair bone is lost. However, if several days have elapsed since an assault, signs of necrosis on the underlying cortical surface may be visible upon close examination. Soon, a layer of subperiosteal new bone begins to form and after about eight weeks this layer gradually begins to blend into the old cortex (32). Such lesions are often thinner than 1 mm. Thus by definition, in some classificatory systems radiographers use, they are not considered clinically significant periosteal reactions (33). Subtle surface signs of resorption and the beginnings of new bone formation are visible upon gross examination after two to three weeks in adults (34). Research to obtain information on the timing of comparable changes in the gross appearance of lesions in children would be highly desirable.

Although healed lesions such as these are readily apparent to a physical anthropologist experienced in skeletal analysis, they are often less than 0.5 mm thick, have smooth margins and are impossible to detect on radiographs even when known lesions are specifically targeted using high resolution, no-screen film.

In our experience, multiple lesions of this type in different stages of healing are only found in the remains of children who have suffered from severe physical abuse. For example, we have not observed them in the skeletal remains of several children who were kidnapped from nonabusive parents and killed by their abductors.

More telling, however, is their absence in the remains of prehistoric children. Collectively we have examined 5,000 or more skeletons of prehistoric children from various parts of the world (35,36). Within this extensive series, we have seen no cases comparable to those described in this paper even in contexts in which children appear to have been frequent victims of warfare. Although accidental trauma may occasionally produce areas of subperiosteal new bone formation, in our experience this is a rare occurrence. Many of the prehistoric children whose remains we have examined lived active lives in hunter-gatherer populations and undoubtedly had numerous opportunities for accidental injuries. The absence of children with multiple, asymmetrically placed subperiosteal lesions in different stages of healing in such a large skeletal series suggests that the behavior pattern responsible for the battered child syndrome is a modern phenomenon.

The rarity of healed subperiosteal lesions in children who have not been physically abused has important forensic implications. First, it can help investigators differentiate deaths associated with a pattern of chronic physical abuse from accidental deaths or those caused by an isolated abuse episode. As our Case 1 illustrates, it is common for chronically abusive parents who kill their child to dispose of the body in a remote area and then claim that the child was kidnapped. In such cases, skeletal material is often all that remains. If these remains show evidence of chronic physical abuse, this suggests that the parents may be responsible for the child's death. If, on the other hand, no skeletal evidence of previous abuse is found, this gives more credence to the statements of parents who maintain their child was abducted.

Differential Diagnosis

It is important to be aware of conditions that produce skeletal changes similar to those resulting from child abuse. Areas of periosteal new bone formation in long bone metaphyses are normal during the first six to eight months of life (37,38). This so-called periostitis of growth can be confused with periostitis of infectious or traumatic origin by someone lacking osteological experience. Fractures of the ribs, clavicle, and humeral midshaft are fairly common forms of birth trauma and are sometimes confused with child abuse (39). Other conditions that should be considered in the differential diagnosis of periosteal lesions in suspected child abuse cases are osteogenesis imperfecta, congenital indifference to pain, congenital syphilis, rickets, scurvy, hemophilia, vitamin A intoxication, infantile cortical hyperostosis, leukemia, Menke's syndrome, and drug-induced lesions such as those associated with prostaglandin E1 therapy (30,40,41,42,43).

Growth Disruption

The growth of chronically abused children tends to be retarded in comparison to nonabused children (44,45,46,47,48,49). Evidence for this abuse-related growth disruption is present in some, but not all, of our cases. The severely abused seven-year-old girl in Case 4 and the adult in Case 5 were both of short stature. In

Cases 1 and 2, however, skeletal dimensions suggest that these boys were of normal size.

The presence of abuse-related stunting has several implications for the forensic analysis of skeletal remains. First, the age estimates of abused children based on skeletal indices are likely to be younger than the child's actual chronological age. Such a discrepancy might become an issue in forensic cases in which the identification of a skeleton as that of a missing child is a matter under dispute. On the other hand, if the remains of a specific child have been positively identified, the presence of stunting may strengthen the case for chronic abuse when used in conjunction with other evidence. It should be noted in this respect, that among the urban poor both nonabused and abused children are likely to be small when compared with national growth standards (44). Wasting, in contrast, is significantly more common among physically abused children.

As Case 2 shows, radiographic and histological evidence of growth disruption can aid in the detection of a history of physical or psychological abuse. The teeth are especially useful in this regard because their histology faithfully records the metabolic history of a child until the time of death. This makes it possible to estimate the chronological sequence of growth disruption episodes with considerable precision (50). As Case 2 illustrates, such information may prove useful in forensic contexts because it suggests a chronology of antemortem traumatic episodes. The presence of many transverse lines of increased density (Harris lines) in radiographs of long bones may also be useful in this regard because they can also be used to date episodes of prenatal and postnatal growth disruption (51). It should be noted, however, that the resorption of these lines with increasing age (10) makes interpreting variation in their frequency difficult. Also, because they record the resumption of growth, children who experience chronically unfavorable conditions will tend not to show them. It is important to emphasize that both Harris lines and dental indications of growth disruption can result from many causes unrelated to abuse.

Aging Injuries and Healing Rates

Evidence concerning when specific skeletal injuries occurred is often crucial in the identification and prosecution of child abuse homicide cases. The discovery of multiple lesions in different stages of healing is evidence for a pattern of chronic abuse. The child in Case 4, for example, had injures dating from many different abuse episodes. Some of her well-healed fractures undoubtedly were incurred when she was an infant. The healing facial and rib bruises and the pelvic lesions, on the other hand, reflect abuse shortly before death. Data on the timing of injuries such as these can reveal discrepancies between the assertions of an abusive parent and the actual pattern of abuse. For instance, the severe cranial injury with evidence of healing in Case 2 was inconsistent with the mother's assertion that the child was perfectly healthy before his sudden death.

Episodes of skeletal trauma often cannot be dated with great certainty. The nature of the injury, presence of infection, and constitutional factors can alter healing rates. Age is also an important factor. Healing rates are faster in rapidly growing children than in adults and may also decrease as a child becomes older (29,30,52,53).

In cases of chronic physical abuse, estimating the time at which an injury was sustained is further complicated by the reluctance of abusive parents to seek medical attention for their children and the often stereotypic pattern of their abusive behavior. For instance, in Case 1, the boy's thighs appear to have been a favorite target of the mother, and in Case 4, the girl's chin was repeatedly traumatized. Stereotyped abuse patterns such as these complicate the healing process enormously because it is repeatedly interrupted by additional trauma. This produces skeletal lesions composed of several superimposed layers of bone showing different stages of healing like those we observed in several of our cases.

Unfortunately, most discussions of healing rates in the clinical literature are anecdotal and refer to the radiographic appearance of lesions. As a result, they are of limited value in deciding the chronological significance of differences in the gross morphology of lesions in skeletonized specimens.

Dating the areas of subperiosteal new bone formation we encountered in all these cases is especially problematic. During the early stages of healing, calcified subperiosteal hematomas are easily identified radiographically. In cases involving skeletal remains like those we have described, evidence of such an early stage of healing is seldom preserved. Within a few weeks, these lesions continue to be visible radiographically as raised or irregular areas. At this stage, they can also be seen upon gross examination of skeletal remains. Although they continue to be visually apparent on bone surfaces, after a few months they can become radiographically invisible. As a result, very little is known about the changes that occur in their gross morphology and histology with increasing age.

Developing ways to estimate the age of such injuries is an area in which much more research is needed. One way to do this is to collect autopsy data on the gross appearance and histology of dated injuries such as the one illustrated in Fig. 6. Analysis of tooth histology may also prove useful in helping us to develop better techniques for dating injuries. As Case 2 illustrates, injuries serious enough to disrupt dental development can be dated with considerable precision through counting cross striations and lines of Retzius in teeth.

In spite of these problems, it is still possible to make a few generalizations about healing rates that can prove useful in forensic contexts. Although gross evidence of new bone formation takes about two weeks to appear in adults (34), in young children, histological evidence of bone remodeling would be expected within a matter of days. Autoradiographic studies show that a marked increase in osteogenic activity occurs about 24 h after trauma (54). The earliest signs of periosteal new bone formation begin to appear radiographically about two weeks after the injury (20,30). At such an early stage, the layer of new bone is not firmly attached to the underlying periosteum and may be lost during the decomposition process in skeletal material. By 14 to 21 days, there is a loss of fracture line definition and a soft callus completely bridging the fracture site. In a month or two, a well-formed hard callus is present (29,53).

Conclusions

The identification of child abuse in cases involving skeletal remains can be challenging to pathologists inexperienced in the analysis of skeletal material. Such remains are often fragmentary and the identification of specific skeletal elements can even be problematic. In such situations, the assistance of a physical anthropologist with appropriate osteological experience should be sought.

The problems encountered by physical anthropologists in the identification of child abuse are in many respects similar to those faced by pathologists dealing with cases involving living children or the recently deceased. Evidence of multiple skeletal injuries in different stages of healing and inconsistencies between specific

injuries and the purported mechanism for their production are key to identifying the battered child syndrome (32,55).

Skeletal remains, however, pose special diagnostic problems. Injuries in the early stages of healing that only affect soft tissue are of course unobservable. Some typical child abuse injuries such as metaphyseal fractures are often impossible to detect because of poor preservation. Even when preservation is good, skeletal injuries that occurred around the time of death, before any healing could occur, may be difficult to distinguish from postmortem damage.

Working with skeletal remains, on the other hand, has the advantage of allowing bone surfaces to be carefully inspected visually for signs of earlier trauma. As we have noted, this often results in the identification of old, radiographically invisible injuries. In skeletal cases, exclusive use of a radiographically oriented approach suitable for diagnosing the abuse of living children results in the loss of valuable information. Well-healed areas of subperiosteal new bone formation were present in all the child abuse homicide cases we have described. Although these "bone bruises" are practically pathognomonic of the severe physical abuse of children, they are usually below the threshold of radiographic detection.

The ubiquity of these radiographically invisible lesions in the child abuse homicides we have worked on suggests that evidence of a history of previous injury is routinely missed in the autopsy of child abuse victims. This is consistent with the findings of Kleinman (31) and his co-workers who found significant histological alteration in the metaphyses of infants with normal radiographs. When a history of previous abuse is a crucial issue, we recommend the dissection and visual inspection of long bone surfaces for well-healed subperiosteal lesions such as those we have described.

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