ISBN 0-315-55550-5

THE UNIVERSITY OF ALBERTA

FORENSIC IMPLICATIONS OF ACETABULAR MORPHOLOGICAL VARIATION

BY

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A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH
IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF

MASTER OF ARTS

DEPARTMENT OF ANTHROPOLOGY

EDMONTON, ALBERTA

FALL, 1989

THE UNIVERSITY OF ALBERTA

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TITLE OF THESIS: 'FORENSIC IMPLICATIONS OF ACETABULAR MORPHOLOGICAL VARIATION'

DEGREE: MASTER OF ARTS

YEAR THIS DEGREE GRANTED: 1989

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research for acceptance, a thesis entitled "Forensic Implications of Acetabular Morphological Variation" submitted by Sabine U. G. Stratton in partial fulfillment of the requirements for the degree of Master of Arts.

Supervisor

Date: October 13, 1989

DEDICATED

TO

THE MEMORY OF

M.

MAY HER DEATH BE

MEANINGFUL

ABSTRACT

This research examines a previously unknown anatomic trait of the acetabulum, "acetabular rim notch" (ARN), which was first noted during the investigation of human remains from Hinton Via Rail train crash of February, 1986. The notch of the anterior acetabular rim is located near the anterior wing of the triradiate cartilage and the iliopubic eminence. The corresponding image found on a radiograph is an indentation of the anterior [illegible] of the acetabular rim. Three hundred roentgenograms from the Office of the Chief Medical Examiner in Alberta were studied, and the correlation between the anomaly and other variables evaluated. The overall occurrence in the study sample was 8.33%. Although this anomaly was originally thought to be sex-related, ARN was found in males as well as females, with frequencies of 8.1% and 8.9%, thereby discounting this possibility. This study found that only whites and natives had this trait. However, one individual, not in the radiological sample and of Inuit origin, exhibited the trait on bone. No association between the anomaly and race variables was discovered; however, an association between those variables is found if one is also female. There is a slightly higher chance that if a female has the anomaly, she is of native origin. ARN was found in all age categories from 17-95, except the 76 to 85 year group; and this absence is explained as a sampling deficiency.

The margins of the acetabulum were found to be sexually dimorphic. The way in which ARN is expressed is different in males and females. The explanation forwarded is the well-known orientational differences between male and female pelves. Females tend to have significantly more mediolateral breadth of the pelvic inlet, with the acetabulum and center of the hip joint being placed farther laterally from the body's center of gravity. This explanation is

used to recommend that future research on the acetabulum should concentrate on the radiographic image of acetabular margins for sexual differentiation. The growth of the acetabulum is cited in order to suggest that a sex determination technique for adolescents of 15 years of age is possible.

ACKNOWLEDGEMENTS

Research is a co-operative effort and I have been fortunate in being given the opportunity to study and work with others in their fields, due to the interdisciplinary nature of my topic. It is said that out of any tragedy some good will occur and it is my hope that this will be the case in regard to the train crash which occurred February 8th, 1986 near Hinton, Alberta, in which twenty-three persons perished. This research would not have been conducted, had that tragedy not taken place.

I would like to begin by thanking my supervisor, Dr. Owen Beattie, who deserves two-fold credit. It was his keen powers of observation during the human identification work on the Hinton Via Rail train crash that led to the discovery of acetabular rim notches and their correlation with ante-mortem x-rays. Secondly, gratitude is expressed for his interest, support, and encouragement throughout this research. I would also like to say that waiting outside your office has taught me great patience and it's been a privilege!

Dr. Ruth Gruhn served as a committee member and I wish to thank her for advice during my days as a graduate student and her excellent editorial assistance with my thesis.

It has been my pleasure to help establish a relationship between the Office of the Chief Medical Examiner (Edmonton) and the Department of Anthropology, since I was the first anthropologist to conduct research at their office. Thus, I wish to thank Dr. Derrick Pounder, former Deputy Chief Medical Examiner, for believing that anthropologists can make a difference to the outcome of certain cases examined by the Office of the Chief Medical Examiner (OCME). To Dr. Graeme Dowling, his successor, go my thanks for allowing me to continue my research and serving as a committee member.

Cyril Chan, the forensic radiographer and photographer, at the OCME deserves my greatest gratitude. This research would not have been possible without his help. He took the control x-rays, photographs, let me use his equipment, and answered all my questions, sometimes five and six times, about x-rays and the radiographic process. To the office staff at the OCME, my thanks for your friendliness in allowing a stranger to work in your midst and to those I pestered with questions --- your patience in answering those questions.

Staff-Sargent Murray Barker, Edmonton Police Service, and Corporal Bruce McLean, 'K' Division (Edmonton), Royal Canadian Mounted Police are acknowledged for being willing to spend time with me in order to answer questions about crime scene investigation.

The use of the x-ray library and the x-ray files of staff members at the University of Alberta Radiology Department was extended through the courtesy of Dr. D. Russell, chairman of radiology. I thank him and all staff members who allowed me the use of radiographs in their offices.

Diane Hollingdale is acknowledged for her excellent rendering of figure 4 and Geoff Lester for the map of the train crash site (figure 1).

For my friends and fellow graduate students, thanks for keeping my spirits up! Very special thanks are extended to Pamela Mayne for her editorial assistance (above and beyond the call of duty) and for the many helpful discussions about my research.

I would like to thank my parents, Hans and Marianne Schmidt, for bringing me up to appreciate intellectual curiosity. Special gratitude is extended my father for his financial support throughout my student career and during the duration of this project.

Last, but not least, to Joe go my love and thanks for your help and being there when I needed you.

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CHAPTER 1

INTRODUCTION

INTRODUCTION AND THE HINTON TRAIN CRASH

The identification of unknown human remains is of critical importance, because throughout human history, man has wished to confer upon the dead some manner of spiritual disposition. Shanidar Cave in Iraq has indicated that five genera of flower pollen are associated with a Neandertal burial. Herbal and medicinal qualities of these plants, besides their aesthetic value, are indicative of probable funerary rite practices and the possession of a kind of religious life (Leroi-Gourhan, 1975; Solecki, 1977). Today there are legal issues to be considered as well: allowing spouses to remarry, issuing death certificates, settling property matters, reading wills, and resolving life insurance claims are among some of these issues. Clyde Collins Snow, while studying the remains of Argentine *desaparicidos* (people missing due to police/military intervention), added another dimension to this issue. Identification of the dead allows the grieving process to continue along its natural course; otherwise, the process is abruptly cut off in mid-stream (Snow, 1986). Ensuring that skeletonized or partially skeletonized remains are identified and documented as part of the *Vital Statistics Act* (Province of Alberta statute; September, 1985) is the realm of forensic anthropology. This task is normally accomplished through consultation with a medical examiner or coroner.

Anthropology is meant to be holistic and the research subject to be introduced certainly transcends many disciplines. At first glance some may think that this research is restricted to physical anthropology, but there are numerous cultural implications. The finding of unidentified human remains has legal and societal implications. Legal implications include: determining the identity of the deceased in order that a person's affairs can be terminated and trying to determine the cause of death in order that law enforcement agencies can be consulted if there is cause for concern. Societal implications include moral issues as well; allowing the deceased to have the funerary rites they had pre-arranged or that the family wishes to confer upon the deceased. Another important aspect, as mentioned previously, is to allow the next-of-kin to grieve for the dead. In this way members of society replacing the deceased will be allowed their rightful place.

Within physical anthropology the subject of anatomic variants, the subject of this research, touches upon human biological variation, which constitutes a large segment of the field. Anatomic variants are of greater importance within forensic anthropology because the investigator is trying to individualize one person from the general population. T.D. Stewart (1979: ix) has defined this field as follows:

> Forensic anthropology is that branch of physical anthropology which, for forensic purposes, deals with the identification of more or less skeletonized remains known to be, or suspected of being, human.

This researcher contends that a forensic anthropologist is a specialist in the human skeleton whose interests are defined by their application to the legal system. Kerley (1978: 160) has stated that forensics in anthropology encompasses:

> ... the specialized subdiscipline of physical anthropology that applies the techniques of osteology and skeletal identification to problems of legal and public concern.

My special sphere of interest lies within the area of human individualization. The ability to single out an individual from the general population falls within the realm of forensic anthropology; and this task differentiates the field from paleopathology, in which a skeletal sample would be studied to gain evidence about the biological profile of a particular group.

Although there are many issues in contemporary forensic anthropology, this field must, of necessity, answer a number of basic questions in dealing with each application. The following, based on Warren (1978) and Snow (1982), are fundamental questions a forensic anthropologist attempts to answer when involved in human identification studies. Is the material bone and, if so, is it human bone? Is more than one individual represented? When did death occur? What was the age at death of the deceased? Can sex, race, stature, body weight, or physique be determined? Are there signs of disease and old injuries, anatomical anomalies, or other characteristics to provide the investigator with an individual identification? What was the cause of death? Lastly, what was the manner of death? This list should not indicate that a forensic anthropologist can answer each particular question for each and every case that he/she investigates; however, a thorough attempt should be made to answer these questions.

Krogman and Iscan (1986: 5) represent forensic anthropology as having the following eight spheres of concern:

1. pre-and post-natal human growth, maturation and age changes
2. archaeological field techniques and a compendium of sites of skeletal finds
3. microscopic and gross anatomy of the body, espec y the skeleton

4. osteopathology and forensic pathology
5. human paleontology
6. war dead and mass disasters
7. tooth morphology and forensic odontology
8. evidence and expert witness testimony.

War dead and mass disasters are listed as a sphere of which a major component is airplane and train accidents. These situations are becoming more prevalent with the hectic lifestyle of modern society, and have the potential for enormous loss of life. These circumstances demand the services of as many experienced investigators as can possibly help to resolve the problem of unidentified commingled human remains. As such, another comment by Kerley (1983: 66) is relevant:

> Forensic anthropologists are physical anthropologists who specialize in applying reconstructive techniques in solving identification problems of public and legal concern. They usually have the task of describing the biological nature during life of individuals from unrecognizable and often otherwise unidentifiable human remains. The need arises when skeletons or badly decomposed bodies are found or when badly charred human remains are recovered.

A forensic anthropologist normally helps to resolve identification problems if the remains are largely skeletonized; however, there is increasing demand for the services of a forensic anthropologist to aid in situations where the remains may be partially or fully fleshed (Charney and Wilber, 1980; AAFS meeting, 1988; abstract from AAFS meeting 1989). One such mass disaster situation occurred on February 8th, 1986, when a train crash in Canada resulted in the deaths of twenty-three persons. A Canadian National Railways freight train collided with a Via Rail passenger train approximately eleven miles east of Hinton, Alberta

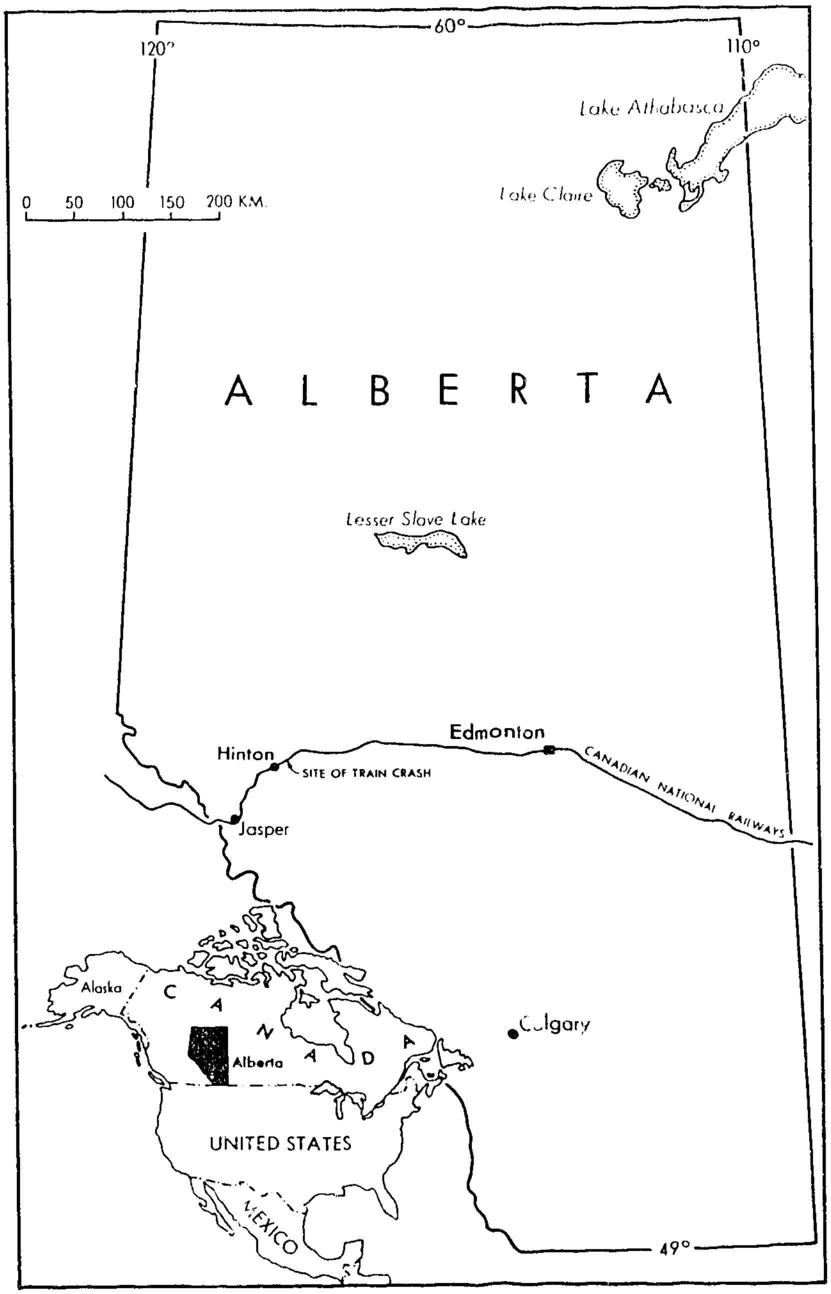
(Foisy, 1986). Figure 1 shows the geographical location of the crash site. Words can not illustrate the massive destruction which contributed to one of Canada's worst railway disasters. Besides the twenty-three persons who perished in the train crash, seventy-one others sustained injuries requiring medical treatment. The cost to both railways is estimated in the area of $35 million. A partial list of the total destruction is revealed in the damage to the freight train only: 3 diesel locomotives; a high speed spreader; 35 grain hopper cars; 7 flat cars, carrying large pipes; and 33 hopper cars carrying sulphur (Foisy, 1986).

Yet it was the fire that was most devastating after the initial crash, burning for several days:

> The destruction and horror caused by the impact was intensified by fire fuelled by the spilled locomotive diesel oil. The fire broke out almost immediately following the impact and engulfed the lead units of both trains, the baggage car and the day coach. The contents of a grain car which was thrown into the wreckage also spilled into the day coach. (Foisy, 1986: 32)

It was in this particular day coach that the majority of the victims perished. Flying debris, such as seats that had come loose, metal from train cars piled on this day coach, personal possessions, broken glass from the windows, and so on, caused earlier body injuries to be compounded by later ones. Complicating these traumas was the fire after the crash, which resulted in the remains being found in various stages of calcination (Herrmann, 1977; Shipman *et al* , 1984). Injuries to the victims who perished were quite variable; consequently, one individual could be visually identified, and at the other extreme were calcined skeletal fragments whose remains could only be identified with the help of physical anthropologists.

Figure 1. Map indicates the site of the 1986 collision between a Canadian National Railways freight train and a Via Rail passenger train ne?r Hinton, Alberta.



The exact sequence of the traumas each individual was subjected to could not be determined because of a number of factors. Foremost among these was the overall amount of body fragmentation with earlier traumas compounding later ones. Another factor was that various parts of the crash site were subjected to widely differing conditions. An excellent example of these conditions was the temperature variation throughout the crash scene. One area was heated by the crash fires and subsequently cooled by the subzero temperatures in the days following the crash; while another area, adjacent to the first, was heated by the crash fires, cooled, and reheated by the burning grain associated with the accident. The range of temperature effects and traumas is evident in observing the colors, shrinkage, distortion, fractures, texture, and weight of the bones. The resulting fragments differed widely in density and weight. Some fragments, such as the acetabulum, were as dense and heavy as porcelain; while others, such as the maxilla, were so delicate that they disintegrated when touched (Herrmann, 1977; Shipman *et al* , 1984).

It took the Medical Examiners' Office approximately nine days (February 9-17, 1986; Foisy, 1986) to sift through the accident site to ensure that a thorough search for human remains had been completed. During this time anxious family members were awaiting confirmation of the deaths of their kin. Physical anthropologists from the University of Alberta were called in by the Deputy Chief Medical Examiner (Northern Alberta), Dr. Derrick Pounder, to aid in the identification of the badly calcined remains. The result was three days of intensive work (February 19 to 21, 1986) to complete the identification of the then - unknown remains. The author was part of the team of physical anthropologists called in to aid with the identification process, whose other members consisted of Dr. Owen Beattie and Walter Kowal. Part of our duties consisted of the determination that there were no passengers aboard the train who were not on the passenger list. The end result was that we aided in the identification of ten of the twenty-three victims. There were three male victims and seven female victims identified through skeletal identification techniqiues. The remains of seven of these victims were badly calcined and skeletonized (Beattie, 1986).

Our initial task consisted of sorting through recovered remains for identifiable fragments in order to segregate them into individuals. The team of anthropologists used many techniques at its disposal, but the fragmentation of the remains demanded that we rely on basics: age, sex, race, stature determination, and determination of skeletal anomalies. It was also fortuitous that numerous ante-mortem x-rays of some of the victims were available. These allowed the matching of ante-mortem to post-mortem x-rays of some victims to be attempted. For the purposes of this investigation, the bones were considered to be 'normal' (uncalcined); that is, although shrinkage and distortion were recognized as factors, not enough information was available to allow proper evaluation of the changes. It must be noted that basic studies on cremated remains should be done to serve as a guideline for color, size, and distortion changes in calcined remains for future cases.

REASON FOR RESEARCH AND HYPOTHESES

During the course of the identification process, it was observed that one relatively intact left acetabulum had an unusual V-shaped notch in the anterior rim (see Plate 1). Since we were fortunate in having access to numerous ante-mortem x-rays, we were able to match this bone fragment to its x-ray as part of the identification process on this particular victim. The ante-mortem pelvic x-ray

Plate 1. The acetabulum found in the Hinton train disaster. Arrow indicates the acetabular rim notch on this specimen.

had a curved indentation of the anterior rim (see Plate 2). The identification team involved in the train crash investigation were not convinced as to the uniqueness of acetabular rim notching as an identification trait. Therefore, a quick test was completed in the Medical Examiner's Office. X-rays of past cases (total: 100) were obtained and the incidence of the trait estimated. The result was that the trait was of fairly low incidence (circa 12%). We realized this was not a systematic or thorough study, but the preliminary results were sufficiently convincing to warrant this morphological variable being used as one of the identifying features of this particular train disaster victim. Eventually on the basis of the elimination of other identified victims and the recovered fragments, the remains were identified as those of a fifty-three year old caucasian female.

The Hinton train crash was Canada's second worst train disaster in terms of loss of life (John Gehrig, National Transportation Board, personal communication, 1989).

During the time that our team was completing the identification of the remains, it was noted that this tragedy would have been a good opportunity for forensic anthropological research to be tested and conducted; yet this type of research could not be done without approval from an ethics review. If the results of certain types of research had been available to us at the time, that data would have sped up the identification process. As family members were anxious to receive the remains of their loved ones, time was too short to extend this investigation. The results of the test sample, convinced me that the possibility existed for something beneficial to be derived from this tragic event, by potentially speeding up future identifications in mass disasters. The acetabular rim notch appeared to be an intriguing morphological variant, deserving further investigation.

Plate 2. Ante-mortem x-ray of the acetabulum illustrated in Plate 1. The arrow shows the anterior lip.

It is the intention of this work to assess whether anterior acetabular rim morphology is a reliable trait for individualizing the human skeleton. Other factors were brought to light by the x-ray test sample: no males with acetabular rim notches could be found, although the x-ray test sample was equally distributed between males and females (50 of each sex were used). Secondly, a majority of the individuals (three-quarters) with acetabular rim notches were Native North Americans. Although a subjective sample was used, the results indicated that anterior acetabular rim notches may be correlated with certain variables. The results are indicative that further research should be initiated to test the incidence and characteristics of this trait. This investigation should survey the frequency of acetabular rim notches and the morphological variability on the bone, plus the occurrence and variability on the corresponding x-rays.

The following hypotheses are in keeping with the preliminary test results:

Hypothesis I - Anterior acetabular rim notching is a genetic variant.

Hypothesis II - Anterior acetabular rim notching is a gender-related morphological variable.

Hypothesis III - Anterior acetabular rim notching is a race-related morphological variable.

Hypothesis IV - Anterior acetabular rim notching is a childbirth-related morphological variable.

Hypotheses I to III are genetically-related variables, and hypothesis IV pertains to body mechanics.

CHAPTER 2

ACETABULAR RIM NOTCHING AS A PELVIC TRAIT

REVIEW OF ANTHROPOLOGICAL PELVIC LITERATURE

To physical anthropologists the pelvis has always been an important area of the skeletal system, due to the possibilities for sex determination of unknown bones. Most studies have concentrated on this aspect, using either metric or non-metric indicators. Metric indicators use numerical values to describe anatomical features, whereas non-metric indicators are based upon visual assessment of morphological variability.

Krogman (1939) illustrated how the non-metric indicators of the entire pelvis could be used to help determine the identity of unknown human remains. Other non-metric studies have tended to concentrate on specific areas of the pelvis. Washburn (1948) commented upon characteristics of the pubis, and revealed that it is possible to sex pelves using the sciatic notch; the results would be correct at a rate of 75 percent or higher. Another observation made by him was that females tended to have an obtuse subpubic angle, and Washburn reiterated the work of turn of the century physical anthropologists who said that pubic length is greater in females than in males.

Phenice (1969) wrote about the ventral arc, sub-pubic concavity, and the size of the ischio-pubic ramus in males versus females. This research is used to assess sex in unidentified remains. Lovell (1989) recommends caution in utilizing Phenice's technique, as the accuracy of these factors tends to decrease when the method is used on older individuals.

Since an important function of the female pelvis is its role in childbirth, numerous studies have concentrated on changes to the pelvis after parturition (Houghton, 1974; and Kelley, 1979a). Houghton commented upon the grooving that occurs in the pre-auricular sulcus with pregnancy, and Kelley on the pelvic changes that occur with parturition. Kelley specifically mentioned three factors: pubic pitting, the pre-auricular sulcus, and grooves at the site of the interosseous ligament insertion. Suchey *et al* (1979) did an analysis of dorsal pitting in the pubic bone to determine the sex of unknown remains using modern American females.

A different observation about the pelvis was made by Saunders (1978) in her study of three prehistoric North American populations. In that research she examined the non-metric indicators in the skeleton; and commented upon the fact that one can occasionally observe the point of union of the acetabulum, which results in a bony projection. This 'acetabular mark' was not assumed to hold any meaningful genetic correlation. Saunders views the mark as being the result of the os acetabulum fusing improperly between the ilium and pubis, or incorrect fusion of ilium and ischium.

The previously mentioned studies have been non-metric. Descriptive research using numbers to express differences in the pelvis is also prevalent in physical anthropology. Hoyme (1957) did research on establishing indices for sexing pelves. She was interested in establishing racial indices for the pelvis, but realized that sex of the unknown remains had to be established first. She examined the work of Washburn (1948) on the ischium-pubis index,which followed the research of Schultz in the early thirties (Washburn, 1948). This theme of using metrics to determine the sex of unknown skeletons has been expanded upon in recent decades, with Kelley (1979b) establishing the sciatic notch-acetabular index to determine sex of fragmented remains. MacLaughlin and Bruce (1987) have examined the applicability of the sciatic notch-acetabular index to a European sample group, and recommended changes for its use on this population. They found the sciatic notch to be a poor discriminator of sex in this population; and suggest a relationship between sciatic notch form and body size, which results in diffe[illegible] values for various ethnic groups. Schulter-Ellis *et al* (1983, part I - black [illegible] and 1985, part II - whites only) have expanded on Kelley's work, using a larger sample and recommending changes to the values used. This group recommended the use of three indices: acetabulum-pubis index; acetabular diameter/pubic tubercle-acetabular rim index; and the ischium-acetabulum height / pubic symphysis-acetabular rim index. Using two of these variables resulted in an ability to discriminate the sex of 98 percent of the white sample and 97 percent of the black sample.

Davivongs (1963) studied sex determination in Australian Aboriginal innominates utilizing the vertical and horizontal diameters of the acetabulum, the ischium-pubis index, and two indices of the sciatic notch. Taylor and Dibennardo (1984) continued this work by establishing discriminant function analyses for the central portion of the innominate using mainly the acetabulum (discriminant function analyses are numbers that compare multiple variables to one another, and comment on possible relationships between those variables). Their investigation tested the indices for sex assessment only (90 percent accuracy) and simultaneous sex and race assessment (60 percent accuracy).

Lang (1987) analyzed a series of male and female innominates using some new osteometric pelvic measurements and four indices. Her results indicated that the maximum length-pelvic height index and minimum length-pelvic height index are higher in males, thereby having excellent potential for use in differentiating sex in unknown human remains.

Research has also shown that the pubic bone is useful in establishing age at death of individuals. The early series of observations by Todd (1920, 1921a, 1921b, 1921c, 1923) on the pubic bones of white males led to a model of 10 typical phases of age in the pubic symphysis. This work has been continued in recent years. Brooks (1955) examined skeletal age at death using pubic bone morphology and cranial suture closure. She re-examined Todd's work, but included differences in her sample. These differences included using females, as well as males, plus prehistoric and modern skeletons. Gilbert (1973) commented on the misapplication of aging the female pubic bone using the male standards, as females 40 years and older were significantly underaged. Gilbert and McKern (1973) suggested a method of aging the female pubic bone, based upon a sample of American white females and following McKern's work on males (McKern and Stewart; 1957). Their system involves evaluation of the progressive morphological changes of three components of the pubic symphysis. Suchey (1979) reviewed the work of Todd, Brooks, McKern and Stewart, and Gilbert and McKern; and decided her own research should be multi-racially based (Katz and Suchey, 1986; Suchey and Katz, 1986; Suchey *et al* ,1986). The resulting technique is a combination of the work of Suchey and Brooks, comprising a 6-phase method of evaluation in assessing age using the pubic symphysis.

Fewer studies have been done on establishing racial affinity from the pelvis. The work of Derry (1923) commented upon the race and sex indicators of the human ilium. Iscan (1983) reviewed the matter of race determination from the pelvis, and did discriminant function analyses on the Terry Collection of the Smithsonian Institution (Washington, D.C.). He concluded that race assessment is done more easily on females than on males. Iscan and Cotton (1985) did a statistical analysis to develop a technique to assess race without knowledge of age at death. They found the indices to be accurate to 76.5 percent in males and 75 percent in females. These percentages had dropped slightly from those in which the age of the individuals was known, prior to race assessment. Non-metric studies using the pelvis to assess race are scarce. At the turn of the century, there was a trend in physical anthropology to try to ascribe the shape of particular pelvic inlets to certain racial groups; but this idea is no longer considered to hold merit.

The majority of the anthropological literature encompasses research on other parts of the pelvis, and not the acetabulum. The work on the acetabulum has concentrated on its use in metric sex determination, since the acetabulum is larger and deeper in males due to their greater body size and the correlated weight-bearing factors (Kelley, 1979b). These descriptions are numerically-based values, while the research on the acetabulum to be introduced in this study will be non-metric in nature, thereby providing a visual appraisal of acetabular morphologic variability.

BASIC ANATOMY OF THE ACETABULUM

The pelvic girdle consists of the left and right innominates (hip bones), the sacrum, and the coccyx. Its main function is to transmit body weight to the lower limbs. Another function is to protect the organs found in the lower abdominal and pelvic cavities (Bryan, 1982). Each innominate is composed of three bones: the ilium, ischium, and pubis. A large feature of the innominate is the acetabulum, commonly known as the hip socket. The acetabulum and the head of the femur join together to form the hip joint, which is a ball and socket joint known as an enarthrosis. The movements this joint allows are flexion, extension, abduction, adduction, lateral (external) rotation, and medial (internal) rotation (Pansky, 1984).

The acetabulum is not quite a hemispherical cavity located on the central, lateral aspect of the innominate bone. It is directed laterally, downwards, and forwards (Williams and Warwick, 1980). The cup-like structure of the acetabulum has an irregularly shaped margin which is incomplete in the inferior aspect; the gap which is formed is called the acetabular notch. The floor of the cavity is non-articular in nature, and is called the acetabular fossa. A cartilaginous rim acts to widen and deepen the acetabulum, plus hold the femoral head in place. This cartilaginous rim, known as the acetabular labrum, or glenoid labrum, is attached to the bony rim. The articular capsule extends from the acetabular rim to the intertrochanteric crest and line of the femur to help hold the femoral head in place. An articular surface (lunate or horseshoe-shaped surface) is situated within the acetabular rim because of the gap formed by the acetabular notch. This surface articulates with the head of the femur. The acetabulum is entirely enclosed in cartilage because of a transverse ligament spanning the gap created by the acetabular notch, which forms a complete band of cartilage. However, this ligament leaves a space to create the acetabular foramen, which allows the nerves and blood vessels to enter and exit the joint (Bryan, 1982). The ligamentum capitis femoris (teres), or round ligament, arises from the acetabular notch (specifically, the transverse ligament) and runs to the fovea of the femur head in order to assist in holding the hip joint (ball and socket) together (Pansky, 1984).

The ilium includes the upper portion of the acetabulum and an expanded, slightly curved, flattened superior area. The ischium, consisting of a body and ramus, forms the inferior and posterior portions of the hip bone. The upper section of the body of the ischium forms two-fifths of the acetabulum

(Bryan, 1982). The ramus of the ischium has anterior and posterior surfaces, which extend slightly upwards to join the inferior ramus of the pubis. The pubis forms the anterior surface of the innominate. It meets with its opposite member at the midline to form the symphysis pubis. This bone consists of a body, a superior ramus, and an inferior ramus. The pubis and ilium are joined at the acetabulum by virtue of the superior ramus extending laterally and slightly superiorly. Demarcation of the juncture between these bones is the iliopectineal or iliopubic eminence (Bryan, 1982). Therefore, the acetabulum is composed of the three main bones of the innominate. In total the ischium contributes two-fifths of the acetabulum, specifically the floor of the acetabular fossa and the majority of the lower and posterior articular surface. The pubis forms the upper and anterior fifth, while the ilium forms the rest of the articular surface (Williams and Warwick, 1980).

The bones of the innominate are separated by cartilage, known as the Y-shaped cartilage or triradiate cartilage, in childhood. The union of these three bones takes place within the walls of the acetabulum during adulthood (Williams and Warwick, 1980). Figure 2 (internal view) and Figure 3 (external view) show the lines of fusion between these bones. Birkner (1978) has pointed out that the acetabulum is the slowest articular development at birth. The acetabulum of the newborn is a flat cavity. During the fifth year, the cavity begins to take on its characteristic hemispherical shape. Between the seventh year and puberty there is an interpelvic rise of the base of the acetabular cavity. This physiological protusion disappears with the cessation of growth. Between the ninth and twelfth years of growth the os acetabulum bone is introduced into the Y-cartilage between the ilial and pubic bones. This bone is also known as the coxae quartum or cotyloid bone to anatomists. Many researchers group the bony ossicle, os acetabulum, with smaller ossicles found in the triradiate

Figure 2. An internal view of the innominate illustrating the fusion areas of the ilium, ischium, and pubis.

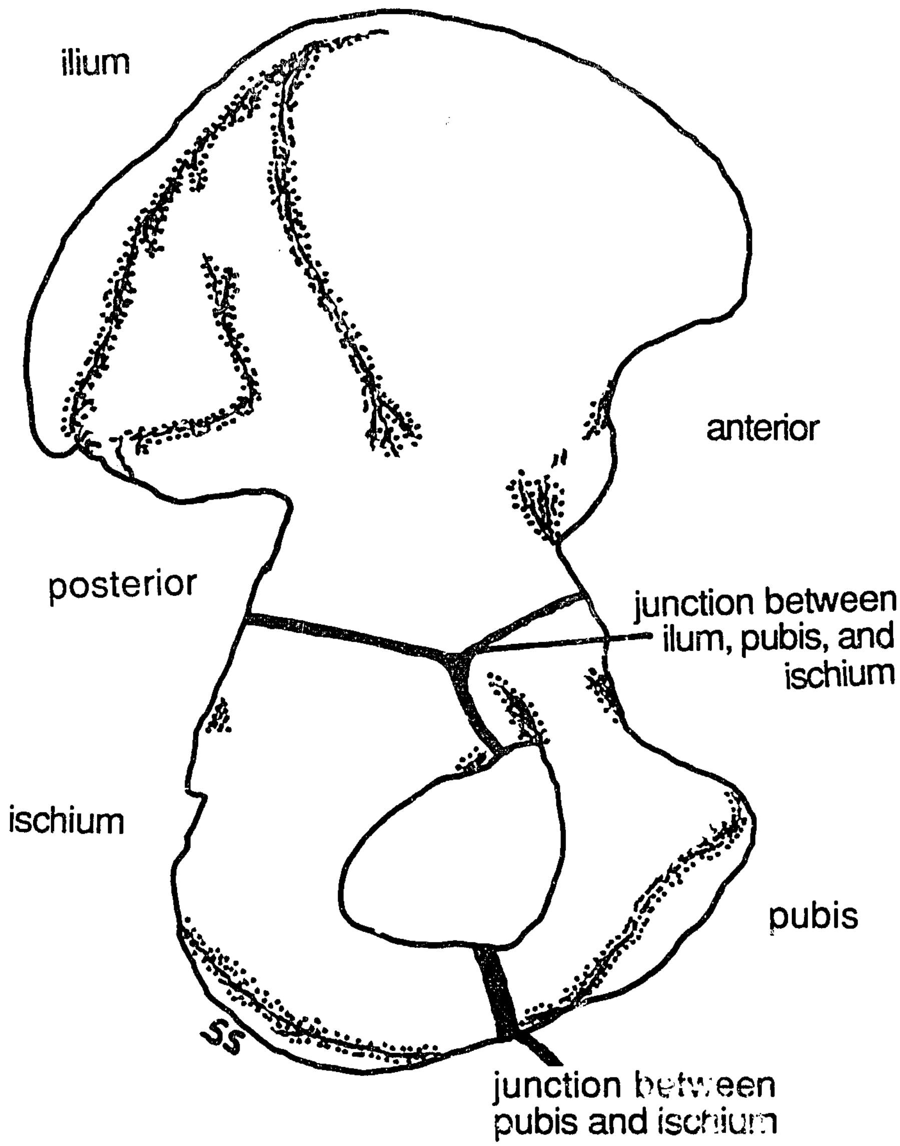
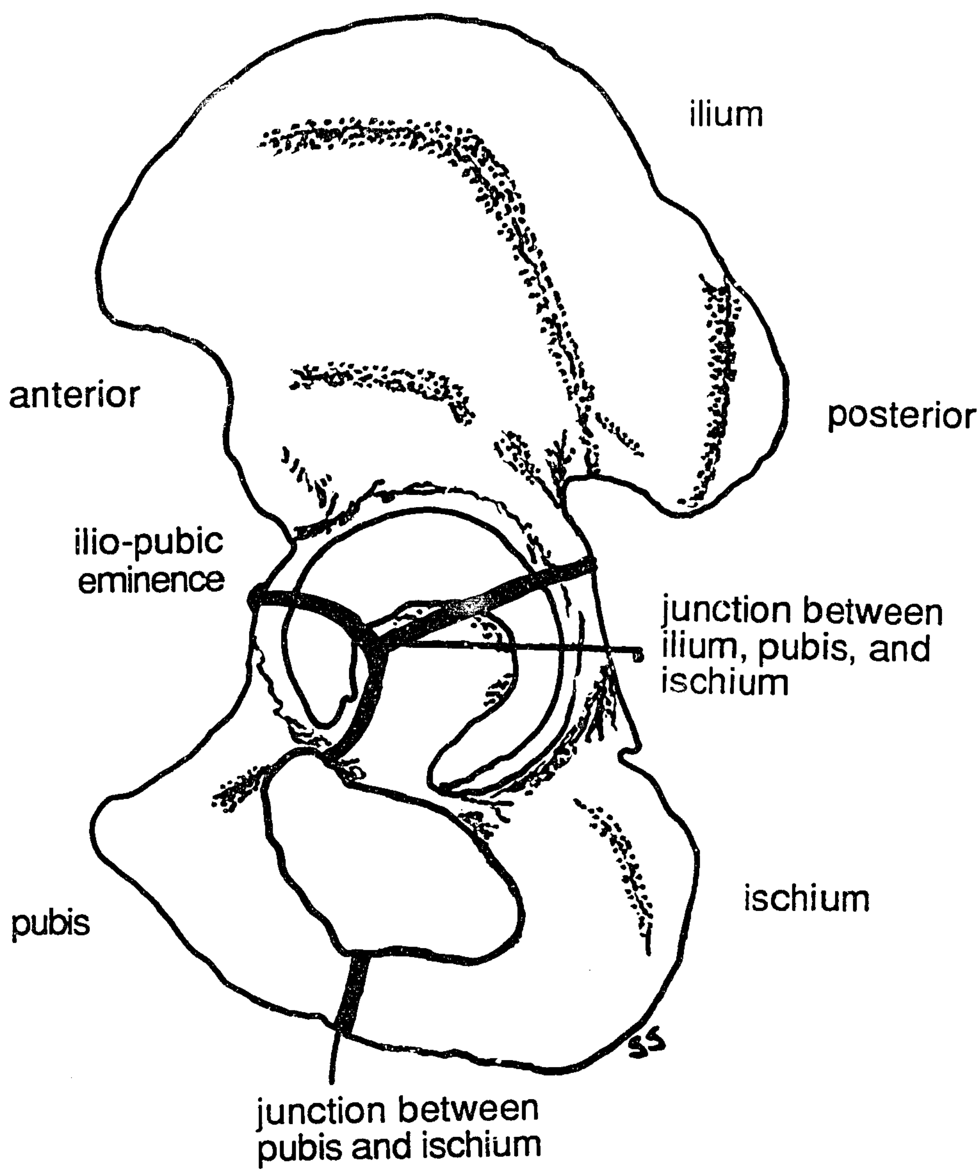


Figure 3. An external view of the innominate illustrating the fusion areas of the ilium, ischium, and pubis.



cartilage; together they are known as "os acetabuli". This use of nomenclature leads to confusion, as readers are unsure if researchers are referring to the skeletal element or a radiological feature also known as "os acetabuli". Further comments on growth and the radiological variant known as "os acetabuli" are found in section on the potential development of the trait.

I have not completed a description of the complete soft tissues of the hip, as the main focus of this study is on the bony landmarks. However, readers are directed to the anatomic study of the hip, part I (Armbuster *et al.* , 1978) included the bony landmarks, while part II describes the soft tissue landmarks (Guerra *et al* ,1978). Rubenstein *et al* (1982; 1983a; 1983b) have described the cross-sectional anatomy of the acetabulum through the use of computed tomography. This work was completed to assess acetabular fractures.

VISUAL CHARACTERISTICS OF THE TRAIT

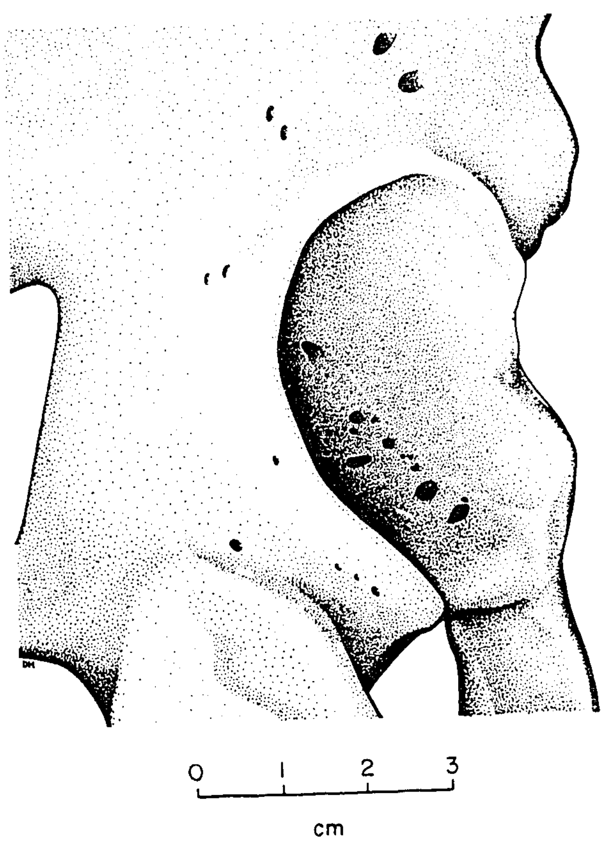
Plate 3 illustrates an acetabular rim notch on a modern bone. Figure 4 is composed of two drawings of the feature: figure 4a exhibits the absence of a notch, and figure 4b the presence of a notch. The notch is a V or U-shaped gap located in the anterior border of the acetabular rim. Its proximity to the anterior wing of the triradiate cartilage and the iliopubic eminence suggests a relationship between the origin of the gap and the development of the triradiate cartilage. Sundick in his 1972 doctoral dissertation has suggested calling this area of fusion the "os acetabuli anterior" (cited in Saunders, 1978: 175). This author refers to this area as the "anterior wing of the triradiate cartilage".

Plate 3. An example of an acetabular rim notch on a modern bone sample.

Figure 4a. Drawing of "normal" acetabulum seen a from a lateral orientation.

Figure 4b. Drawing of acetabulum with an acetabular rim notch, seen from a lateral orientation.


DH
0 1 2 3
cm


DH
0 1 2 3
cm

NOMENCLATURE

Although realizing that there is potential for confusion between the "acetabular notch" and the "acetabular rim notch", this researcher decided to name this trait "acetabular rim notch" for numerous reasons. Firstly, the name is descriptive of its location and appearance. The trait is found in the acetabulum, and is a notch in the rim. The acetabular rim notch(es) may easily be abbreviated as "ARN". Secondly is the fact that there may be a relationship between ARN and the superior roof notch described by Johnstone *et al* (1982) and discussed in the next section.

During the course of this study it was discovered that there is confusion in the nomenclature between physical anthropologists and radiologists. A radiologist prefers to refer to the margin of the acetabular rim as the "lip". The acetabular rim on a radiograph is very dense, thereby opaque, whereas the lips of the acetabular rim margins, anterior and posterior, are more difficult to locate, due to relative radiolucency. It is suggested that anthropologists adhere to the practice of calling the acetabular rim as such when referring to gross anatomy. However, when examining radiographs, it is more appropriate to subdivide the larger unit (acetabular rim) into smaller units (acetabular margin, anterior lip, and posterior lip). Of greater importance is that anthropologists be aware that this problem exists.

POTENTIAL DEVELOPMENT OF THE TRAIT

The pelvis is a much studied part of the human anatomy because this area contains the major component of bipedal locomotion. Anthropologists are interested in this part of the anatomy for its possibilities for sex, race, and age determination, plus clues to the origin of bipedal locomotion; while medical doctors are interested in aiding patients with locomotor abnormalties. While the literature is extensive, a search of the medical and anthropological literature found no reference to an acetabular rim notch. Even atlases of skeletal development variants of the pelvis and hip joint fail to mention this trait (Matzen and Fleissner, 1970; Birkner, 1978; Keats, 1988). However, Johnstone *et al* (1982: 27) have investigated a radiologic discontinuity in the medial aspect of the acetabular roof, which they have called the superior roof notch. Their investigation has concluded that this accessory fossa has no functional component, and represents an anatomic variant in the development of the acetabulum. It is worth emphasizing that on an x-ray the superior roof notch of the acetabulum appears as a discontinuity, whereas ARN is an indentation of the anterior lip. The present investigation has failed to clarify if a relationship exists between ARN and the superior roof notch.

Although the pelvis and hip joint of primates, especially man, are among the most studied part of the anatomy, researchers have tended to concentrate on the role of the femur in locomotion (Coleman, 1969; Williams and Warwick, 1980: 476; Iscan 1983, Rubenstein *et al* , 1982, 1983a; Taneda, 1987). Unfortunately, the correlate is that very little information exists on the growth and development of the acetabulum in comparison, especially in adolescence (Ponseti, 1978). The anatomic studies which have been done (Zander, 1943; Acheson, 1957; Harrison, 1958; Ehler, 1959; Waschulewski, 1967; Coleman, 1969; Rális and McKibbin, 1973; Negri *et al*, 1977; Ponseti, 1978; Mészáros and Kéry, 1980; Nikoli´c, 1980; Siffert, 1981) do not have enough microscopic detail to determine the origin of ARN. Studies have concentrated on the femoral head because, at a certain stage of adolescent development, the shape of the acetabulum is determined by the interaction between the femoral head, pelvic muscles, and acetabulum (Ponseti, 1978; Nikoli´c, 1980). This interaction has a phenomenal effect on the hip, contributing to disorders which are of interest to medical researchers.

An excellent source of information about the growth of the acetabulum has been radiological material. The following will be a combination of what is known anatomically and radiologically. Conclusions will be drawn about the potential development of ARN.

There are eight centers of ossification for the innominate, three primary and five secondary. The three primary centers are the ilium, ischium, and pubis; while the five secondary are crest of ilium, anterior inferior iliac spine, tuberosity of ischium, pubic symphysis, and an irregular center in the acetabular growth cartilage (Y-shaped cartilage). Rubenstein *et al* (1982, 1983a) state that Judet originally described the ilium and pubis as forming an anterior column of the triradiate cartilage, with the ilium and ischium forming a posterior column. The weight-bearing portion is centered where these three bones meet. Several smaller secondary centers may occur in the Y-shaped cartilage, yet most authors have referred to each of these smaller ossification centers as an "os acetabulum" (Gruebel Lee, 1983). This usage leads to confusion regarding the nomenclature used in describing the ossification of the triradiate cartilage. The classification system regarding ossa acetabuli and ossa limbi (meaning border) acetabuli proposed by Ehler (1959: 258) should be placed in wider usage to alleviate this problem:

> It should be noted that all ossification centers found in the Y-shaped cartilage are os acetabuli. They may be differentiated through their position into:
>
> (1.) an "os acetabuli iliopectineum", which lies between the os ilium and os pubis on the ventral [anterior] acetabular rim.

(2.) an "os acetabuli ilioischium" between the os ilium and os ischium on the dorsal [posterior] acetabular rim.

(3.) an "os acetabuli puboischiadicum" on the acetabular floor between the ischium and ilium.

(4.) an "os acetabuli central" between the three previously named socket bones in the Y-shaped cartilage.

(5.) an "os acetabuli incisurae ischiadicae majoris" on the "incisura ischiadica major" in the Y-shaped cartilage.

The ossa limbi acetabuli lie in the cartilage of the facies lunata; through their position they may be discriminated into:

(a.) an "os limbi acetabuli prepubicum" is situated in front of the pubic bone.

(b.) an "os limbi acetabuli preiliacum" is situated in front of the ilial bone.

(c.) an "os limbi preischiadicum" is situated in front of the ischial bone.

The "os acetabulum" proper, as qualified by Zander (1943), is referred to as the bony area forming the anterior wall (pubic area) of the acetabulum.

Acheson and Dupertuis (1957) point out that the rate of skeletal maturation is quite variable which creates the difficulty of assessing the chronological age of skeletal material. Another problem is that authors report the appearance of primary ossification centers in the innominate, without recording whether they are observing the date of appearance, first union, or final union of the epiphyses. For example, Krogman (1939) writes that the primaries unite to form a single innominate bone at 12 years, 9 months in females and 15 years, 3 months in males. Krogman and Iscan (1986) report the observations of Flecker who stated that males pelves fuse at 15 years of age and females at 13 years of age. Stewart (1979) simply indicates that one should record the age of male fusion and subtract 2 years for the female age. Mészáros and Kéry (1980) noted that there is a growth spurt of acetabular development between the ages of 14 and 15, which they explain as the conclusion of the growth of the bony acetabular rim. It should be emphasized that their study included males only. All these statements tend to confuse readers interested in doing identication of unknown remains.

It is important to note that there is a difference between the pelves, and therefore the acetabulae of males and females (Coleman, 1969; Armbuster *et al* 1978; Brinckmann *et al* , 1981a; Stein, *et al* ,1982; and Krogman & Iscan, 1986), specifically discussed in an upcoming section. Chung (1981) has emphasized that ossification of the acetabulum occurs sooner in girls than in boys; and there is a related racial correlation, in that ossification also occurs sooner in blacks than in whites. Acheson and Dupertuis (1957) have cited numerous workers, including themselves, who believe that this variation has a genetic basis.

Acheson (1957) stated that the differrential rate of ossification is due to individual osteoblast and osteoclast formation. Todd (1933) also pointed out that illness and malnutrition can disturb the rate of ossification. Garn *et al* (1973) studied the economic impact of post-natal ossification, and supported the finding of Todd. They suggest that future studies of post-natal ossification include a statement about both economics and ancestry, as both variables are associated with timing of ossification.

Another study by Garn *et al* (1969) indicates that the timing of ossification may be attributed to genes on the "X" chromosome. The correlations between sister-sister appearance of epiphyses and ossification rates greatly exceeded brother-brother and sister-brother correlations. This postulate goes a long way in explaining why girls mature faster skeletally than boys. Rice *et al* (1976) in their study of United States youths state that the mean skeletal ages for girls were 24.9 months ahead of boys at 12 years of age, but this rate decreased to 1.5 months at 17 years of age. Garn (1987) remarks that we should keep in mind that one of the reasons young boys are behind girls in the timing of ossification is that they have a larger bone mass. Coleman (1969) says there is some indication that the actual adolescent growth spurt lasts longer in boys than in girls. Thus both heredity and environment appear to play a part in determining the pattern and timing of skeletal maturation in children.

Morrison (1932) states that the primary ossification centers have extended their growth to the bottom of the acetabulum by the thirteenth or fourteenth year of life, being separated by the now completely formed Y-shaped cartilage. The os acetabulum appears about the age of 12, between the ilium and pubis, and forms the pubic part of the acetabulum.

The separate os acetabulum develops with considerable frequency in humans and chimpanzee, but rarely in the orang-utan (Schultz, 1944). Unfortunately, as a *Pongo* innominate was not available to this researcher, the implications of its absence could not be verified; that is, whether the missing bone is in the same location as ARN. The prevailing mode of locomotion in man, bipedalism, appears to be the determining factor in the relative size of the acetabulum, according to Schultz (1969).

Studying the hip joint from the viewpoint of a radiologist brought interesting information to light. Morrison (1932) wished to demonstrate the existence of an additional "genetic" (read secondary ossification) center on the superior acetabular rim. This center is divided into an anterior, superior, and posterior segment. His research shows that at thirteen years of age a new epiphysis is advancing to reshape the existing outer acetabular rim. Another point emphasized is the fact that the os acetabulum has a very distinct ossification center. At this age the iliac portion of the acetabulum is doubling or trebling in size, and this change is attributed to the new ossification center in the superior acetabular rim. A definite lip on the fully formed acetabulum is apparent at 14 years, 4 months. Morrison made the following remark about a case study of this age: if a radiographic view were taken through the anterior lip, then epiphyses would be found there. This anterior epiphysis can best be viewed stereoscopically, he notes.

Morrison (1932) explains that an ossification center is an area of cartilage in which bone is laid down to complete the formation of bone. This task is accomplished by sending out irregular periosteal buds into the cartilage. Expanding in all directions, the buds create a trabeculated, roughened or ragged appearance, observed on several of the radiographs in his survey. On the other hand, an epiphysis is a bone germinating center with a line of cartilage which disappears after the bone has reached the limits of its growth, and it allows the smaller element to fuse onto the larger one. Morrison's study concludes that the bony elements in the rim do not grow as was postulated for an ossification center; instead there is a definite layer of cartilage between the bones on what would be the diaphyseal side.

Another comment by Morrison has tremendous import for the present study:

> As an additional proof that these acetabular rim elements are true epiphyses, we frequently find ossicles placed on the anterior, superior and posterior acetabular rim. These serve to deepen the acetabular socket. It is well known that an epiphysis during its formative period may possess a conjugal cartilage which for some reason unknown may fail to ossify. (Morrison, 1932: 499)

As explained by Morrison, an epiphysis can execute its function in one of three ways: (1.) fuse to the diaphysis in a normal manner; (2.) remain separated from the diaphysis by a layer of cartilage, which has failed to ossify and join the epiphysis to the diaphysis; and (3.) an ossicle may result due to the disappearance of the conjugal cartilage, which leaves a joint cavity between the ossicle and its diaphysis. The os acetabulum can be considered an ossicle which is prone to the conditions mentioned by Morrison. By the age of 17 years the acetabular rim is completely formed.

The survey of x-rays by Morrison has been somewhat confirmed by the study of Harrison (1958) on the pelvis in the rat. Harrison (p. 256) considered that "the os acetabuli and acetabular epiphysis are secondary centres of ossification, constant as to position, times of origin and fusion, and in every respect equivalent to other bony epiphyses". Furthermore, they develop in the epiphyseal cartilage of the roof and the anterior wall of the acetabulum, and not in the anterior wing of the Y-shaped cartilage. Growth in volume of acetabular triradiate cartilage and the periosteal growth of the acetabular rim increase the size of the hip socket, and are correlated with a change in its spatial position as well.

The development of the acetabulum can only be studied within the entire locomotor complex states Nikoli'c (1980); and the implication is that numerous variables must be studied simultaneously, specifically the interaction between femoral head, pelvic muscles, and acetabulum. At birth the acetabular rim is still completely cartilaginous, being thicker in the postero-superior area. Negri *et al* (1977) contend that while the acetabular rim differentiates through a further grouping of cells, it shows a distinctly different developmental potential from other parts of the acetabulum. For example, if the acetabulum is subject to subluxation, then the outer border is generally subjected to uncharacteristic stresses, resulting in the flattening of the margin and related head deformity of the femur.

The relationship between the triradiate cartilage and the femur head-hip socket balance is not well understood. When the head is dislocated, unrestricted growth of articular cartilage results in the acetabulum becoming increasingly shallow. When the femoral head does not exert pressure directly upon the triradiate cartilage, as in dislocation, the growth of the femoral head may not appear to be affected (Siffert, 1981).

Kuba *et al* , (1985) assert that the posterior and anterior columns of the triradiate cartilage play a dominant role in acetabular growth. Surgical trauma to the triradiate cartilage of rabbits has been studied histologically by this group, and a hypertrophy of the outer cortex in the acetabular edge was found plus hypertrophy in the numbers of chondrocytes in that layer.

Growth mechanisms about the pelvis are quite dependant on an adequate vascular supply. It is feasible that trauma disrupts significant portions of the blood supply to the central germinal zone of the epiphysis, further contributing to permanent disruption of growth (Bucholz *et al* , 1982). Injury to the acetabular triradiate epiphyseal cartilage has been known to cause early closure of the ossification centers (Makin, 1980; Bucholz *et al* , 1982; Heeg *et al* , 1988). Since ARN acetabulae appear to be normal in shape, this disruption of the growth mechanism due to trauma almost certainly does not apply. Normal development of the acetabular roof requires ample vascularization of the roof cartilage and a secondary proliferative activity of the growth zone (Wosko, 1974). Therefore, the acetabular rim could be prone to the same problems.

At this point in time, it is not possible to determine if or how the radiological variant, "os acetabuli" (also known as "os ad acetabuli" or "os ad marginalis superior"), which has previously been noted (Schinz, 1923; Zander, 1943; Schmidt, 1954; Schmidt and Braun, 1961; Schmidt, 1967; Waschulewski, 1967; Matzen and Fleissner, 1970; Mardi, 1973; Keats, 1988), is related to ARN. Morrison (1932) in his treatise on the radiological development of the hip joint indicated that these ossicles can result from the improper fusion of the acetabular epiphyses. The radiological variant "os acetabuli" are ossicles found at the superior (acetabular roof), and lateral or inferior edges of the acetabulum on a roentgenogram. Newcomers to the literature find this term confusing, because it is the same as the word for the bone that develops between the ilium and pubis, although similar origins and function have not been postulated. A valuable contribution to future literature would be for researchers to refer specifically to the "anatomic" or "radiological" os acetabuli. As mentioned previously, anatomists may find it beneficial to adopt the more specific references to the anatomic os acetabuli provided by Ehler (1959).

Another approach to investigation of the origin of ARN would be from a locomotor point of view (biomechanics). Oonishi *et al* (1976) conducted research on the surface shape and contours of the femoral head and acetabulum, with degenerative changes of the articular cartilage. They found that the weight-bearing area of the femoral head is broader than the acetabulum, and this feature results in the degree of degeneration of the surface of the acetabulum being more severe. A number of researchers have concentrated on the thickness of the acetabular cartilage in order to discover if thickness is correlated with weight-bearing. The results of Oonishi *et al*, plus the work of others (Pauwels, 1976; Oberländer, 1977; Kurrat and Oberländer, 1978; Tillmann, 1978; Oberländer and Kurrat, 1980; Brinckmann *et al*, 1981b; Bombelli *et al*, 1984; Afoke *et al*, 1987; Taneda, 1987), have indicated that the maximum weight-bearing part of the acetabulum is slightly posterior to the upper (superior) outer margin.

A morphological and functional analysis of the cartilage on the human femur has concluded that the largest extension is in an anterolateral direction while the smallest is in the medial direction. Since the different cartilage distributions of the acetabulum could not be classified into categories, an average acetabular cartilage distribution was computed for use in that study (Breul *et al* , 1979). Other research has concentrated on the width of the facies lunata, and found that an equivalent amount of stress can be noted in the width variations surrounding the acetabulum (Oberländer *et al* , 1978).

Articular pressure is not only reflected in the composition of the cartilage, but also in the make-up of bone. Oberländer (1973) has completed a study of bone stress in the human hip; and concluded that there is an increase in the density of the compact bone at the lateral acetabular margin, plus a corresponding increase in the mass of spongy and compact bone. Tillmann (1978) confirmed this earlier work in his monograph.

A new trend in these studies, with the advent of computers, has been studies of the deformation of the pelvis and the acetabulum under stress. Jacob *et al* (1976) constructed an epoxy model of the pelvis in order to examine stress and strain in its function. They conclude that subchondral bone transmits most of the bearing load in the hip joint to the acetabular rim and then onto the cortical shell of the ilium. The cancellous material is stressed to a much lower level. Dietschi *et al* (1975) constructed the same type of model, and came to similar conclusions as Jacob *et al* ; however, their research focus differed in that they wished to comment upon the effect that hip implants would have on the destruction of acetabular bone.

Brinckmann *et al* (1981a), upon noting that the femoral head is significantly smaller in females, studied the stress level in the hip joint of females. They conclude that the peak stress value on the hip joint is on average larger for females because on average their pelves are smaller than males, due to smaller body size.

In sum, this literature seems to suggest that ARN is not locomotion related because the trait is not found in an area of peak stress in the acetabulum. It is suggested that ARN do not appear to produce a biomechanical effect, because the acetabular labrum "bridges" the gap in the bone.

Whether or not the environment affects the genetic predisposition toward a trait is a complex issue. Saunders (1978: 46-47) presents some valuable comments:

> The question of genetics versus environment affecting discrete traits has been hotly debated with little resolve. There is definitely some evidence for the "familial" nature of these traits but also a lot in favour of so-called environmental forces. Harris (1971) has made the point that whether a disease (substitute "trait") tends to be regarded as genetical or environmental in origin largely depends on the relative prevalence of a genetically determined predisposition to the condition on the one hand, and of the particular environmental situation which elicits it on the other. If the genetical predisposition is relatively rare, and the significant environmental factor is common or indeed universal we say the disease is inherited. If however, the genetical predisposition is relatively common and the unfavourable environmental situation occurs infrequently, then the environmental factors *appear* as the most important. He cites scurvy as an extreme example. All primates are genetically incapable of synthesizing L-ascorbic acid. So therefore, scurvy is considered to be a disease caused by an unfavourable environment, that is, a dietary deficiency of vitamin C. Corruccini (1974) perceived the sense of this when he said that "epigenetic" variation implies imposition of phenotype discontinuity during development rather than at zygote formation, therefore realizing the possibility of environmental action on traits. He states that the question is whether genetic or external influence predominates. Actually the question seems to be, which of the two factors is *noticed* more?

The proximity of the notch to the anterior branch of the triradiate cartilage, and the correlation between the occurrence of these anatomical features, lead to the conclusion that a developmental variant of the acetabular rim contributes to the appearance of this trait. The preceding literature information indicates that the following postulates can explain the appearance of ARN:

(1.) the os acetabulum fails to appear in the anterior wing of the triradiate cartilage and form the pubic portion of the acetabulum.

(2.) the os acetabulum fails to fuse properly to the acetabular rim: the result is the disintegration of the ossicle and a gap in the anterior lip of the acetabulum.

(3.) the superior acetabular rim epiphysis fails to form its anterior branch.

(4.) failure of both the os acetabulum bone and the superior acetabular rim epiphysis to perform their intended bone development functions.

These ideas need to be substantiated through research. Whether or not these potential occurrences are the result of a genetic disposition, or are controlled by internal environmental conditions is open to speculation. Morrison (1932) added another dimension to this problem when he stated that the variation in the timing of ossification could be due to endocrine levels. Perhaps elevated or lowered levels of certain endocrines (for example, the levels of growth and sex hormones) create the correct internal environment to impede proper ossification of the acetabulum, aggravated by other factors, such as the interaction between the acetabulum and femoral head.

Most modern physical anthropologists would use the pre-auricular sulcus and dorsal pitting of the pubis as an indicator of parturition. It is interesting to note that Todd (1921a: 40) did not believe that pregnancy and childbirth leave any permanent stamp upon the skeleton. Kelley (1979a: 544) in his work on parturition and pelvic changes has suggested that "... the visible bony changes associated with pregnancy and parturition are slowly obliterated once the child-bearing years are over". This conclusion seems to support the contention that ARN is not childbirth-related because the train disaster victim with the trait was past child-bearing years.

CHAPTER 3

MATERIALS AND METHODS

MATERIALS: BONE

This research was originally intended to be two-fold: first, to examine the incidence of ARN and its morphological variability on the bone; and secondly, to examine its occurrence and variability on corresponding x-rays. Unfortunately, I did not have access to a large modern bone collection; however, certain acetabulae containing notches have been brought to my attention. The first example was found in the modern bone collection at the Department of Anthropology, University of Alberta. It is illustrated in plate 3. The second bone was found at the Kekertin Site on Baffin Island in the eastern Canadian arctic, but could not be removed from the site. Individual number 40 was assessed as an adult Inuit female, whose age was estimated at greater than 45 years (Keenleyside, 1988: 67-68). The third is a female burial (possibly metis), originating from a historic archaeological site in southeastern Alberta, Cow Camp (Borden #Ef0t6), whose remains are housed at the Archaeological Survey of Alberta. An examination of the innominates in the departmental collection brought only the one specimen to light. This assemblage consists of 80 innominates in the teaching collection, and numerous archaeological specimens (Pamela Mayne, personal communication, 1989).

The Office of the Chief Medical Examiner (OCME) is a potential place of study where large numbers of acetabulae could be examined. However, the current Province of Alberta Statute (*Fatality Inquiries Act* , Chapter F-6, 26-2b) does not allow the removal of any part of the body which is not related to the cause or manner of death. The exceptions to this regulation are tissues listed in the *Human Tissue Gift Act* , and pituitary glands (Chapter F-6, 27-1). If I wished to include a bone sample in this study, the provincial statute meant that I would have had to spend my time at the OCME observing all autopsies being performed, but my observations would have been limited to photographs. This course of action would have been impractical because the autopsy sample size could not be predetermined, and the time factor involved in completing the study would have been considerable.

MATERIALS: X-RAYS

WHAT IS A RADIOGRAPH?

Glass plates coated with silver bromide crystals were originally used to create the earliest radiographs. The crystals were changed chemically after exposure to x-rays and development, producing a visible permanent record. This permanent image has numerous names: radiograph, roentgenogram (taken from Wilhelm Röntgen's discovery of x-rays), x-rays, plates, and x-ray film are all synonymous terms. Silver bromide crystals are the essence of a radiographic image. In order to create a suitable image these crystals should be 0.1 to 0.5 microns in size. Larger crystals can be used, but image quality deteriorates. The addition of gelatin to silver bromide crystals creates the emulsion found on x-ray film (Hiss, 1983).

Medicolegal investigation for identification purposes routinely includes x-ray examination, as the practice allows for the detection and aging of injuries, dental identifications, the location of foreign objects, and the possibility of matching ante-mortem to post-mortem plates. Radiographic images must meet certain standards to be valuable. Visibility of detail and sharpness of detail are required. The projected x-ray beam is primarily responsible for the second factor. Exposing an x-ray film properly depends upon several components, according to Ortner and Putschar (1985). These factors include (1.) electrical current flow, (2.) energy of current, (3.) time of exposure, (4.) distance between the x-ray source and the film, (5.) the speed of the film emulsion, and (6.) density of specimen. They state that current, energy, and time are variables limited by the x-ray machine. When energy is increased the penetrating ability of the x-ray is increased. According to Hiss (1983) the optimal radiographic quality can be achieved if contrast, sharpness, and density are balanced. Other proportional factors are focal film distance, focal spot size, and object to film distance.

Differences in radiographic tones (densities) produces contrast, and proper radiographic contrast produces visibility of detail. The image seen on the film is the absorption pattern resulting from the x-ray photons being randomly trapped by the body. The elements of radiographic contrast are subject contrast, film contrast, and scatter control. Scatter of x-ray beams can be controlled through film grids and beam limiting devices. Film contrast is defined as the inherent sensitivity of a particular emulsion (film) to the gradations in intensity of the remnant photons striking the film surface. Film sensitivity is required, and has to be built-in by the manufacturer, because different body areas have different subject contrasts; for example, the chest region has a high degree of subject contrast. Should a high contrast film be used, the result would be a radiograph outside the optimum range; thereby tonal quality would be narrow, and only black or white would be perceived on the x-ray. Films are also classified as being "narrow" or "wide" latitude. Wide latitude films allow abrupt transitions between areas of the body to still give good detail, whereas narrow latitude films would lose detail (Hiss, 1983).

Subject contrast is related to the form and absorption characteristics of the human body. Four major substances are found in the body: fat, fluid, muscle, and bone. Another substance found in the body is air. Trying to choose the correct exposure for a clinical x-ray depends upon the distribution and quantity of these substances in the body. Of the soft tissues, muscle contains more water than fat; and this fact has a bearing on the radiographic image. Muscle is likely to cause a considerable decrease in radiographic contrast. Large amounts of muscle tissue would produce more scatter than an equivalent amount of fat tissue. Body fluid is more absorbent to x-ray photons; therefore, water is very efficient in producing scatter radiation, a fact which implies that too much or too little water will have an adverse effect on the x-ray image. Too much water means that the x-rays cannot properly penetrate to strike the film surface. Dehydration and poor muscle tone, found especially in older patients, require that the kilovoltage be reduced in order to increase subject contrast. Low subject contrast is prevalent in the abdominal area because water is found in the stomach. Bone tissue has the most variable absorption rate in the body. Water content in bone is low; but calcium, an extensive component of bone, is an element that absorbs x-rays. With the amount of calcium found in bone varying with age, the image produced also varies. Healthy bone absorbs more x-ray photons than fat or muscle. Tooth enamel is the greatest absorbing substance in the body (Hiss, 1983).

Photography and radiography share many of the same problems, because a three-dimensional image is being converted to a two-dimensional one. Distortion can be minimized by keeping certain principles in mind. Radiographic equipment is designed to radiate the x-ray beam from a focal spot. X-rays are generated from the entire surface of the focal spot and spread out in a cone from each individual point in the area of the spot. Distortion produced by the design of the focal spot is decreased when the distance between the focal spot and the film plane is increased. Parallax distortion, another effect when three-dimensional objects are converted to two-dimensional objects, is also diminished. This type of distortion will turn a round object into a long oval one. However, as pointed out by Ortner and Putschar (1985), there are practical limits to the distance between focal spot and film plane. Of importance is a principle known as the inverse square law, which states that x-rays are spread over a larger area as distance increases, because the x-rays diverge as they spread from the source. The consequence is that the number of x-rays must be increased by elevating the exposure time or the current, if one increases the distance. A consideration with increasing the exposure time is the deleterious effect of x-rays; however, there are no radiation exposure problems when working with the dead or archaeological bone specimens (Ortner and Putschar, 1985).

LITERATURE REVIEW

Professor Wilhelm Röntgen, a German physicist, discovered the fluorescence of a barium platinocyanide screen that was near a vacuum tube, filled with gas, through which electricity had been passed. He named this x-radiation because Röntgen was not sure of the nature of this substance. Further investigation showed that this radiation passed through objects, including the human body; and by 1895 the medical authorities had heard of this technique (Eckert and Garland, 1984).

Utilization of radiographs in the identification of unknown human remains today has been classified as "specific" and "scientific" by Krogman and Iscan (1986). The "specific" technique attempts to match the individualizing characteristics on an existing radiograph to a particular missing person. ARN would be included in this category.

This category also encompasses mass disaster identification. Many authors have written about these cases. Singleton (1951) considered the identification of victims of the fire which broke out on the Great Lakes liner *Noronic* , in which one hundred and nineteen passengers lost their lives. Charney and Wilber (1980) reported on the methods adopted in identifying the victims of the Great Thompson flood of 1976, and mentioned that radiographic comparison could be applied in many of the 139 deaths. Mulligan *et al* (1988) presented the radiographic identification done on the two hundred and fifty-six U.S.A. army servicemen who were victims of an airliner crash in Gander, Newfoundland, before Christmas of 1985.

Specific identification of individual cases was performed by Dutra (1944), Atkins and Potsaid (1978), Teige (1978), and Murphy and Gantner (1982). Murphy *et al* (1980) have detailed the numbers of unknown human remains identified radiologically between April 1978 and July 1979 at the Office of the Medical Examiner in the city of St. Louis. Their report showed that chest, skull, and abdominal radiographs were most frequently helpful in establishing identification. Special radiographic identification using a dorsal defect of the patella (Riddick *et al* , 1983) and identification by a single clavicle (Sanders *et al* , 1972) have also been noted in the literature.

The "scientific" technique is based upon data input in which particular patterns of the skeletal system are studied; for example, morphological variation in sinuses, mastoid processes, and sella turcica. The works of Culbert and Law (1927) and Ubelaker (1984) has examined this type of data. Greulich (1960a and b) has shown the value of x-ray films in hand and wrist identification, especially where young persons are involved. Radiography is useful in cases of fragmented remains, and can be used to differentiate human from non-human remains. Johanson and Saldeen (1969) showed how calcined remains could be separated from other debris and used for identification with ante-mortem radiographs.

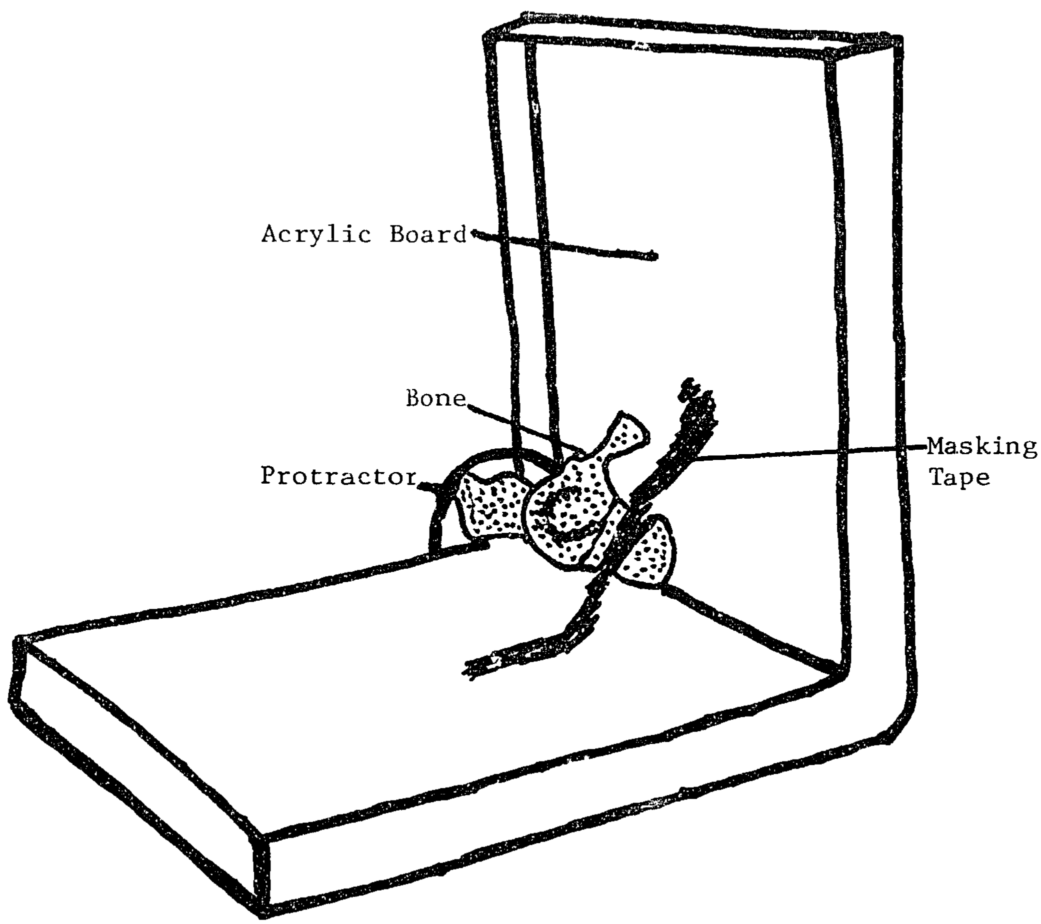
Newer studies are concentrating on the validity of using ante-and post-mortem radiograph comparison, and they are welcome additions to this area of the literature. Martel *et al* (1977) conducted an experiment on the thorax in which two experienced radiologists were asked to match nine unidentified plates to a control group. The final observations of both examiners were correct for all cases. Most human identification specialists have debated about the effects of aging on the ability to compare ante-and post-mortem radiographs. The work of Sauer *et al* (1988) and Sauer and Brantley (1989) reveals that the ability to distinguish the landmarks used in radiographic comparison does not appear to be impaired with the passage of time.

In sum, radiographic comparison has precedence in forensic science. These comparisons would form the basis of ARN use as an identification technique in situations in which human remains become commingled. This technique presupposes that there are radiographs taken of the person during his/her life. Since the study of osteological material appeared to be difficult, I decided to turn my efforts toward studying the variability and incidence of ARN from radiographs.

METHODS

Control x-rays were taken to illustrate the relationship between the acetabular rim notch and its appearance on a radiograph. These x-rays were taken of a modern bone sample found in the Department of Anthropology collection, at the OCME by Cyril Chan, forensic radiographer and photographer. Figure 5 shows the set-up used to generate these items. A thin

Figure 5. A drawing of the arrangement used to generate control x-rays.



copper wire was attached to the acetabular margin with masking tape. The innominate was taped to an L-shaped clear acrylic board, with a protractor placed at one end. The x-rays were taken by tilting the board to the required angle. Tilting was oriented in a medial direction in the body, which meant the anterior acetabular rim was tilted medially, while the posterior rim was tilted laterally. The board and bone were oriented as if lying in the human body. X-rays were taken at: 90^{o}, 60^{o}, 30^{o}, and 15^{o}. The first set (two x-ray plates) of radiographs were oriented as if there were a pelvic centering point ; that is, the center of the x-ray beam was projected to where the anterior sacro-iliac joint and the symphysis pubis would form a line in the body. The degrees were chosen to illustrate the appearance of the notch in various directions from the x-ray beam (see Plate 4 as an example of the 60 degree x-ray). However, it was found that the 90^{o} angle conformed most closely to the general appearance of acceptable hospital anteroposterior (A-P) pelvic radiographs (see Plate 5). With this in mind, the third x-ray film was taken at 90 and 110 degrees, using an abdominal centering point. In abdominal x-rays the centering point of the x-ray beam is at the lower costal margin. The other degrees (60, 30, and 15) were not deemed to be relevant. However, 110 degrees was chosen to show rotation of the hips in the opposite direction.

Figure 6 shows the outline of the notch when an abdominal versus pelvic centering point for the x-ray beam is used. An abdominal centering point appears to shorten the outline of the anterior margin, but the notch outline is not changed substantially.

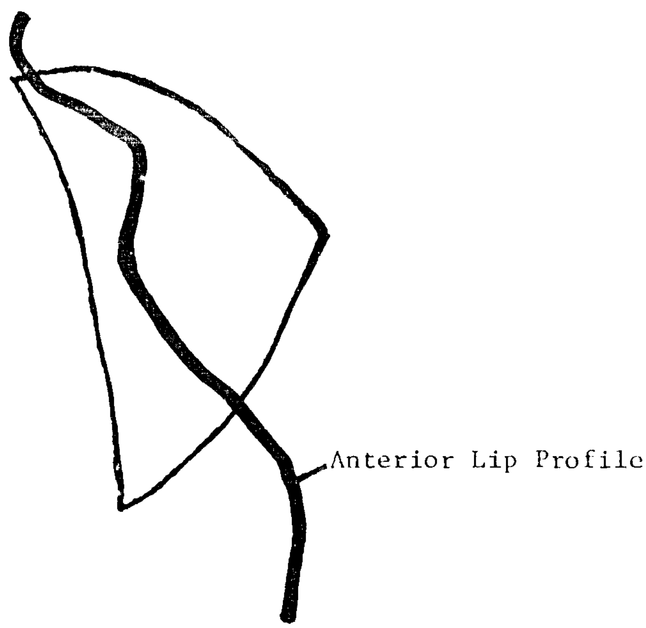
The control x-rays were used for comparison purposes. Two hundred (200) A-P (mainly abdominal centering point) x-rays were to be examined at the OCME, and another two hundred (200) A-P x-rays (pelvic centering point) were to be examined at the University of Alberta Hospital Radiology Department.

Plate 4. Control x-ray in 60^{o} orientation with pelvic centering point for x-ray beam. The arrow marks the ARN.

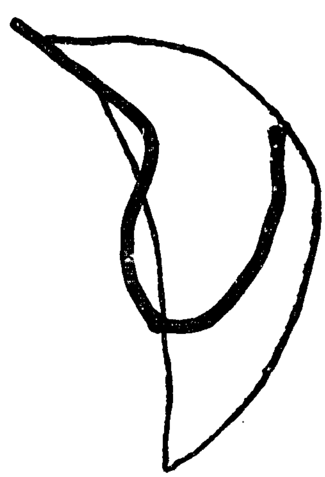
Plate 5. Control x-ray in 90^{o} orientation with pelvic centering point for x-ray beam. The arrow marks the ARN.

Figure 6. Drawings of the tracings of the anterior acetabular lip profile on antero-posterior x-ray projections. The top represents a pelvic centering point for the x-ray and the lower drawing represents an abdominal centering point for the x-ray.

X-Ray 1



X-Ray 3



These were intended as an outside, unbiased sample with the radiographs taken under optimum conditions. A data sheet was developed to record the statistics (sample data sheet is found in Appendix I). Several versions of the data sheet were used during the study; but the only item changed on the data sheet was the title, in order to differentiate sample groups.

CHOICE OF X-RAYS

Each radiographic case was examined using the following procedure, with the list applying mainly to the OCME sample:

1. Sampling began at the end of 1988 with the x-ray envelope labelled 401; then went to 400, 399, and so on until case 1 was reached. This procedure was followed with x-ray
case 427 of 1987, and continued downwards to case 1. For 1986, the sample began with case 559 and continued until case number 126 was reached, when the total study sample of 300 x-rays was reached. This process ensured systematic random sampling. In other words, no effort was made to select persons who are representative of the population of interest. By ensuring that I did not designate the population elements for the sample, statistical bias was minimized. This study sample is called a 'convenience sample', because it consists of a population conveniently at hand (Neter *et al* , 1978).

2. The existence of abdominal or pelvic x-rays for that decedent was ensured. Some decedents' x-ray records consist of areas of special interest to the forensic pathologist. An example would be a radiograph of the hand to study a fracture. For obvious reasons, they could not constitute part of my study sample. It must be noted that part of the standard x-rays taken for most cases at the

OCME is an A-P projection of the abdominal area which includes the acetabulae, but occasionally pelvic x-rays are taken. Therefore the OCME x-rays generally had an abdominal centering point to the x-ray, which could be compared to set two of the control x-rays.

3. It was ensured that x-rays are those of an adult (the primary elements of the acetabulum had fused) whose pelvis is in relatively intact condition.

4. X-rays that do not fall into the above guidelines were discarded. The conditions set out above required that roentgenograms of infants (babygrams) and x-rays of young persons be omitted, along with evidence of trauma to the pelvis. Table 1 shows the reasons that x-rays were discarded from the sample. This table does not include the number of babygrams and pre-adolescents. See below regarding the age of the sample.

Table 1. The reasons some x-rays were discarded from sample.

Reasons	Number
Decomposed-Burnt-Fragmented Remains	60
Fractures and Dislocations of the Pelvis	64
Young Person (Epiphyses in Acetabulum or Femur)	11
Poor Contrast On X-Ray	19
Pocket Materials	4
Others	2
Total Discarded	160

Some of the reasons these x-rays were discarded are illustrated in Plates 6 to 8. Plate 6 is a decomposed body, and the margins of the acetabular rim are difficult to follow due to gas bubbles obscuring the margins. Plate 7 shows that the acetabular margin can be seen, and appears to be unaffected by pelvic fractures; but to remain consistent and not bring unknown factors into the sample, the x-ray was discarded. Plate 8 illustrates an x-ray with poor contrast. Again, the margins of the acetabulum are difficult to trace. Beginning with the first category in Table 1, the explanation for discard is as follows. Destruction of the bone in burnt and fragmented remains make the radiograph difficult to interpret. Fractures and dislocations can change the orientation of the acetabulum, making it difficult to compare these x-rays properly with the control x-rays taken. The young people in the survey were discarded if the decedents were under the age of 17 years because the acetabulum is not fully formed: epiphyses could be seen in the acetabulum or in the femur. Individual variation in growth patterns would have caused the data to become too complex to analyze adequately. Seventeen years of age was chosen as the youngest age allowed in the study because according to McKern and Stewart (1957: 57) the acetabular triradiate cartilage may fuse as late as 17 years of age in males, and Morrison (1962) states that this area fuses by the age of 17 years. Poor contrast on the radiograph made the reading of the radiograph difficult, due to the fact that acetabular lip outlines could not be seen. Pocket materials refers to foreign objects obscuring the view of the acetabulum. Radiographs at the OCME are generated with clothing on the body (if the body is clothed), and this procedure means that coins, pocket knives, coat zippers, and other items can hide the acetabulum on the x-ray. The "others" category in Table 1 consisted of two x-rays in which the first had a double hip replacement

Plate 6. X-ray of a decomposed body illustrating the obscuring of ARN.

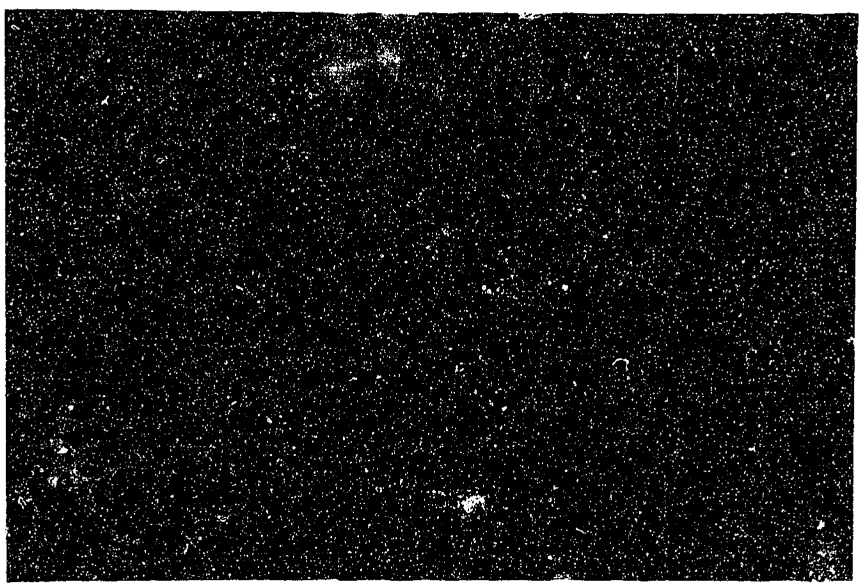
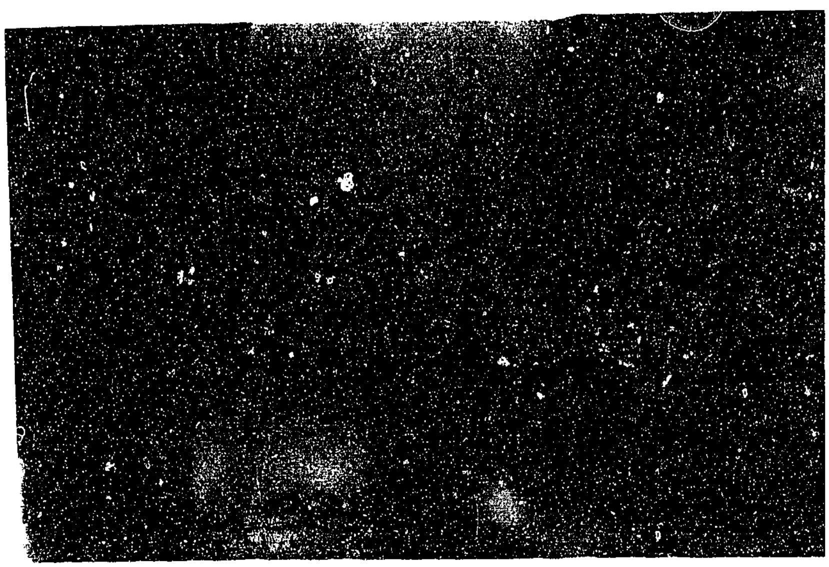


Plate 7. X-ray of the pelvis with fractures in pubic and ischial regions.

Plate 8. Poor contrast on this x-ray makes the anterior and posterior lips difficult to distinguish.



operation; and in the second, the abdominal x-ray did not show enough of the acetabulum.

5. Each x-ray was examined for ARN. The data sheet was filled in for: case number, if notches found on x-ray, if the notches are bilateral, and any comments. Comments potentially included "possible adolescent" or "reexamine x-ray", and so on.

6. The records department was visited to fill in the rest of the information on the data sheet, if available: sex, age, race, and weight. If the case records indicated that the decedent was under the age of seventeen years, then the case was rejected.

7. Those x-rays that were discarded were replaced in the sample by going through procedures 1 to 6 again until the sample was brought up to the required number.

CHAPTER 4

RESULTS

HOSPITAL X-RAYS

In order to become familiar with the appearance of acetabular rims on x-rays, I examined 400 x-rays at the Medical Examiner's office. The 400 x-rays were examined in groups of 200 each, in order to prepare for the actual assessment of the test sample. In this way, a step-by-step procedure was established and used for the examination of the x-rays; and it helped to resolve problems in evaluation I encountered along the way.

For an outside x-ray sample, x-rays at the University of Alberta Hospital Radiology Department were viewed. Conversation with several department members elicited the fact that new Alberta government regulations would not in the future allow certain information to be collected from patients, including the person's sex and ethnic origin, as the practice is deemed to be discriminatory. The implication for my study was that the "race" variable could not be tested at the hospital. It was suggested that it would be extremely difficult to get each individual patient's permission to examine his/her records and x-ray.

Since the Radiology Department has an x-ray library, it was proposed that these radiographs be used for my sample. While observing the library x-rays, several new problems were uncovered. Most x-rays were approximately twenty-five years old, the majority being kept as teaching tools which illustrate unusual diagnostic values. Few had complete patient records. The next problem encountered was that the x-rays being kept in the library were not sufficient in number to constitute my sample. At this point in time, I learned that staff members keep x-rays in their offices. Upon receiving this information, permission was obtained from each staff member to use his/her office and look at the x-rays. The result was that most x-rays had to be discarded from my sample. For example, one person's office x-rays consisted of all manner of pelvic fractures, dislocations, and locomotor problems in general. As these conflicted with my methodology, they were discarded, because abnormalities could possibly influence the "normal" orientation of the acetabulum. The pelvic x-rays of another staff member consisted of x-rays of women pregnant with twins and triplets, whose inclusion would have resulted in two changes to the sample: firstly, an inordinate number of females was being sampled; and secondly, the effect on the orientation of the pelvis by multiple pregnancy could not be established. To ensure straight forward, basic results from my sample, these x-rays were rejected. Although the x-ray sample at the OCME consisted of an inordinate number of males compared to females, this fact was not known at the time the hospital x-rays were examined.

In the end the decision was made to eliminate the hospital x-rays from the study for the following reasons: sparse patient history and the numerous pelvic abnormalities (those perceived and seen in actuality). In light of this decision, the sample size at the Office of the Chief Medical Examiner was increased to 300 x-rays from 200. The radiographic study began at the end of 1988, and included the examination of all cases back to early 1986.

EXAMINATION OF X-RAYS FOR NOTCHES

I do not consider myself an expert in tracing the entire outline of the anterior and posterior lips on an x-ray; however, I have examined enough x-rays (greater than 900) to become familiar with the variability of the acetabulum on an anteroposterior (A-P) pelvic or abdominal x-ray. This familiarity has allowed me to make the following suggestions for persons attempting to determine if acetabular rim notches are found on a radiograph. The most important aspect of the A-P projection of the pelvis is that the individual interpreting the radiograph has to familiarize himself or herself with viewing overlapping images. These images must be separated in one's mind. A three-dimensional image is converted to a two-dimensional image through radiographs, resulting in the cup-shaped acetabulum being flattened. The outline of the femur and the ischium tend to complicate the image that the forensic anthropologist views (see Figure 7). Plate 9 shows how the ischium can appear to be the posterior lip of the acetabulum, and radiolucency mimic a notch. Another complication may be the quality of the x-ray being examined (see Plate 8).

When examining an x-ray for the presence of an acetabular rim notch, it is easiest to divide the acetabulum into thirds. The notches (as evidenced by the control x-rays) can be located only in the first or upper one-third of the acetabulum (see Plates 10 to 13). Plate 14 shows how the radiolucent gap not produced by a notch can be found in the second section of an acetabulum visually divided into thirds.

The posterior lip of the acetabular rim on an A-P x-ray is generally located more laterally to the medial anterior lip of the acetabular rim (Armbuster *et al*, 1978). Very occasionally, the orientation of the x-ray will be such that the posterior and anterior lips directly overlap one another as a result of the legs being rotated laterally or medially. Rotation of the hips produces an image in which the posterior portion of the articular surface is well represented on the image (Plates 15). An actual notch will leave a radiolucent gap in the anterior one-third of the acetabulum between the anterior and posterior lips, and this image must not be confused with the image of the anterior and posterior lips of

Figure 7. A drawing of the antero-posterior projection of the right innominate on an x-ray.

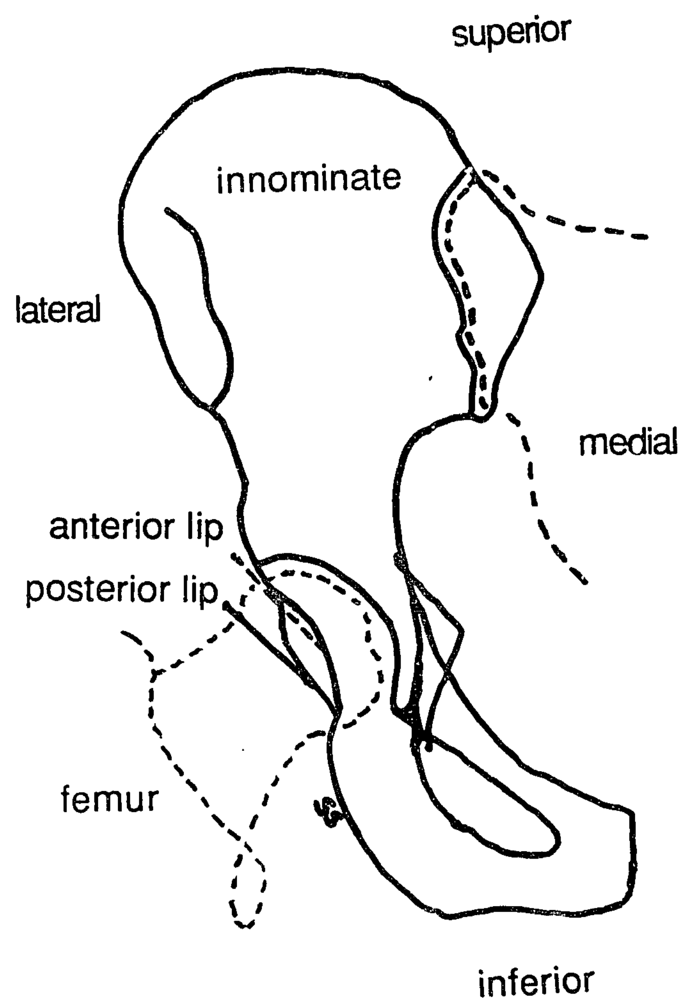


Plate 9. The ischial image is quite radiolucent and makes the acetabular margins difficult to distinguish.

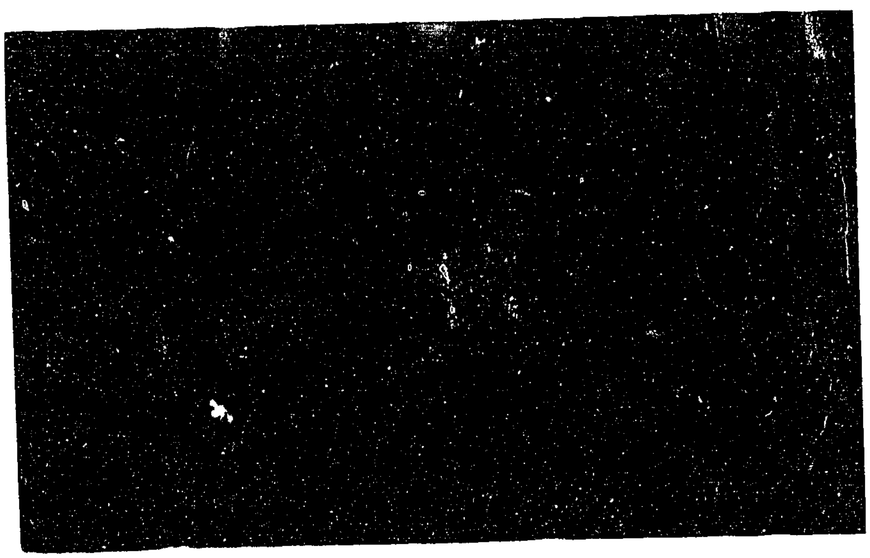


Plate 10. An x-ray with an acetabular rim notch. The arrow indicates the deepest portion of the notch.

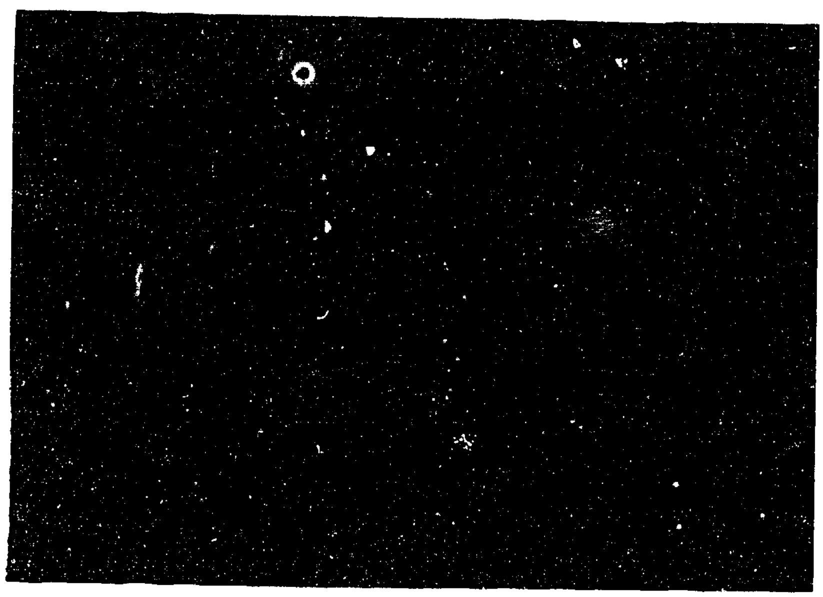


Plate 11. An x-ray with an acetabular rim notch. The arrow indicates the deepest portion of the notch.

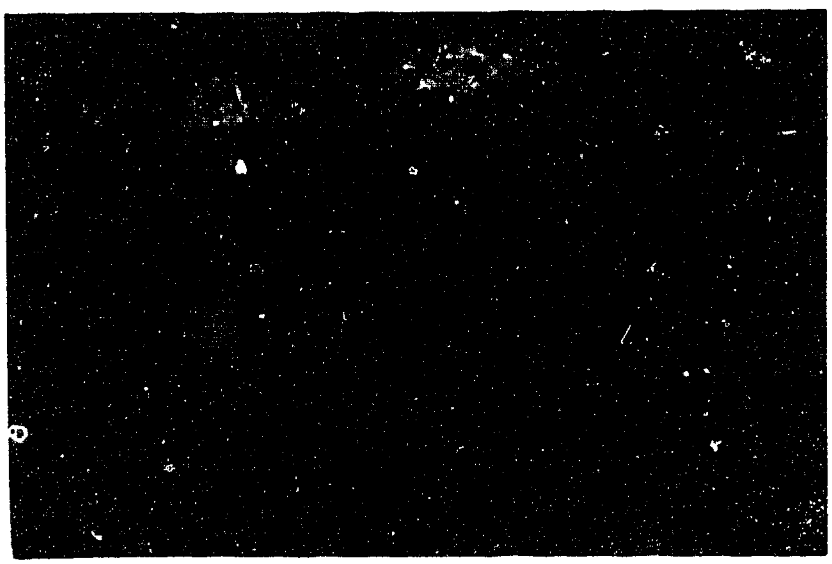


Plate 12. An x-ray with an acetabular rim notch. The arrow indicates the deepest portion of the notch.

Plate 13. An x-ray with an acetabular rim notch. The arrows indicate the anterior lip.

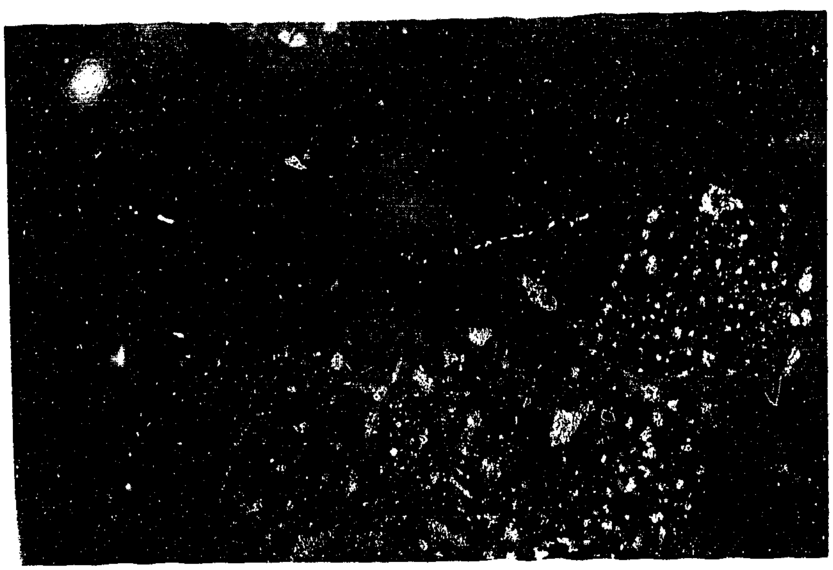
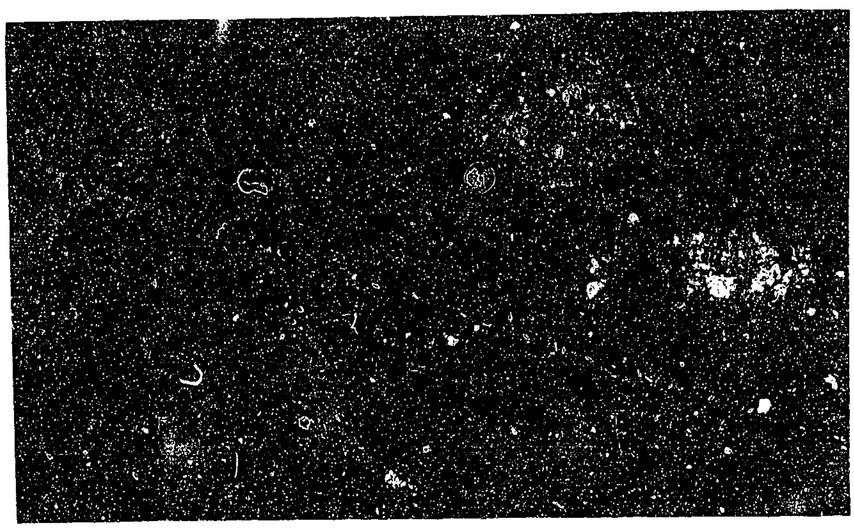


Plate 14. An example of an acetabulum, in which the greatest radiolucency between the anterior and posterior lips is found in the middle of the acetabulum.

Plate 15. The hips on this antero-posterior x-ray projection are rotated to produce irregular anterior and posterior lip outlines.



the acetabular rim crossing over to form an indentation in the image. An actual acetabular rim notch will leave a radiolucent image which indents toward the medial wall of the acetabular rim, and is quite noticeable (see Plates 10 to 13).

For those readers having difficulty orienting themselves to the image of the acetabulum on an x-ray, the most inferior portion of Köhler's teardrop (see Plate 16) can be used to indicate the presence of the inferior notch of the acetabulum. Köhler's teardrop is a radiologic artifact which is best seen on x-rays with an abdominal centering point . The teardrop figure can be traced with lead (Katz, 1969) and it is found that the superior margin of the acetabulum, along with the center of the acetabular fossa and the inferior acetabular notch form the lateral border. A medial border is formed by the upper margin of the obturator foramen and its extension along the inner wall of the true pelvis just posterior to the iliopubic eminence (Katz, 1969, 1979; Schindlmaisser and Kotz, 1972; Kölbel, 1977; Bowerman *et al* , 1982; Saks, 1986). Since people tend to have irregularly shaped lips on the acetabular rim, the general outline must be examined. A useful technique for examining the x-ray is to turn it sideways or upside-down. From this vantage point, a gap at the anterior one-third of the acetabulum will be seen to be a notch, or show the actual "cup" orientation of the acetabulum; in other words, a gap mimicking a notch. Plate 17 has been turned sideways to illustrate the "cup-shaped" orientation of the acetabulum (no notch); and Plate 18 has also been turned sideways, but this acetabulum does have a notch.

It must be noted that the A-P projection of the acetabulum which was sampled in the train crash x-ray survey did not contain a notch (see Plate 14). There is so much variability in the appearance of the anterior and posterior lips on a radiograph that this variability could not be appreciated with a small sample size. This finding does not affect the identification made during the

Plate 16. The arrows indicate Köhler's teardrop, whose most inferior portion represents the inferior acetabular notch. An abdominal centering point is used in this x-ray.

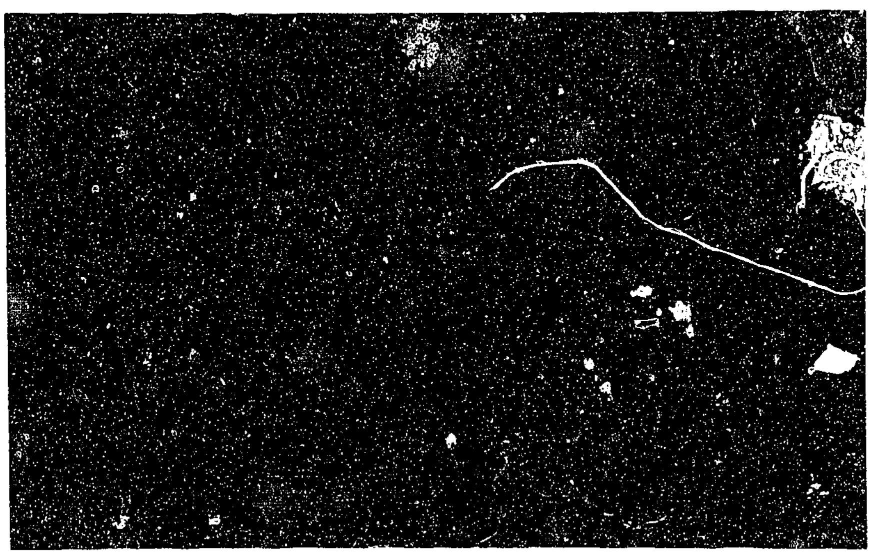


Plate 17. An x-ray of the acetabulum oriented sideways (lateral at the top to medial at the bottom). This specimen has no acetabular rim notch.

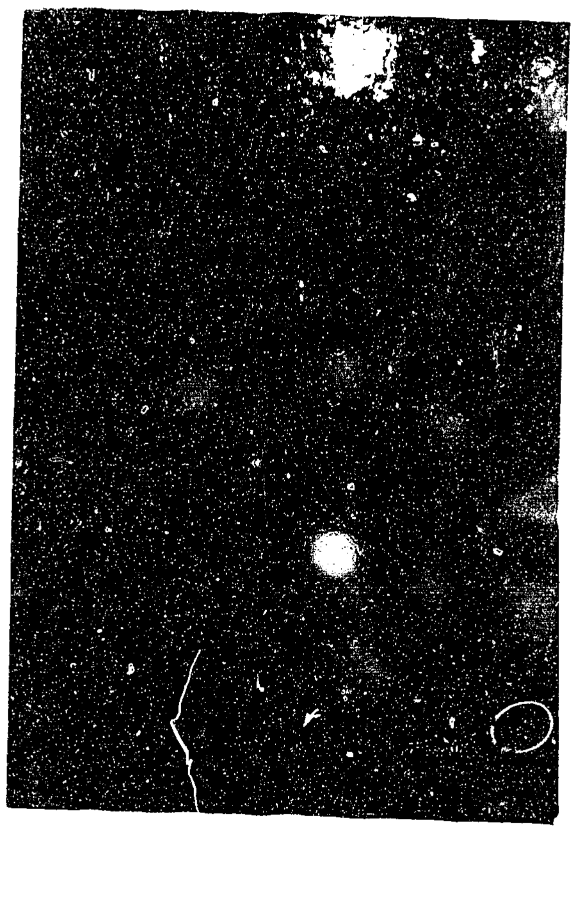


Plate 18. An x-ray of the acetabulum oriented sideways (lateral at the top to medial at the bottom). The arrow indicates the deepest portion of the acetabular rim notch.

forensic work with human remains of the train crash, as ARN was not the only method used to identify that train crash victim and the feature could clearly be seen on the decedent's ante-mortem x-ray.

RESULTS AND DISCUSSION OF THE STUDY

The statistics generated in this study show that a number of variables examined are biased in one way or another. The most obvious sampling bias was that males were sampled approximately three to one in comparison to females (see Table 2). This sampling bias did not appear to affect whether or not a particular sex had ARN, as the percentages remained relatively even (8.9% for females and 8.1% for males).

Table 2. The frequency of acetabular rim notches.

	Percentages
Total Sample = 300	100%
Males = 222	73.66
Females = 78	26.33
ARN in Total Sample = 25/300	8.33
ARN and Female = 7/78	8.97
ARN and Male = 18/222	8.10

An important finding in this study was the fact that males also have ARN (refer to Table 2). This finding immediately dispels the possibility that ARN is a sex-related or childbirth-related morphological variable. However, what does appear to differ in the way in which this trait is expressed in males and females (see Figure 8, females and Figure 9, males). Females tend to have triangular outlines of the radiolucent gap one sees between the anterior and posterior lips in x-rays with ARN, while males tend to display ovoid patterns. There is overlap between the sexes and a larger sample size should quantify the amount of overlap. This finding has significant implications for future research. I would suggest that the well known orientational differences in male and female pelves affect the outline of the acetabular rim on a radiograph (Coleman, 196[illegible]). This being the case, it should be possible (with further research) to orient an isolated acetabulum (fragmented innominate), without ARN, in the proper position for an A-P projection of the pelvis, and examine the outline of the acetabular margin to determine the sex of the individual. The implications for human identification in mass disaster situations, or in determining the identity of unknown human remains is obvious.

The incidence of ARN in this sample (8.33%) shows it to be a meaningful anatomical variant. The suggestion can be made that the finding of this anatomical variant is in such low incidence that a technique based on the finding of the trait would show high probability of a match being made between unknown human remains and a missing person.

The pote[illegible] [illegible]mine ARN to see if unilateral frequency is greater on one side or the other, could not be tested. Saunders (1978) describes a method used by Siegel and another researcher McNemar which I wished to attempt. The suggested technique involves eliminating all bilateral occurrences from the test. [illegible]ey (1980) has also recommended this procedure. Use of this method left me with an extremely small sample size (one - left side only and one - right side only). I do not believe that use of this sample size would give valid results. It can be stated that, in general, ARN occur bilaterally. This observation

Figure 8. Tracings of the outlines of female acetabular margins with an acetabular rim notch, on an antero-posterior x-ray projection. The top line represents the anterior lip and the bottom, the posterior lip.

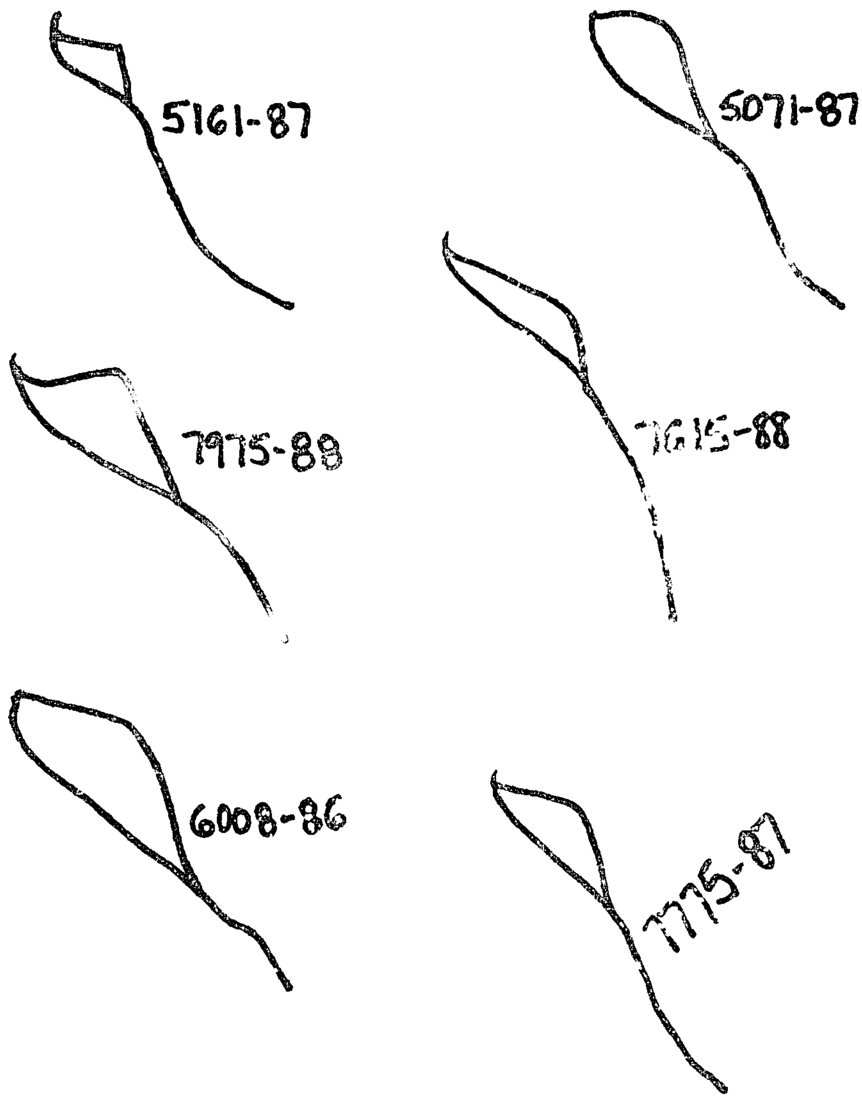


Figure 9. Tracings of the outlinesof male acetabular margins with an acetabu rim notch, on an antero-posterior x-ray projection. The top line represents the anterior lip and the bottom, the posterior lip.

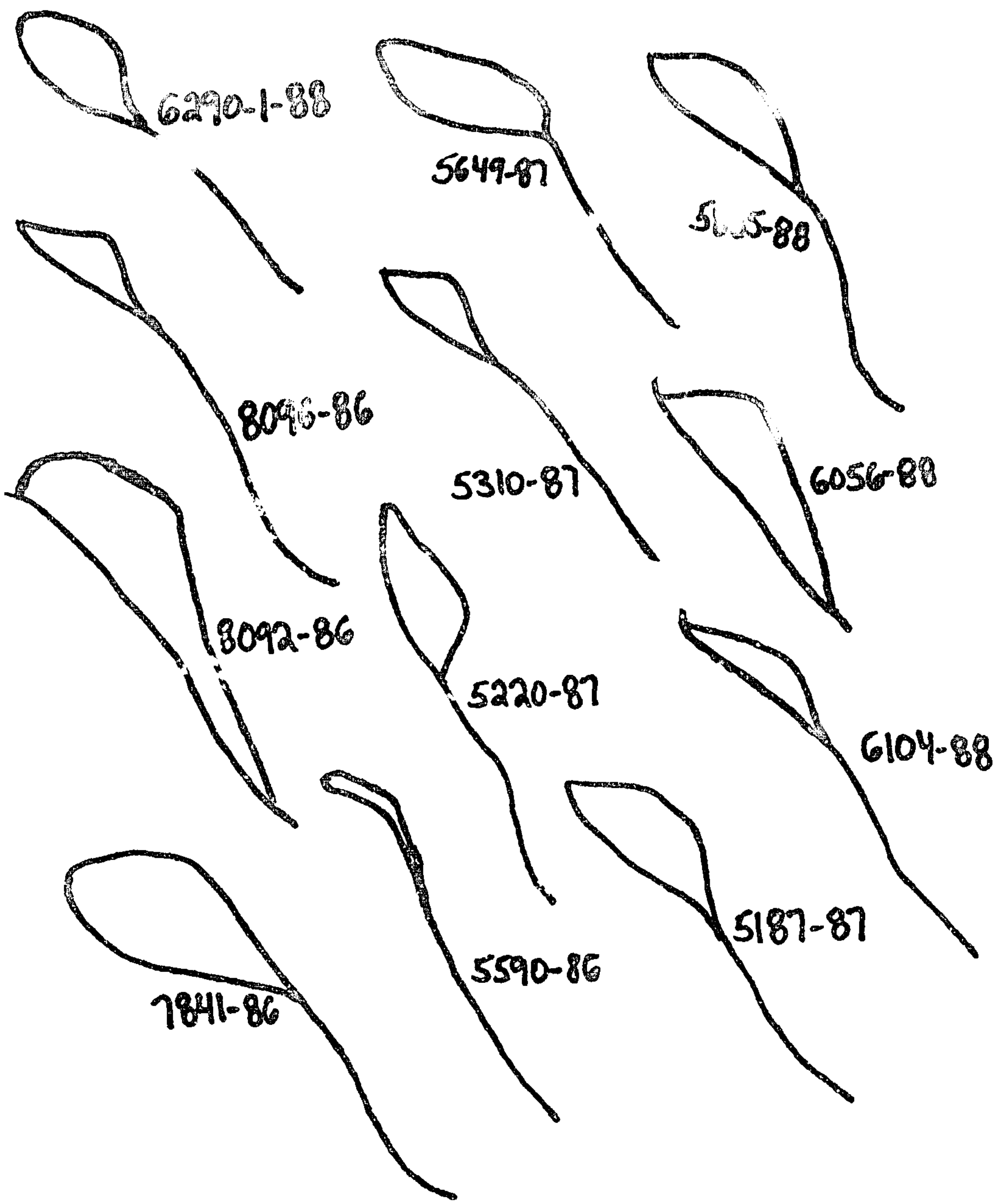
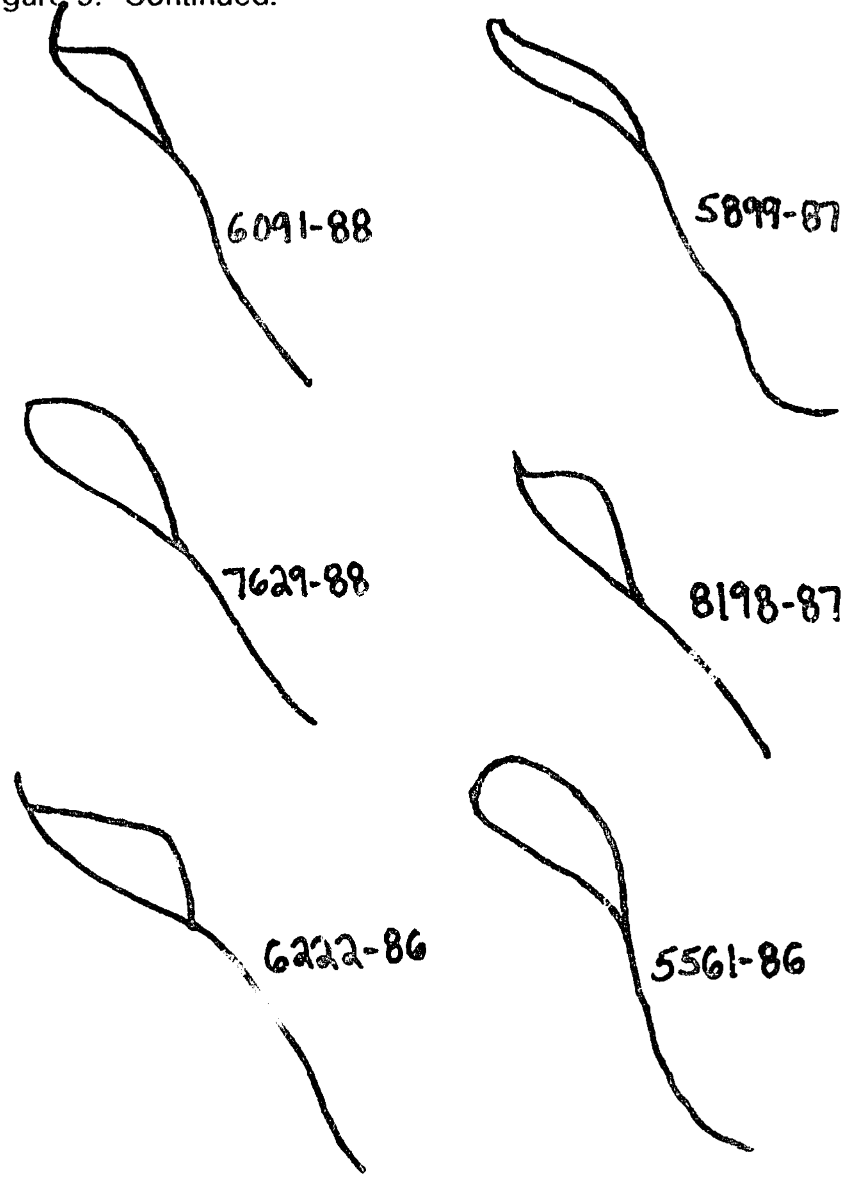


Figure 9. Continued.



is meaningful because there were two cases of unilateral occurrence in the sample . Case one involved a nineteen year person in which I commented that the os acetabulum did not appear to be completely fused, and the second case involved an x-ray in which the one side could not be evaluated for ARN. An assumption could be made in case two that the trait was bilateral, but this fact could not be stated with absolute certainty. The bilateral occurrences constituted 95.8 percent in the sample (23/24).

The age range in the study (see Table 3) shows that ARN occur in all age categories except the 76 to 85 year group (see Table 4). This finding is a sampling problem, since the age category was represented by 10 x-rays of the 300 and was not the age category with the smallest representation in the study. That was the 86-95 year category, which had the smallest expression, but one example of ARN.

Table 3. The age.range and means of the sample (years).

Age Range	17-95
Age Range (Males)	17-89
Mean (Males)	37.23
Age Range (Females)	17-95
Mean (Females)	39.48

Table 4. The age categories of subjects with notches in sample.

Categories	Years	Females Categories	Number	Males Categories	Number
1	17-25	1	1	1	7
2	26-35	2	6	2	5
3	36-45	3	0	3	2
4	46-55	4	0	4	1
5	56-65	5	0	5	1
6	66-75	6	0	6	1
7	76-85	7	0	7	0
8	86-95	8	0	8	1
		Total:	7	Total	18

Looking at Table 4, it is of greater interest that the majority of subjects with notches are found in the 17 to 35 year old age group. This finding may or may not be significant. Persons requiring x-rays at autopsy, in general, tend to be young persons involved in motor vehicle accidents. However, I would like to suggest that the statistics for ARN may be artificially inflated due to sampling of individuals whose triradiate cartilage is in the final stages of union. Plate 19 shows an example of an acetabulum which I deemed to have a notch in this study. Yet the radiolucency seen in the anterior region of the rim (a notch) may not be there in ten years, when the bone has solidly fused.

Race, in the records at the OCME, is recorded as: "white", "black", "native", "metis", "oriental", "east indian" and "eskimos" or "inuit". I converted

Plate 19. An x-ray of the acetabulum illustrating incomplete fusion of the os acetabulum.

these categories to the following: caucasian (includes east indian), native, mongoloid (oriental), inuit (eskimos), and admixture (the only group mentioned in this study were metis). Table 5 illustrates that 5 racial categories were sampled in this study: white, native, mongoloid, metis, and inuit. The results show that only whites and natives have ARN (see Table 6). No mongoloids, metis, or inuit were found with the trait. However, the numbers sampled were so small that the finding is not statistically valid. An obvious deficiency in this study was the lack of Blacks in the sample.

Table 5. The frequency of racial groups in total sample.

Race	Number	Percentages
White	238	79.333
Native	51	17.0
Mongoloid	6	2.0
Metis	3	1.0
Inuit	1	.333
Unknown	1	.333

Table 6. The frequency of racial groups in the sample with the anomaly.

Race Male	No.	%	Race Female	No.	%	Race Total	No.	%
White	17/25	68	White	3/25	12	White	20/25	80
Native	1/25	4	Native	4/25	16	Native	5/25	20

Table 7. The racial groups found in the sample without the anomaly.

Males	Number	Females	Number
White	166	White	52
Native	32	Native	14
Mongoloid	3	Mongoloid	3
Metis	2	Metis	1
Inuit	1	Unknown	1
Total	204	Total	71

The original study sample done during the train crash identification seemed to indicate that the trait may be correlated with being native. The statistics of this study do not confirm this original finding. Tables 5, 6, and 7 were used to create contingency tables (Tables 8, 9, 10) to examine the race and anomaly variables. A Chi Square test was chosen because the test results indicate differences between the observed sample frequencies and the expected sample frequencies. Use of this determination assesses if an association exists between variables. The first chi square crosstabulation (Table 11) shows there is no association between race and the anomaly (SPSS-X, 1988). However, a suggestion could be made that if one is female and has a notch, then the probability is slightly higher that one is native, rather than white (Table 13, SPSS-X, 1988). The reason the findings can be interpreted in this manner is that Chi Square is a two-tailed test; in others words, the relationship between the variables can go in either direction. The implication of this characteristic is that the significance factor can be divided in half, giving a value of .0509, which is slightly significant at the .05 level. Yet the reverse is true; if one is male and has a notch, chances would be higher the unknown male would be White (Table 12, SPSS-X, 1988).

Table 8. Contingency table for anomaly and race variables (total sample).

	White	Native	Totals
Anomaly	20	5	25
No Anomaly	218	46	264
Totals	238	51	289

Table 9. Contingency table for anomaly and race variables (males only).

	White	Native	Totals
Anomaly	17	1	18
No Anomaly	166	32	198
Totals	183	33	216

Table 10. Contingency table for anomaly and race variables (females only).

	White	Native	Totals
Anomaly	3	4	7
No Anomaly	52	14	66
Totals	55	18	73

Table 11. Chi square crosstabulation of anomaly by race (total sample).

Count Expected Value Column Percentage Residual	Race White	Race Native	Row Totals
Anomaly	20 20.6 8.4% -.6	5 4.4 9.8% .6	25 8.7%
No Anomaly	218 217.4 91.6% .6	46 46.6 90.2% -.6	264 91.3%
Column Total	238 82.4%	51 17.6%	289 100%

Significance = 0.7468 (With Yates Correction)

Significance = 0.9614 (Before Yates Correction)

Degrees of freedom = 1

Table 12. Chi square crosstabulation of anomaly by race controlling for sex (male).

Count Expected Value Column Percentage Residual	Race White	Race Native	Row Totals
Anomaly	17 15.2 9.3% 1.8	1 2.8 3.0% -1.8	18 8.3%
No Anomaly	166 166.8 90.7% -1.8	32 30.2 97.0% 1.8	198 91.7%
Column Total	183 84.7%	33 15.3%	216 100.0%

Significance = 0.3924 (With Yates Correction)

Significance = 0.2311 (Before Yates Correction)

Degrees of Freedom = 1

Table 13. Chi square crosstabulation of anomaly by race controlling for sex (female).

Count Expected Value Column Percentage Residual	Race White	Race Native	Row Totals
Anomaly	3 5.3 5.5% -2.3	4 1.7 22.2% 2.3	7 9.6%
No Anomaly	52 50.7 94.5% 2.3	14 16.3 77.8% -2.3	66 90.4%
Column Total	55 75.3%	18 24.7%	73 100.0%

Significance = 0.1018 (After Yates Correction)

Significance = 0.0360 (Before Yates Correction)

Degrees of freedom = 1

The race variable in this study can not be deemed significant on two counts. The first is the statistics generated, and the second is a perceived sampling bias. No correlation was found between ARN and the race variable in

Table 11. Secondly is noted a perceived sampling bias, determined by discussion with local law enforcement officials.

Being interested in human biological variation, I decided to find out how non-anthropologists perceive the concept of "race". I noted that the records at the OCME included a category called "race" and I was curious as to how the "race" of a dead person would be determined. Cyril [illegible]an (personal communication, 1988) informed me that for the vast majority of bodies that arrive at his office, it is the law enforcement agencies who have determined "race". This being the case, I decided to interview two local law enforcement officers. Murray Barker (personal communication, 1988), of the Edmonton Police Service described the following procedure when personnel arrive on the scene of a death. The officer walks through and describes the scene. Part of this description includes a description of the body. A description might include: "male, apparently native". In other words, the predominant physical features are described (generally skin color); and in cases of admixture, the decedent would be described by the more predominant features. Police go to the next-of-kin to determine difficult cases; for example, if someone should be classed as "black" or "mulatto". Generally the question is phrased as: "what race would person X have considered themselves to be?". Identification with the birth certificate is the last step, but this record does not include "race". Interestingly enough, differentiation is made between an East Indian (person from India) and a person from the Middle East (person from Lebanon), although most anthropologists would not make such a distinction (these categories would all be included in "caucasian").

An interview with Bruce McLean (personal communication, 1988), of The Royal Canadian Mounted Police ('K' Division, Edmonton), provided me with similiar information to that given by Staff-Sargent Barker. However, there was an interesting difference; many R.C.M.P. officers are assigned to small communities for several years, and the officer gets to know the members of the community. These officers would know ahead of time, in most cases, if the deceased, for example, would have classified himself or herself as "reservation indian" or "metis".

The interpretation I placed on these interviews is that physical characteristics, especially skin color, are the predominant method of determining race by law enforcement officials. For a true scientific study, this situation must be viewed as inappropriate methodology. Use of the criteria I have outlined indicates that race is assigned in a subjective manner and results would be expected to be slightly ambiguous.

Although weight was recorded on the data sheets, more as a matter of interest than anything else, there was no significant correlation between weight and the presence of ARN. The main reason is that the weight variable has many factors which are not easily controlled in a study. One does not know if the decedent recently lost or gained weight, and there are other factors attached to weight; such as nutritional intake. Weight records were unavailable for the sample from the University of Alberta Hospital. Since the weight variable was only examined at the OCME, other factors were involved, such as the manner in which the person died. Obviously the remains of a person cremated in a fire would not weigh the same as the person did during his or her lifetime.

CHAPTER 5

COMMENTS AND CONCLUSIONS

The nature of this study is diverse because it transcends numerous fields of study. This fact necessitates comments about the areas the research has touched, which are also diverse in nature; however, these comments can be classified as observations, recommendations, and conclusions.

The OCME has excellent potential as a facility for carrying out scientific research on skeletal anatomy, the caveat being that this research be of a legitimate nature, which considers the ethical concerns of interested parties. As all universities currently require various levels of ethics review for any research involving human subjects, I believe that the interests of the community and government would be served in individual cases. Another worthwhile note is that it would be beneficial to have a pre-approved ethics review for mass disaster situations. This approval should not be carte blanche in nature. Rather than to conduct scientific experiments on the deceased, the intent of this ethics approval would be to allow scientific data to be gathered; for example, anthropomorphic or osteometric measurements, which can be analyzed at a future date.

During the identification process in the OCME after the train crash, the forensic anthropology team was hindered in accomplishing its task on a few occasions because of difficulty in trying to imagine the layout of the crash site. It was difficult to picture in our minds train cars piled on top of one another, the angle of each car, and the fact that upper cars fell through lower ones, resulting in a distortion of the original layout of debris. OCME personnel did an excellent job of trying to remedy this situation by mapping the grid search pattern of the one Via Rail passenger car on the floor of the garage at the Edmonton office, and supplementing this layout with diagrams. Yet the fact remains that an extraordinary amount of time would have been saved if the forensic anthropology team had been called to the crash site to assist in locating remains. The reasons for this suggestion are two-fold: most physical anthropologists, and certainly forensic anthropologists, are specialists in the identification of human osteological material; and secondly, this procedure would have saved our identification team the trouble spent in travelling back and forth between investigators to verify the location of important finds.

I was impressed by the suggestion of Mulligan *et al* (1988), who investigated the Gander, Newfoundland air crash, regarding the use of a revolving illuminator. The top of this device carried ante-mortem radiographs and the bottom post-mortem radiographs. Revolving the bottom of the illuminator meant that rapid searches and comparisons were possible. I suggest that this method would be quite advantageous in large mass disasters. In terms of the number of people who perished in the train crash, the numbers were small; however, there were extensive medical records for most of the victims and keeping them in a box created the difficulty of keeping track of which ante-mortem x-rays were available for post-mortem matches.

The results of this study indicate that of the four hypotheses proposed, two can be rejected. Hypothesis I, that ARN is a genetic variant, can be provisionally accepted, given the evidence known to-date. A genetic predisposition for this trait is indicated by the research of Johnstone *et al* (1982). Their report appears to indicate that the superior roof notch is similar to ARN, but an unrelated morphological variant. The origin of ARN seems to be related to the failure of the os acetabulum or the superior rim epiphysis to fulfill their intended functions, and possibly a combination of both failing in their duties. This researcher contends that traumatic damage to this area cannot be the cause of ARN because notches should be found in the posterior wing of the triradiate cartilage as well, and this feature has not been shown in the present study.

My examination of radiographs leads me to suspect that there is greater variability in the time of complete fusion of the triradiate cartilage of the acetabulum, than one expects by examining the anthropological literature (eg. McKern and Stewart, 1957; Stewart, 1979; Krogman and Iscan 1986). A suggestion for future research is the effect on the ossification of the acetabulum played by the secondary ossification centers. I realize that this problem is most easily studied radiologically, but research is required on the environment affecting ossification of the triradiate cartilage. Only in this manner could the question be resolved as to whether ARN are genetic variants or are based on a genetic predisposition, given particular conditions at a crucial time during the ossification process.

The other hypotheses, namely that ARN are particular to one sex and a childbirth-related morphological variable, must be rejected, given the fact that males with acetabular rim notches were found. However, the examination of radiographs does indicate that the expression of the trait varies according to the sex of the individual, with females exhibiting notches which have a V-shaped (triangular) profile, whereas males exhibit a U-shaped (ovoid) profile, when the profiles are viewed mediolaterally from a slightly oblique and superior position on the radiograph (see Figures [illegible] and 9). Hypothesis IV, that ARN is a race-related variable, is given weak support by this study. Radiographic samples indicate that ARN are found in Whites and Natives, while the extremely small number of bones in which the trait has been found have fortunately shown that Inuit also carry this anomaly. No mongoloids of oriental origin, or metis with ARN were sampled in this study. An obvious deficiency in the sample is the fact that no Blacks are included in the study. It must be noted that the mongoloid, metis, and inuit components in this study were so small compared to the total number sampled and the fact that ARN was not found in these groups does not represent statistical validity . Chi Square test results show that an association exists between race and having ARN if one is also female. The implication of this association can be expressed thus: should unidentified human remains be found which have ARN, and are female, then the forensic anthropologist should search through the native population on the missing persons list, before searching for those individuals of white origin.

The suggestions for future research on this trait are unlimited; therefore I will restrict myself to a few recommendations. The most obvious proposal is that a large dry bone collection be studied in order to examine the incidence and variation of notches. I am presently planning to analyze the Terry Collection at the Smithsonian Institution in Washington, D.C. There are other intriguing questions: does a notch change in appearance over time due to bone remodelling? This study has shown that ARN occur in all adult age categories except the 76-85 year category, and I believe this omission is simply a sampling bias. Therefore, the potential exists for studying this trait with the passage of time. Do persons of other racial groups; that is, blacks, mongoloids of oriental origin, or metis possess this trait? It would also be of interest to study the family relationships between possessing the trait and passing that trait onto one's offspring (inheritability factors).

In regard to future research on radiographs, I would suggest that other projections of the pelvis be examined (especially, lateral) to determine how notches are manifested in those images. With computed tomography (CT) scans becoming more prevalent, there is another avenue of research to pursue. Since an understanding of CT scans should be evaluated in co-operation with a radiologist, I would suggest that there be increased co-operation between forensic anthropologists and radiologists. I realize that radiology department staff members are busy with their patient loads, but the potential for interdepartmental co-operation and thereby scientific advancement is enormous.

The well-known orientational differences of the pelvis in males and females makes it possible to comment on the fact that fragmented female and male innominates may be differentiated, given future research into this possibility. Females grow significantly more laterally than males (Coleman, 1969). It is noted that females have greater mediolateral breadth of the pelvic inlet, with the acetabulum and center of the hip joint being placed further laterally from the body's center of gravity. Ruff and Hayes (1983) state that the relatively shortened moment arm of the gluteal abductors in females increases mediolateral bending moment about the hip. Coleman's study has plotted the configuration of the pelvis on radiographs, using millimeter graph paper to record various osteometric points over several years in males and females. Point 21 in the study is the maximum transverse diameter of pelvic inlet (inlet breadth). As males grow, this point moves laterally, but also in a slightly more superior or posterior direction, along the wall of the pelvic inlet. Females show the reverse trend. Greatest breadth of the inlet moves inferior because there is maximum lateral growth of the ischial area. This information can be used to infer that the acetabular rim could be radiographed to delineate sex differences. Coleman (1969) studied the attainment of sexual differentiation in the pelvis, and has stated that the acetabular margins are the most sexually dimorphic portion of the pelvis. The present study has shown that the manner in which ARN is expressed is sexually dimorphic, and the correlate would be that the outline of margins of individuals without ARN should also be linked to sex.

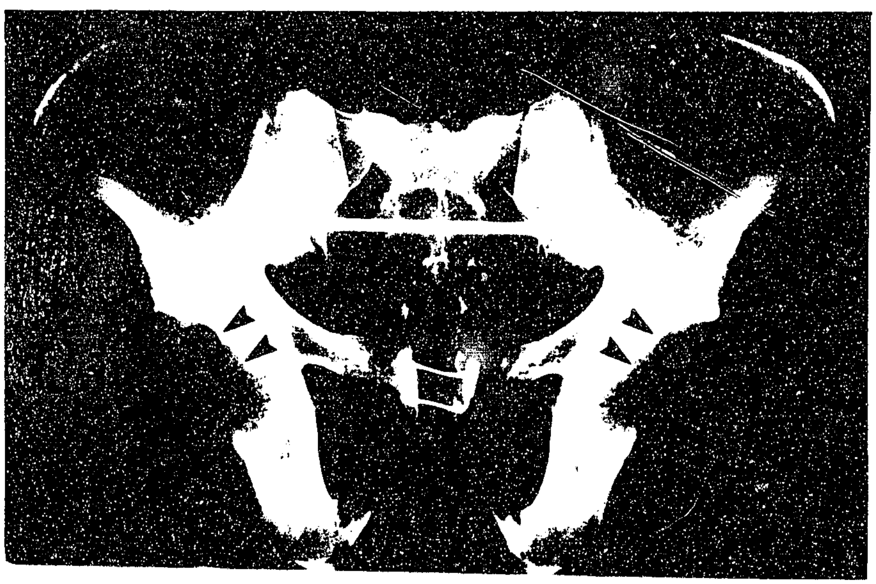
Plates 20 (female) and 21 (male) illustrate the differences in the margin appearance of two articulated pelves from the Department of Anthropology modern bone collection.

It is interesting to note that this research would not be as complicated as the evaulation of x-rays in the present study; the reason being that the femoral head would not complicate the image viewed on the radiograph. The fact that Morrison (1932) has said there is a definite lip on the acetabular rim by 14 years, 4 months allows me to suggest that x-raying the acetabulae of adolescents of 15 years of age may result in a sex determination technique for these post-cranial elements, if one is examining unknown remains. This technique would be particularly valuable, as the sexing of adolescent human remains has been extremely difficult (Stewart, 1979; Krogman and Iscan, 1986).

Although the configuration used in the test sample during the train crash did not necessarily have ARN, this study has shown that the trait is of sufficiently low incidence that it can be used as an identification technique for unidentified remains. The anomaly would have to be found in lower incidence in order to use the match of ante-mortem x-ray and acetabular bone with ARN as a positive identification technique. The sample size of three hundred is of sufficient size to ensure that the 8.33% occurrence is close to the population mean for this trait. The statistical postulate concerned is the central limit theorem, which states that as sample size increases one gets closer to the population mean for the tested variable (Neter *et al* , 1978). Acetabular rim notches, as an identification technique, have excellent potential in future mass disaster situations, as shown by their utilization in the Hinton train disaster of 1986. The characteristic has promising potential for future applications because the anomaly occurs in relatively small frequency and matches between ante-mortem and post-mortem x-rays would prove beneficial as an accessory identification technique. It is

Plate 20. An x-ray of a female articulated pelvis. The arrows show the appearance of the acetabular margins.

Plate 21. An x-ray of a male articulated pelvis. The arrows show the appearance of the acetabular margins.



useful to note that not having ARN is just as advantageous in an identification situation. If the ante-mortem x-ray for a particular person does not have an acetabular rim notch, but the specimen one is trying to identify does, then an exclusion can be made.

Finnegan and McGuire (1979) express the opinion that non-metric traits in forensic identification are advantageous over metric traits. Many forensic (and archaeological) cases have incomplete remains, and measurements cannot be taken. Another problem is that traditional metric analysis requires that the sexes be separated prior to applying the data to discriminant function analysis. This task may be difficult to accomplish on partial remains. My hope is that the explanation of this technique in this study is succinct enough that anyone may adopt the technique. The acetabulum is a very dense portion of the skeletal system, and tends to survive various traumas and the decomposition process. It is also hoped that future research will add to the knowledge about this trait and extend its applications in order that rapid identifications can be made in situations where commingled human remains are required to be separated.

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APPENDIX I

X-RAY DATA III (M.E.'S)

CASE # ____________________ X-RAY # ________________

ACETABULAR RIM NOTCH:

LEFT _____ RIGHT _____ BILATERAL _____ NONE _____

SIDE INDETERMINABLE _____

SEX :

MALE _____ FEMALE _____ AGE: _____

RACE:

WHITE _____ NATIVE _____ BLACK _____

INUIT _____ MONGOLOID _____ ADMIXTURE _____

WEIGHT: __________

COMMENTS:

____

____

____