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thesis entitled

POSITIVE IDENTIFICAION USING COMPARISONS OF
LUMBAR SPINE RADIOGRAPHS: A VALIDATION STUDY

presented by

JANE C. WANKMILLER

has been accepted towards fulfillment
of the requirements for the

M.S. degree in Criminal Justice

Major Professor's Signature

12-10-2010

Date

POSITIVE IDENTIFICATION USING COMPARISONS OF LUMBAR SPINE RADIOGRAPHS: A VALIDATION STUDY

By

Jane C. Wankmiller

A THESIS

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

MASTER OF SCIENCE

Forensic Science

2010

ABSTRACT

POSITIVE IDENTIFICATION USING COMPARISONS OF LUMBAR SPINE RADIOGRAPHS: A VALIDATION STUDY

By

Jane C. Wankmiller

Forensic anthropologists commonly use the comparisons of antemortem and postmortem medical or dental radiographs to positively identify unknown decedents. It is important to establish the validity of such methods due to increased scrutiny of the rules for admissibility of expert witness testimony. This study is designed to evaluate the validity of comparing of x-rays of the lumbar spine for the purposes of making a positive identification. Twenty-five participants were provided with sets of 20 radiographs that simulated antemortem x-rays of known individuals that they were asked to compare against 10 radiographs simulating postmortem x-rays of unknown individuals. The x-rays were all taken of cadavers from the Gross Anatomy Lab at Michigan State University. All 5 "unknown" individuals had corresponding matches in the set of 20 "antemortem" individuals, and the participants were evaluated on their ability to correctly identify the appropriate matches. Each participant also completed a two-part data sheet that asked for a number of personal details and their answers to the identification test. The participants achieved an overall accuracy rate of over 90%, and an overall error rate of 4.17%. This study shows that observers who have more experience are less likely to attempt a match that is negatively impacted by confounding factors, such as poor image quality, and are more successful overall than those with less experience. Results also show that correct matches are most often achieved by taking into account a combination of gross structures and minute details.

I would like to dedicate this document to my family. Your unwavering faith in me has enabled me to have faith in myself.

ACKNOWLEDGEMENTS

It will be nearly impossible for me to adequately express my gratitude to the people who have so generously helped and supported me throughout this process. Dr. Sauer, thank you for all of your advice and patience and for reminding me to keep it simple. Dr. Foran, thank you for keeping me positive and motivated and for never letting me forget that I had a thesis to complete. Dr. DeJong, thank you for all of your statistics help and for being a calming force for me in times of utter panic. Dr. Fenton, thank you for your support and for taking the time to counsel me when you saw that I needed it. Thank you to the Forensic Sciences Program, School of Criminal Justice, for providing financial support for this project. Bruce and Deb in the Anatomy Lab at MSU, thank you for helping to generate the sample of cadavers I used for the x-rays for this project. To Jacque Liles and Kristin Liles, Willed Body Program, MSU, thank you for the permission to use the cadavers from the gross anatomy lab. Thank you to Dr. Mysliwiec for your permission to duplicate my x-rays at the Ingham Spine Center. Greg Eis, thank you for all of your help and kindness—you single-handedly restored my faith in people. Thank you to my fellow graduate students at MSU, particularly Michael Koot and Colleen Milligan, and to my family and my husband who took the time to talk with me about statistics, research, and life. You all helped me to maintain my sanity, and I love you for it. A special thank you to all of the volunteers who participated in this study. I deeply appreciate your willingness to take the time out of your busy schedules to help a graduate student who, in most cases, you had never met. Without you this project would not exist, and I cannot thank you enough.

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Introduction

Positive Identification

Two types of identification are possible for an unidentified decedent: presumptive identification and positive identification. Presumptive identifications are based on characteristics that are not considered unique to an individual, such as tattoos, scars, or physical abnormalities; or items that may be circumstantially associated with the body, such as a driver's license, credit cards, or clothing (Dix *et al.* 2000). On the other hand, according to Dix *et al.* (2000: 75), positive identification "entails scientifically establishing identity through the presence of unique characteristics." Such identifications are made only in situations where the investigator is confident that the information acquired from the decedent (radiographs, fingerprints, or DNA) and any corresponding antemortem information can only have come from the same individual, "...essentially excluding every other person on earth" (Baker 2005: 2). Presumptive identifications are often one step in establishing positive identifications—they can lead to a potential name for the decedent, which can then be used to acquire additional information with the hope of eventually arriving at a positive identification. Common methods used by forensic scientists to obtain a positive identification are DNA analysis, the comparison of fingerprints or the comparison of antemortem and postmortem medical or dental radiographs. The same methods can also be used to exclude a presumptive identification if there are inconsistencies between the antemortem and postmortem records (Murphy *et al.* 1980; Owsley and Mann 1992; Sanders *et al.* 1972; Valenzuela 1997).

Positive identification of an unknown decedent is extremely important in a medicolegal investigation—family members cannot receive compensation for their loss until there is a death certificate, and the medicolegal community must know the person's identity, cause and manner of death for any legal proceedings (Lichtenstein *et al.* 1988; Murphy *et al.* 1980; Sanders *et al.* 1972). Often it is the duty of the Medical Examiner, Coroner, or Forensic Pathologist to determine the identity of a deceased individual. However, when human remains are too badly burned, decomposed, or fragmented to be identifiable, they often require the expertise of a forensic anthropologist to determine a positive identification. The method most frequently employed by forensic anthropologists to arrive at positive identification of human remains is the comparison of antemortem and postmortem medical or dental radiographs.

Admissibility of Expert Witness Testimony

Throughout the last decade and a half, the forensic sciences have experienced an increased emphasis on validation and standardization of methods, techniques, and record keeping. The movement gained momentum in 1993 after the *Daubert v. Merrell Dow Pharmaceuticals, Inc.* Supreme Court decision, which established several guidelines for the admissibility of expert testimony, particularly with regard to scientific evidence: 1. A method must have been or must have the potential to be empirically tested; 2. A method must have established error rates; 3. A method must have been subject to peer review; and 4. A method must be generally accepted in the relevant scientific community (Brogdon 1998; Christensen 2004a). According to Rogers and Allard (2004: 203), "if the defense requests a *Daubert* hearing on the technique used for identification and if the technique is deemed inadequate, the identification will be inadmissible and the prosecution's case may be seriously threatened." The *Daubert* decision resulted in the

Court acknowledging a "gatekeeper" role for trial judges, under Rule 702 of the Federal Rules of Evidence. Its application greatly restricted the admissibility of scientific testimony, which until this time, under the *Frye v. United States* (1923) ruling, had only required the general acceptance of a method among the relevant scientific community. While *Daubert* has become a federal standard for the admissibility of evidence, some states have decided not to adopt it at the state level in favor of using the *Frye* standard. The admissibility of expert witness testimony under *Daubert* specifically concerned scientific experts and said nothing of experts with technical expertise. It was refined somewhat by the *Kumho Tire Co., Ltd, et al. v. Carmichael et al.* (1999) Supreme Court decision, which expanded the admissibility of expert witness testimony to include experts from scientific or technical backgrounds as long as the method is relevant to the task at hand and rests upon a reliable foundation (*Kumho Tire Co., Ltd., et al. v. Carmichael et al.* 526 U.S. 137; http://law.onecle.com/ussc/526).

This push toward increased standardization and validation of forensic science techniques was more recently impelled by the release of the 2009 National Academy of Sciences (NAS) report on forensic science in the U.S. The NAS found that there is a large amount of variability across the forensic science disciplines in the quality of education, facilities, and the extent to which methods and record keeping have been validated and standardized; their message to the forensic science community is that there is a tremendous need to reduce, and ideally eliminate, such disparities. In the 2009 report, the NAS presented recommendations to Congress, encouraging legislators to provide support for research that would lead to standardization of methods, terminology, reporting and education, validation of forensic methods, quantifying error and accuracy rates for those methods, laboratory accreditation, and quality control (National Research Council 2009).

Among the techniques being brought into question by the NAS report are such things as fingerprint comparisons and medical and dental x-ray comparisons. The report cites these techniques as being based on an expert's interpretation of his/her observations, making them highly susceptible to inter-observer variation. Techniques such as DNA analysis are "laboratory based," according to the NAS report, making them less susceptible to such variation. According to the NAS, the observer-based techniques across forensic science disciplines are greatly in need of standardization and validation. It is this push toward validation of techniques that rely on expert interpretations that inspired this study. The following thesis will present a research project designed to validate the practice of comparing antemortem and postmortem abdominal radiographs, focusing on features of the lumbar spine, for the purpose of securing the positive identification of an unknown decedent.

Chapter 1: History and Background of Forensic Radiography

Wilhelm Röntgen discovered x-rays in 1895 during an experiment he was conducting to study cathode rays. The first forensic application of the newly discovered x-rays followed within one year of their discovery (Brogdon 1998; Evans *et al.* 1981). In an 1895 case in Montreal, x-ray images were used to find a bullet that had been lodged in a man's leg. The x-ray plate was submitted as evidence in court and the shooter was convicted of attempted murder (Brogdon 1998). X-ray evidence was first accepted into a U.S. civil court in July of the same year. In the U.S. case, a man named James Smith fell from a ladder while working on someone else's property and he saw a respected doctor for the diagnosis of a leg fracture. The doctor was unable on several occasions to diagnose a fracture, so Smith never received treatment. Smith sued the doctor for malpractice and won the case based on x-ray evidence that was submitted which showed clear evidence of a femoral neck fracture (Brogdon 1998).

The skeleton, or at least fragments of it, is known to be able to withstand and survive taphonomic forces that destroy other tissues of the body, such as decomposition, burning, and carnivore activity (Kahana and Hiss 1997; Murphy *et al.* 1980). Additionally, many people from developed countries have had or will have x-rays taken at some point during their lives to diagnose injury or disease. Skeletal features are often visible on radiographs, even if the purpose of the x-ray was to examine soft tissue. Because skeletal elements are also often available for x-ray postmortem, they are ideal for comparing with the goal of matching radiographs of a decedent to those of a missing person.

Radiography was first suggested for use in identification of unknown decedents in an 1896 article in the *Journal of the American Medical Association* (Brogdon 1998), but was not used in this manner until the 1920's. In 1927, Culbert and Law presented the first known case of positive identification made using a comparison of antemortem and postmortem radiographs which specifically focused on aspects of the frontal sinus and mastoid air cells (Brogdon 1998; Elliott 1953; Evans *et al.* 1981; Jablonski and Shum 1989; Sauer *et al.* 1988). Since that time, forensic radiologists, forensic pathologists, and forensic anthropologists have expanded the use of comparative radiography to identify whether remains are human or non-human, to assess personal attributes like age and sex, to locate evidence of healed and recent injury, disease, foreign objects, congenital anomalies, and to identify unknown decedents. One of the largest early applications of forensic comparative radiography was during the 1949 *Noronic* disaster (Brogdon 1998; Elliott 1953; Jablonski and Shum 1989), when the *Noronic*, an ocean liner, caught on fire at Toronto, Canada, killing 119 people. In many cases, the bodies were fragmentary and burned far beyond recognition, so the investigators took x-rays that could be compared against antemortem records they were able to acquire from 35 of the missing persons from the disaster. Of those 35 victims, 24 were positively identified by comparing antemortem and postmortem radiographs.

As mentioned above, anthropologists have been publishing on the utility of x-ray comparison in positive identification since the 1920s (Brogdon 1998; Kahana and Hiss 1997; Sauer *et al.* 1988; Ubelaker 1984). Radiographs of a human skeleton, according to Hogge *et al.* (1994: 373), "...present unique skeletal anatomic information analogous to a fingerprint and provide for a reliable means of identification when comparison radiographs are available." A similar sentiment is shared by a number of other researchers (Angyal and Dérczy 1998; Brogdon 1998; Brogdon *et al.* 2010; Christensen 2004b; Ciaffi *et al.* 2010; Cornelison *et al.* 2002; Elliott 1953; Evans *et al.* 1981; Fischman 1985; Hogge *et al.* 1994; Jablonski and Shum 1989; Kahana, Goldin and Hiss 2002; Kahana and Hiss 1997; Kavanaugh 2002; Koot *et al.* 2005; Mundorff *et al.* 2006; Murphy and Gantner 1982; Murphy *et al.* 1980; Owsley and Mann 1992; Owsley *et al.* 1993; Quatrehomme *et al.* 1996; Rich *et al.* 2002; Sanders *et al.* 1972; Sauer *et al.* 1988; Scott *et al.* 2010; Telmon 2001; Ubelaker 1984; Valenzuela 1997; Weiler *et al.* 2000). Monozygous twin studies have also revealed that twins can be distinguished from one another based on the radiograph comparisons (Greulich 1960; Marsh 2003).

Validation of X-ray Comparison

The comparison of x-rays in the forensic anthropology setting relies heavily on visual interpretation of the films. Radiograph comparison is similar to fingerprint analysis, where both gross and minute details are compared and, based on the assumption that all individuals possess individualizing, unique characteristics and combinations of characteristics, an identification is either made or excluded. However, unlike fingerprint analysis, a minimum number of points required for a positive identification has yet to be established for comparing radiographs. Presumptive identifications are either confirmed or excluded based on the existence of similarities or differences between the pairs of images. In order for the identifications in these instances to be considered "positive," corresponding features must be identified between the antemortem and postmortem films, and if there are any differences between the two, they must be explainable as age-related changes, surgical procedures, trauma, or disease (Rich *et al.* 2002; Sauer *et al.* 1988; Telmon *et al.* 2001; Weiler *et al.* 2000). According to Kahana and Hiss (1997), the features must also be unique to the individual and must remain stable over time despite life processes.

A number of published cases reports demonstrate positive identifications that were made in forensic cases by comparing antemortem and postmortem radiographs of various regions of the body (Angyal and Dérczy 1998; Brogdon *et al.* 2010; Elliott 1953; Quatrehomme *et al.* 1996; Scott *et al.* 2010; Telmon *et al.* 2001). Other reports have presented cases that involved radiographs of the spine, specifically. The *Noronic* disaster, mentioned above, made use of various skeletal features, and according to Elliott (1953), the spine was particularly useful in many of the identifications. Owsley *et al.* (1993) present a case study where they were able to identify one of Jeffrey Dahmer's first victims, who had been dismembered and severely fragmented and dispersed across Dahmer's backyard, using x-rays of the head and cervical spine, in addition to dental periapical x-rays. Kahana and Hiss (1997) published on the utility of comparing trabecular patterns in the proximal humerus that are often visible in chest x-rays; however that site, in particular, was found to be problematic by Ciaffi *et al.* (2010) because of the difficulty in duplicating the position of the humerus from radiograph to radiograph. Mundorff *et al.* (2006), Scott *et al.* (2010) and Telmon *et al.* (2001) also present cases for which chest radiographs were useful in making positive identifications, and all focused primarily on the cervical spine. Owsley and Mann (1992) reported on using radiographs of the abdomen and pelvis, and Hulewicz and Wilcher (2003) and Valenzuela (1997) found that features of the lumbar spine were particularly useful in determining the identity of unknown decedents.

Comparing antemortem and postmortem radiographs of several regions of the body for positive identification has been validated by researchers. Christensen (2004b) quantified the differences in frontal sinus morphology using Elliptic Fourier analysis and Euclidian distances. Her study, which involved a sample size of 584 individuals, proved that skeletal variations visible in cranial radiographs can be quantified and that her subjects could be statistically distinguished from one another. The same statistical method was employed by Paolello and Cabo Pérez (2008), who were able to quantify the difference in morphology of left transverse processes of the second lumbar vertebra from over 70 individuals. Kuehn *et al.* (1997), Martel *et al.* (1977), and Weiler *et al.* (2000) examined the validity of comparing variations in the thoracic spine that were visible in chest x-rays; Koot *et al.* (2005) studied the comparison of x-rays of the hand, focusing on bone morphology and trabecular patterns; and Hogge *et al.* (1994) looked specifically at the experience level of the examiner and to what extent it has an effect on his/her ability to positively identify or exclude an individual. Finally, Rich *et al.* (2002) examined the utility of comparing surgical interventions that were visible on foot and ankle radiographs, and found that their presence and position in combination with associated bony response are highly reliable for making positive identifications. All of these studies have repeatedly functioned similarly to establish x-ray comparison as a reliable means for arriving at positive identifications, to publish error and accuracy rates, and to identify some best practices for comparing radiographs. This study was designed to add to the existing literature by validating and presenting error and accuracy rates for making identifications based on radiographs of the lumbar spine.

Chapter 2: Research Questions, Goals and Hypotheses

This study was conducted to establish error rates and accuracy rates, using a reproducible test scenario, for the practice of comparing medical radiographic images of the lumbar spine to determine a positive identification. Admissibility of an expert witness' testimony is crucial, and ideally the information discovered through the process of this study will serve to reaffirm this type of evidence as valid and within the boundaries of the legal frameworks established by the *Frye*, *Daubert*, and *Kumho Tire* Supreme Court rulings.

Research Questions

1. Is the comparison of x-rays of the lumbar spine a valid means for arriving at a positive identification for unidentified human remains?
2. What is the overall error rate for individuals who use the comparison of x-rays of lumbar vertebrae to arrive at a positive identification?
3. What are the rates of false positives and false negatives for this type of identification?
4. To what extent do personal variables—such as level of education, years practicing forensic anthropology, and the amount of radiograph comparison case experience—affect the performance of the test subjects in making matches between radiographs?

Goals

1. To validate and establish accuracy and error rates for making identifications based on comparisons of lumbar spine radiographs.
2. To discern to what extent the performance of individuals on the x-ray comparison test is affected by personal attributes such as level of education, years practicing forensic anthropology, and the amount of previous case experience they have.
3. To evaluate which are the most reliable and most unreliable anatomical features to use when matching radiographs of the lumbar spine.
4. To offer recommendations to forensic anthropologists as to the most effective means for comparing radiographs of the spine in order to increase their chances of correctly identifying or excluding a decedent or correctly determining that a decision cannot be made based on the available information.

Hypotheses

Several hypotheses were developed to allow for meaningful statistical analysis of the data that were collected from the study participants. The hypotheses are as follows:

H_{A1}: The accuracy rate among all of the participants in the study for positive identifications using x-ray images of the lumbar spine will be 100%.

H_A2: The performance of professional forensic anthropologists will be significantly different from that of students.

H_A3: Participants with different levels of education (PhD, MA/MS, BA/BS) will have significantly different performance on the x-ray matching test.

H_A4: Results achieved by participants with a greater amount of experience—years in the field, number of radiograph comparison cases, number of cases involving comparisons of x-rays of the spine, specifically—will be significantly different from those achieved by participants with less experience.

H_A5: Participants who work within academia will be significantly different from participants who work outside of academia.

H_A6: The number of anatomical features cited by the participants with greater education and experience will be significantly different from the number of features cited by participants with less education and experience.

Chapter 3: Materials and Methods

The materials for this study included two sets of radiographs—one simulating the antemortem condition of known individuals and the other simulating the postmortem (skeletonized) condition of unknown individuals—as well as a two-part data sheet/brief survey that the participants were asked to complete.

Radiographs

All x-rays for this project were taken from a sample of cadavers that were used with permission from the Michigan State University Willed Body Program, Department of Radiology, Division of Anatomy. The cadavers used for this study were all donated to the Gross Anatomy Laboratory at Michigan State University through the Willed Body Program. Because the specimens are crucial for the education of medical students enrolled in the College of Osteopathic Medicine and the College of Human Medicine at MSU, it was only possible to dissect the spines from bodies that were scheduled for cremation at the end of the term during which the x-rays were taken, Spring 2007. It was not possible to know in advance (before taking the x-rays) which specimens would be most suitable for the simulated antemortem and postmortem radiographs that would constitute the main materials for this study. Bodies scheduled for cremation were x-rayed first. Once suitable simulated antemortem images were chosen, the 5 from which the spines would be dissected out were selected, and then it was possible to continue x-raying the other bodies that would serve as foils in the comparison test. The constraint of only being permitted to remove the spines from a small number of cadavers is a limiting factor for this study.

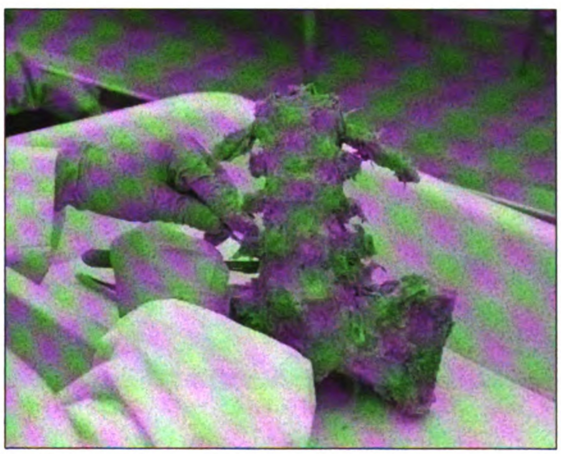
Bodies that were relatively consistent in size were chosen so that the size of the vertebrae would not be an obvious distinguishing feature for the study participants, forcing them to focus on the more nuanced bony details. It also had to be possible to physically maneuver the bodies in order to be able to place the x-ray films beneath them, so the majority of the bodies chosen were of small to medium builds. Size, therefore, was another limitation of the sample that could be used for the antemortem, and subsequently, postmortem, x-rays for this project. Initially, 13 cadavers were available for dissection, 10 of which satisfied the body size criterion. Another 19 cadavers that were not scheduled for cremation also satisfied the body size criterion, making the total number of bodies that could potentially be used in this study 29. All 29 were x-rayed, and based on the quality of the resulting images, only 19 were useable for the study itself. As a result, two of the 20 simulated antemortem images (*Known 2* and *Known 19*) are of the same individual, neither of which were matches for any of the simulated postmortem images. For details regarding specific cadavers used for this study, see Appendix A.

The x-rays for this study were taken using a General Electric Amx2 Portable X-Ray machine, which is housed in the Michigan State University Forensic Anthropology Lab. Three duplicate sets of x-rays were created, using an XMA 3600 Duplicator, so that identical sets of study materials could be sent simultaneously to three separate locations, thereby maximizing the number of possible participants and minimizing the time it would take to collect responses from all of the participants. The simulated antemortem radiographs were taken according to standard clinical guidelines for KUB (Kidneys, Ureters, Bladder) Anterior-Posterior abdominal x-rays (Bontrager 2004; Brogdon 1998;

Evans *et al.*1981). With the body lying supine, legs extended, and the arms at the sides, the beam was aligned in the mid-sagittal plane and was oriented perpendicularly to a point centered at the level of the iliac crests. Care was taken to ensure that the iliac crests were level and that there was minimal rotation to the bodies. The x-ray settings varied depending upon the completeness and the size of the bodies—the kVp setting ranged from 65 to 85, and the mAs setting ranged from 40 to 64. The wide range in kVp and mAs settings is due to varying degrees of dissection of the bodies, the increased density of embalmed, in some cases long-preserved internal organs, and the collection of embalming fluid in the abdomens.

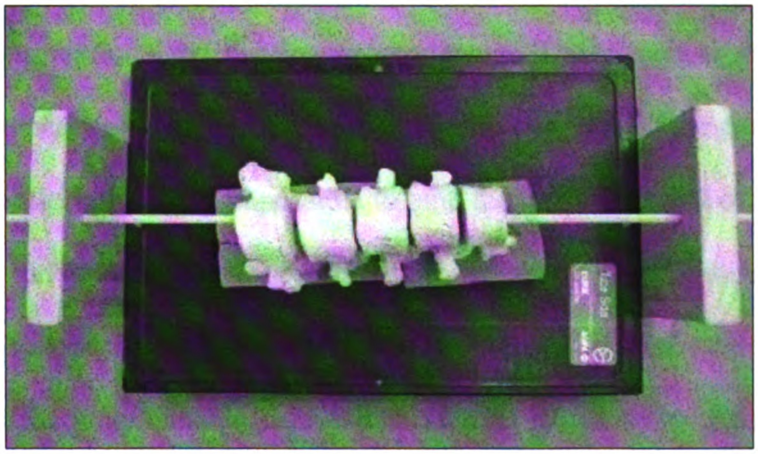
The simulated postmortem sample was generated by removing the lumbar vertebrae from a subgroup of the individuals for which simulated antemortem radiographs had already been taken. The vertebrae were dissected from the bodies, macerated, and cleaned according to the procedures outlined by Fenton *et al.* (2003). They were then were allowed to dry for at least 24 hours before they were x-rayed a second time.

Figure 1: Lumbar vertebrae were de-fleshed before they were cleaned according to the procedures outlined by Fenton et al. (2003)



In any forensic case where comparisons of radiographs are involved, the positioning of the elements and the x-ray beam itself are crucial in order to maximize the potential for a meaningful comparison (Ciaffi *et al*. 2010; Jablonski and Shum 1989; Kahana *et al*. 2002; Koot *et al*. 2005; Kuehn *et al*. 2002; Martel *et al*. 1977; Mundorff *et al*. 2006; Quatrehomme *et al*. 1993; Sauer *et al*. 1988; Weiler *et al*. 2000). With this in mind, special attention was paid to the orientation of the vertebrae, which were matched as closely as possible to the orientation of the vertebrae of the same individuals from the antemortem films. The beam was consistently perpendicular to the spines being radiographed. To maintain consistency, a wooden brace was used to hold a dowel, which ran through the vertebral foramina to keep the vertebrae vertically aligned, and florist foam was used to brace the spinous processes so the vertebrae would not shift side-to-side during the x-ray process (see Figure 3). The x-ray settings for the simulated postmortem radiographs were much more consistent; the kVp setting ranged from 55 to 65 and the mAs setting ranged from 20 to 25.

Figure 2: Vertebrae were held in position over the x-ray film using a wooden dowel in a brace and florist foam



Selection of Participants

The selection of participants for this project began with an e-mail that was sent to all of the Diplomates of the Physical Anthropology section of the American Academy of Forensic Sciences. The Diplomates were chosen to be the core of the sample because they have all earned their PhDs, and because there is a minimum level of knowledge and experience that must be satisfied in order to earn that distinction. Because one of the objectives of this study was to evaluate the extent to which an individual's levels of experience and education affect their performance, a sample of graduate students was also selected to take the test for comparative purposes. Therefore, all of the participants in this study are either professional forensic anthropologists or forensic anthropology graduate students who were drawn from a nonrandom sample of volunteers around the United States.

Over a period of two years, from November 2007 through November 2009, the study materials were sent out to participants around the United States. Initially, 40 people volunteered to participate in the study and the expectation was that each participant would have the study materials in his/her possession for no more than 2-3 weeks; however a number of participants kept the materials for months at a time, due to a variety of personal and professional extenuating circumstances. The average time the packages spent at any one location was approximately 2 months. Because of the extended time period for data collection, it was impossible to send the materials to all of the anthropologists and graduate students who initially volunteered while maintaining a reasonable timeline for the completion of the project. In all, 25 of the volunteers were able to complete the x-ray matching test and return their data sheets to Michigan State

University.

Each of the study participants was presented with a set of twenty radiographs (numbered 1-20) that simulated the antemortem images of known individuals to compare against ten radiographs (lettered A1/A2-E1/E2) that simulated the postmortem images of five unknown individuals. Two different exposures of each of the five "postmortem" spines were included in order to maximize the participants' ability to compare various details. The participants were not provided with information regarding the age, sex, or ancestry of the individuals in the x-rays being compared. See Appendix B and Appendix C for images of the radiographs that were presented to the study participants.

Data Sheets

This project complies with the requirements and the approval of the Michigan State University Institutional Review Board. Each participant was asked to complete a two-part data sheet, which was coded using a 3-digit, randomly generated number. These numbers were strictly for the researcher's use during the data collection and analysis phase of this research; they are no longer linked in any way to the participants themselves because the anthropologists and graduate students who volunteered for this study are from a small, nonrandom group of colleagues, making it imperative to maintain confidentiality of their identities. They were asked to return the data sheets to the researcher in a self-addressed-stamped-envelope along with their signed consent forms. When the envelopes arrived at Michigan State University, the letters were opened and the data sheets were separated from the consent forms. The consent forms were then stored in a folder inside of a locked filing cabinet and were kept separate from the data sheets.

Part 1 of the data sheet asks for a number of personal details, such as level of education, years practicing forensic anthropology, number of cases involving identifications made by comparing radiographs, and the number of cases specifically involving radiographs of the spine. Part 2 of the data sheet includes five sections, asking which of the twenty "known" radiographs correspond to the five lettered "unknown" images. Beneath each of these questions, the participants were asked to indicate how many individual points of similarity they were able to identify between the radiographs and "which specific anatomical features" they used to make the identification. A final open-ended statement at the bottom of the page invited the participants to add any additional information they wished to include. See Appendix D for sample data sheets.

Chapter 4: Results

This study involved a number of independent and dependent variables that were recorded from the data sheets each participant completed. The following table (*Table 1*) outlines the variables that were compared with one another in the two phases of analysis: contingency tables and in the nonparametric tests.

Table 1: Independent and Dependent Variables Used in this Study

Independent Variables	
Total Sample	
Highest Degree (BA/BS, MA/MS, PhD) PhD or Not PhD Student or professional	Number of radiograph cases Any radiograph cases involving the spine Number of radiograph cases involving the spine
Students	*Professionals*
Highest Degree (BA/BS, MA/MS) Years in graduate school Type of graduate program Expected degree ABD or not ABD* Number of radiograph cases Any radiograph comparison cases involving the spine Number of radiograph cases involving the spine	Highest degree (BA/BS, MA/MS, PhD) PhD or not PhD Years practicing professionally Work primarily within or outside of academia Number of radiograph cases Any radiograph comparison cases involving the spine Number of radiograph cases involving the spine
Dependent Variables	
Score out of 5 Potential outcomes include: 5/5, 4/5 (non-identification), 4/5 (misidentification), 3/5 (non-identifications), 3/5 (misidentifications), 3/5 (1 non-identification, 1 misidentification) *Error/No Error* In this category, scores are divided according to whether the participant answered with a misidentification or with either a correct answer or a non-answer. *Number of Points* This category represents the number of specific anatomical features each participant cited when making matches. It was evaluated as part of this study to see whether a relationship exists between the independent variables and the number of points used to make a match.	

Accuracy and Error Rates

The primary goal of this study was to validate the comparison of radiographs of the lumbar spine for the purpose of identifying and unknown decedent. This study is based on a repeatable test for assessing the performance of practitioners in making identifications based on the comparison of antemortem and postmortem radiographs of the lumbar spine. For the purpose of this test, abdominal A-P x-rays were taken, according to clinical guidelines for diagnostic procedures, of 19 cadavers in varying degrees of abdominal dissection. These radiographs simulate the antemortem condition of 20 known individuals. The spines of 5 of the cadavers of which simulated antemortem x-rays had been taken were removed, de-fleshed, rearticulated, and x-rayed a second time to simulate the skeletonized postmortem condition of 5 unknown individuals.

Because all of the "unknown" individuals were derived from the sample of "known" individuals, all 5 had the potential to be correctly matched. Therefore, a correct answer for a given identification means that the participant correctly matched the simulated antemortem and postmortem radiographs that were taken of the same individual. There are two classes of incorrect answers: 1) Misidentifications, where the participants identified one or more of the "unknown" individuals as the incorrect "known" individual; and 2) Non-identifications, where the participants failed to find any corresponding "known" individual for one or more of the "unknowns." Only the misidentifications are considered in this study to be errors. Non-identifications are neither considered to be correct answers, nor errors. There was no potential for the participants to identify true negatives or false negatives as part of this study because all of the "unknown" individuals had matches in the sample of "known" individuals. The term, "identification," will be used throughout the remainder of this document to refer to matches between radiographs. As was discussed in Chapter 1, for an identification to be a "positive identification" in the truest sense of the term, more information would have had to have been provided to the participants—this will be addressed again in Chapter 5.

Sixteen practicing professional forensic anthropologists and 9 graduate students participated in this study. Professional anthropologists have earned either an MA/MS or a PhD and are either currently working as forensic anthropologists or have worked as such at some point during their careers. They range in professional experience from 1-5 years in the field to more than 20, and in radiograph comparison case experience from 0 to more than 100 cases. The 9 graduate students have earned either BA/BS or MA/MS degrees and are all currently enrolled in forensic anthropology or physical anthropology Masters or Doctorate programs. They range in years of graduate school from less than 1 to more than 6, and in radiograph comparison case experience from 0 to more than 20 cases. *Table 2* (page 24) presents a summary of the performance of the graduate students and the professional anthropologists on the x-ray matching test.

Of the 16 professional anthropologists, 3 have earned a MA/MS as their highest degree, and 13 have earned their PhD. Of the 3 professionals with their MA/MS, 1 scored 100% on the x-ray matching test, 1 misidentified *Unknown D*, and 1 misidentified *Unknown E*. Eleven of the 13 PhDs scored 100% on the matching test; 1 PhD misidentified *Unknown D* and 1 misidentified *Unknown E*; the PhD who misidentified Unknown E also chose not to identify *Unknown D*; and 1 PhD chose not to identify *Unknown D* or *Unknown E*.

Because the sample of professional anthropologists who have earned an MA/MS as their highest degree is so small, for the purposes of presenting the results of this study, professionals will be taken together as one group. In all, the 16 professional anthropologists were asked to make an aggregate of 80 identifications. Seventy-three of those identifications were made correctly, there were 4 instances of misidentification and there were 3 instances where the professionals declined to make matches. Therefore, the accuracy rate for professional anthropologists is 91.25% [calculated: total correct/(total Mis-IDs + total Non-IDs + total correct)] and the error rate for professional anthropologists is 5% [calculated: total incorrect/(total correct + total Mis-IDs + total Non-IDs)].

Table 2: Participant Performance

Subject	# Correct (True Positives) Total Possible = 5	# Incorrect	False Positives (Misidentifications)	No Identification Attempted	Accuracy
Graduate Students					
1	5	0	0	0	1.00
2	3	2	2	0	0.60
3	5	0	0	0	1.00
9	5	0	0	0	1.00
10	5	0	0	0	1.00
11	4	1	0	1	0.80
19	4	1	0	1	0.80
20	5	0	0	0	1.00
25	5	0	0	0	1.00
Total:	**41**	**4**	**2**	**2**	**0.91**
	41/45 (91.1%)	**4/45 (8.9%)**	**2/45 (4.4%)**	**2/45 (4.4%)**	
Professionals					
4	5	0	0	0	1.00
5	5	0	0	0	1.00
6	4	1	1	0	0.67
7	5	0	0	0	1.00
8	4	1	1	0	0.80
12	5	0	0	0	1.00
13	5	0	0	0	1.00
14	5	0	0	0	1.00
15	5	0	0	0	1.00
16	3	2	0	2	0.60
17	3	2	1	1	0.60
18	4	1	1	0	0.80
21	5	0	0	0	1.00
22	5	0	0	0	1.00
23	5	0	0	0	1.00
24	5	0	0	0	1.00
Total:	**73**	**7**	**2**	**3**	**0.91**
	73/80 (91.25%)	**7/80 (8.8%)**	**4/80 (5%)**	**3/80 (3.8%)**	
Group Total:	**114**	**11**	**4**	**5**	**0.91**
	114/125 (91.2%)	**11/125 (8.8%)**	**4/125 (3.2%)**	**5/125 (4%)**	

Of the 9 graduate students who participated in this study, 6 scored 100% on the x-ray test, 1 graduate student misidentified *Unknown C* and *Unknown D*, and 2 graduate students chose not to identify *Unknown D*. The 9 graduate students were asked to make an aggregate of 45 identifications. Forty-one of those identifications (91.11%) were made correctly; there were 2 instances of misidentification (4.44%); and there were 2 instances where the graduate students declined to make one identification each (4.44%). The accuracy rate for graduate students, therefore, is 91.11% [calculated: total correct/(total correct + total Mis-IDs + total Non-IDs)]. The error rate among graduate students is 4.44% [calculated: total incorrect/(total correct + total Mis-IDs + total Non-IDs)]. One graduate student is responsible for both of the misidentifications associated with graduate students; that student noted on his/her data sheet that he/she had been attending graduate school for less than one year at the time.

In all, there were 25 participants in this study who were asked to make a total of 125 identifications (25 participants x 5 identifications each = 125 total identifications). Of the 125 total possible identifications, 114 (91.2%) were made correctly, there were 5 (4%) misidentifications, and there were 6 (4.8%) instances where participants declined to make a match based on the available information. The participants in this study have an overall accuracy rate of 91.2% [calculated: total correct/(total correct + total mis-IDs + total non-IDs)]. The overall error rate is 4% [calculated: total incorrect/(total correct + total mis-IDs + total non-IDs]. The discrepancy between the accuracy rate and the error rate lies in the fact that only the misidentifications are considered to be true errors. When only attempted matches are taken into consideration for these calculations, in other words, when non-identifications are removed from the calculations, the overall accuracy rate increases to 95.8% [calculated: total correct/(total correct + total mis-IDs)]. If this calculation is performed for professionals and graduate students separately, in other words when only attempted matches are taken into consideration for each group, the accuracy rate among professionals increases to 94.81% and among graduate students to 95.34%. The significance of the observed differences presented above is discussed in the following section.

Effect of Personal Attributes on Performance

The second goal of this study was to assess whether personal attributes, such as level of education and amount of experience, affected the participants' performance in making matches between the simulated antemortem and simulated postmortem images. This section presents the results of the statistical tests that yielded significant results concerning the relationships between the participants' personal attributes and their performance. As was discussed in the previous chapter, two separate statistical tests were carried out using the data that were collected during the course of this study. First, contingency tables were used as descriptive statistics to explore whether any of the independent and dependent variables were acting together. Second, once it was established that some of the variables were not acting independently, the data were subjected to independent samples nonparametric tests—either the Kruskal-Wallis Independent Samples test or the Mann-Whitney U Independent Samples test, depending upon the type of data and the number of possibilities for each variable being compared. The independent variables (see *Table 1*, page 20) included personal attributes such as level of education, years practicing, and the amount of radiograph experience the participants have had. The dependent variables include the participants' scores on the matching test, whether they answered all of the identification questions correctly, misidentified, or chose not to identify one or more of the simulated unknown individuals, and the number of specific anatomical features they used to make the identifications (see *Table 1*, page 20).

Contingency Tables

The first step in the data analysis was to carry out contingency tables where each of the independent variables was tested to see if there were relationships between them and each of the dependent variables. The vast majority of the contingency tables failed to indicate the existence of a relationship between the variables; however relationships were found to exist between five of the independent variables and several of the dependent variables. The following section presents the results of the contingency tables, which were used to evaluate the existence of relationships between the variables, and nonparametric tests which were carried out to determine if the aforementioned relationships, where found, are statistically significant. Because of the small sample size, all of the contingency tables produced using the data that have been collected for this study contained a number of cells with expected values of less than five or zero. This is known to artificially inflate the value of chi-square, therefore increasing the probability of finding significant differences. This must be considered when interpreting the results of the contingency tables. (See Appendix E for significance values associated with the contingency table phase of data analysis.)

Total Sample

Out of all the contingency tables that were carried out to evaluate the presence of relationships between the independent and dependent variables—taking the entire sample into consideration (n = 25)—only two yielded significant results. The contingency tables indicate the following variables do not act independently: *Student or Professional* and *Average Number of Points*, and *Number of Radiograph Cases* and *Score out of 5*. Only 22 valid cases exist for the variable, *Average Number of Points,* because one professional did not answer the question about how many points he/she identified when making matches, and two indicated that they used "multiple" or "many" points of similarity when making matches—answers that could not be quantified for this type of analysis.

The contingency table involving *Student or Professional* and *Average Number of Points* yielded a significance value of $p = 0.005$. All nine students cited an average of less than 10 points of similarity between radiographs. Four of the professionals cited less than 10 points, 7 cited an average of 11-20 points, and 2 cited an average of over 20 points when making their matches. It is clear that within the parameters of this study, students cited fewer average points of similarity than their professional counterparts when making matches between radiographs. The second significant relationship indicated by a contingency table, taking the entire sample into consideration, is between *Number of Radiograph Cases* and *Score out of 5*. This contingency table yielded a significance of $p = 0.039$. Three of the participants have had zero case experience involving radiograph comparison. Of those three, one scored 5/5, one scored 4/5 (non-identification), and one scored 3/5 (two misidentifications). Eight of the participants have had experience with 1-10 radiograph comparison cases, five of whom scored 5/5 and three of whom scored 4/5 (misidentification) on the matching test. The remaining 14 participants have worked on more than 10 cases involving radiograph comparisons, 11 of whom scored 5/5, 1 scored 4/5 (non-identification), 1 scored 3/5 (2 non-identifications), and 1 scored 3/5 (1 misidentification/1 non-identification). The results from this comparison may be affected by the small sample size. The number of participants in this study who have worked on more than 10 radiograph comparison cases is higher than the number of participants in the other two categories combined. It is not surprising, therefore, that a greater number of those participants also scored higher on the x-ray matching test. This relationship is further discussed in the following chapter.

Professionals Only

Significant results were produced by two of the contingency tables that examined variables relevant to only the professionals: *Years Practicing Professionally* and *Score out of 5*, and *Number of Radiograph Cases* and *Score out of 5*. In both of these cases, the small sample size (n = 16) likely affected the outcome of the contingency tables. When the relationship between *Years Practicing Professionally* and *Score out of 5* was evaluated, the contingency table produced a significance value of $p = .039$. The number of professionals who have been practicing for greater than 20 years is more than double the number of professionals who have worked for 10 or fewer years. It is not surprising, therefore, that the number of professionals who have been practicing for many years and scored 5/5 is larger than the number of professionals who have been practicing for fewer years—there are simply more of them.

When the relationship between *Number of Radiograph Cases* and *Score out of 5* was evaluated, the contingency table produced a significance value of $p = .039$. A similar problem exists with this relationship as exists with the relationship discussed immediately above, in that the number of professionals who have worked on more than 10 radiograph comparison cases more than doubles the number of professionals who have worked on fewer than 10 radiograph comparison cases. It is possible that while these two variables appear to be acting together, it may be a function of the small sample size.

Students Only

While relationships were detected by contingency tables when the entire sample and professionals are considered, none of the contingency tables that were carried out involving only students indicated that any of the variables were acting together. The lack of significance is likely related to the small number of students (n = 9) among the participants in this study.

Tests for Significance

Subsequent to the contingency table phase of analysis, each of the independent variables was then calculated against each of the dependent variables to assess whether any relationships between the variables are statistically significant. This process was carried out for each of the variables in part to verify the results of the contingency tables—to make sure that relationships do not exist where the contingency tables did not find relationships, and to evaluate the significance of the relationships that were detected. (See Appendix F for significance values associated with the non-parametric tests phase of this analysis.)

The relationships between three sets of variables were found to be statistically significant. When only professionals were taken into consideration (n = 16), *Years Practicing Professionally* was found to be related to *Score out of 5* and *Number of Radiograph Cases* was found to be related to *Score out of 5*. *Student or Professional* was found to be related to Average *Number of Points*, when the total sample (n = 22, three of the participants did not provide information regarding the number of points they cited) was taken into consideration. When only students were taken into consideration, no statistically significant relationships were detected among the variables.

When the entire sample (n = 22) was taken into consideration, only the relationship between the independent variable *Student or Professional* and the dependent variable *Number of Points* was found to be significant. For the analysis in this case, the Independent Samples Kruskal-Wallis Test was chosen because it is the appropriate test to use when there are greater than two possibilities for any one of the variables. The Kruskal-Wallis test produced a significance of 0.030. Professionals, who have a greater level of education and have been actively working as forensic anthropologists for more years than any of the students, cited significantly more points on average than any of the students. There are several different possible interpretations for this relationship, which will be discussed in the following chapter.

When only professionals (n = 16) are taken into consideration, two relationships between variables appear to be statistically significant. *Years Practicing Professionally* appears to have a statistically significant relationship with *Score out of 5* and *Number of Radiograph Cases* also appears to have a statistically significant relationship with *Score out of 5*. Both cases indicate that participants with more experience performed better on the x-ray matching test. The Independent Samples Kruskal-Wallis Test was used in both cases, and in both cases the significance value was 0.049. The results, particularly from these two tests, allows us to reject the Null Hypothesis that assumes that the participants' performance would be consistent regardless of their level of experience and it indicates that with greater levels of experience, the participants are expected to perform better on the x-ray matching test. This will be discussed further in the following chapter.

Chapter 5: Discussion

Throughout the data analysis phase of this project, several points became clear, and they will be discussed in detail in the following section. First, it was found that the amount of experience the observers have appears to be directly related to their performance on the x-ray matching test. Second, many of the other personal attributes that were expected to be significantly related to performance were not. Third, there appears to be a direct relationship between the observers' experience and the number of specific anatomical features they cited when making identifications. All three points will be discussed in greater detail below.

Effect of Personal Attributes on Performance

Students

It is not surprising that neither the contingency tables nor the nonparametric tests indicated significant relationships between the variables that were tested when only students were taken into consideration. This is most likely due to the small sample size (n = 9). Variables like, *ABD or not ABD* (ABD stands for "All But Dissertation," and refers to students in doctoral programs who have satisfied all of their degree requirements except for the dissertation) and *Type of Program* were found to have no bearing on the performance results of the participants. Only one student was ABD at the time the data were collected, and that student did not out-perform students who were not ABD, so there is no way to deduce a relationship between that variable and their performance. Six of the 9 students indicated on their data sheets that they are enrolled in Forensic Anthropology programs; 4 of those 6 are enrolled in Master's programs; the other 2 are enrolled in PhD programs. Of the 3 students who are not enrolled in exclusively Forensic Anthropology programs, 1 indicated that he/she is enrolled in a Forensic Anthropology/Physical Anthropology program, 1 indicated that he/she is enrolled in a Forensic Anthropology/Bioarchaeology program, and 1 indicated that he/she is enrolled in a Physical Anthropology program. All of the students are attending universities with active forensic labs, and therefore probably have similar access to and participation with forensic cases. It is for these reasons that *Type of Program* is believed to have no influence on the students' performance with regard to the x-ray matching test.

Though there were no significant relationships detected, there are some notable differences in performance among the student group. Six students scored 5/5—3 with a highest degree of MA/MS and 3 with a highest degree of BA/BS. Two students scored 4/5 (non-identification), 1 with a highest degree of MA/MS and 1 with a highest degree of BA/BS. One student, with a highest degree of BA/BS, scored 3/5 (misidentifications). Of the two students who declined to make one match each, 1 had been in graduate school for at least 4 years and one had been in graduate school for less than 2 years at the time of data collection. Among the students, only two errors were committed, and both were committed by the same person. The student who scored 3/5 (misidentifications) is the only person out of the entire sample of participants (n = 25) who misidentified two of the *Unknowns*, constituting the highest number of mistakes made by any single participant. The graduate student who misidentified two of the simulated *Unknowns* had been in graduate school for less than one year at the time of data collection, which may suggest that this person's lack of experience, both with regard to coursework and to case experience, may have led to his/her poor performance.

The two students declined to make one of the matches each both chose not to identify *Unknown D*. One of the two indicated that he/she could not find a match for *Unknown D*, and the other indicated that he/she was not satisfied with the number of points of similarity he/she was able to find between *Unknown D* and any of the *Known* radiographs (see Appendix G for the answers participants provided for the questions asked on the data sheets). A non-identification is neither a correct answer nor an error because it is a conservative approach to the problem and those who answered this way would not come away having misidentified a decedent.

Professionals

In response to conclusions of previous research (Hogge *et al.* 1994; Koot *et al.* 2005), this study explored whether PhDs perform better on the test than MA/MS professionals. Only 3 of the professionals who participated in this study have a highest degree of a MA/MS; the other 13 have earned PhDs, and there was no statistically significant relationship between whether the participants have earned a PhD or a MA/MS and their performance. Two of the 3 MA/MS professionals scored 4/5 on the matching test, both of whom misidentified one individual each. Two of the 13 PhDs misidentified one individual each. The sample of MA/MS is far too small to draw any meaningful conclusions from a comparison between MA/MS and PhDs.

As expected, the data analysis for this project revealed a significant relationship between *Years Practicing Professionally* and *Number of Radiograph Cases* when those variables were evaluated with respect to *Score out of 5*. This study produced results that support the conclusions of previous researchers whose studies focused on other regions of the body and found that observer experience is an important variable. It was somewhat surprising to find that the number of radiograph cases involving the spine was not significantly related to the participants' performance. Thirteen of the 16 professionals included in this study have had experience comparing x-rays of the spine for the purpose of positively identifying an unknown decedent, so it is possible that the sample size is too small to draw a meaningful conclusion regarding this variable. It is not possible to know, however, whether the number of professionals lacking experience with radiograph cases involving the spine would increase given a larger sample size.

Total Sample

Several trends are notable in the data analysis phase of this project. Though, proportionally, students appear to perform similarly to professionals on the x-ray matching test, making the statistical tests produce insignificant results when the relationships between variables were evaluated, there are some nuances that require further discussion.

Though it was expected that students would not perform as well as professionals on the x-ray matching test, it was found that the difference in performance between professionals and students was not significantly significant, so dividing the sample into student/professionals may not be a meaningful distinction. It is possible that this particular comparison is affected by the disproportionately greater number of professionals in the sample, and with a larger number of student participants the result may have been different. It is possible, however, that the lack of a significant difference between students and professionals could be the result the nature of the student sample included in this evaluation. The students may be predisposed to perform well on such a test because they are all enrolled in graduate school programs focused on forensic anthropology and physical anthropology, therefore they are already a self-selected group of people who have expressed interest in human identification and skeletal anatomy. It is possible that their interest in human identification and skeletal anatomy may enhance their ability to do well on the x-ray test. The majority of them performed very well on the x-ray matching test, even though most of the students had been in graduate school for no more than 3 or 4 years. The results may have been different given a larger sample size; however it is not possible to know.

Significant relationships were found to exist regarding only a handful of the variables: *Highest Degree*, *Student or Professional*, and *Number of Radiograph Cases*. The only significant relationship that existed between the variable *Student or Professional* and any of the dependent variables involved the *Average Number of Points* they cited when making matches between the radiographs. All 9 of the students cited an average of 10 or fewer points of similarity between radiographs, while 9 of the professionals cited an average of over 10 points, and only 4 averaged 10 or fewer. Only 13 of the 16 professionals are included in this analysis; the remaining 3 did not provide information on their data sheets regarding the number of points of similarity they were able to identify between the radiographs.

A significant relationship was found to exist between *Highest Degree* and the number of points the participants cited as well. In the sample, there are 5 participants with a highest degree of BA or BS, 7 with a highest degree of MA or MS, and 13 with a highest degree of PhD. The lack of evidence for a significant relationship between

Highest Degree and the dependent variables is probably because proportionally, the three groups performed similarly on the x-ray matching test. All 5 BA/BS participants cited an average of 10 points or fewer when they made matches; 4/7 MA/MS participants cited an average of 1-10 points and the other three cited an average of 11-20 points. Four of the 10 PhDs who answered this question on the data sheet cited an average of 1-10 points, 4 cited an average of 11-20 points, and 2 cited an average of over 20 points. PhDs are the only group that included any participants who cited an average of over 20 points, while the BA/BS are the only group who cited exclusively 1-10 points, which makes it appear as though the participants with more education are citing more specific points of similarity between radiographs than those with lower levels of education. There is some amount of discrepancy among participants with regard to the interpretation of what was meant by "specific anatomical features" as it was indicated on the data sheet, which may have an effect on the results presented above. This will be discussed in further detail later in this chapter.

When *Number of Radiograph Cases* was tested against *Score out of 5*, a significant result was revealed. Three of the 25 participants have had zero experience with cases involving the comparison of radiographs. Eight of the participants have worked on 1-10 cases involving radiograph comparison, and 14 have worked on greater than 10 radiograph comparison cases. Of the 3 participants with zero case experience, 1 scored 5/5, 1 scored 4/5 (non-identification), and 1 scored 3/5 (misidentifications). Five of the 8 participants who have worked on 1-10 radiograph comparison cases scored 5/5 and the other three scored 4/5 (misidentification). Eleven of the participants who have had greater than 10 cases involving radiograph comparison scored 5/5, 2 scored 4/5 (non-identification), 1 scored 3/5 (non-identifications), 3 scored 4/5 (misidentification), and 1 scored 3/5 (1 misidentification and 1 non-identification). Two of the 4 misidentifications made by participants were made by a single student who had been in graduate school for less than one year at the time of data collection and who has zero case experience, which may lend even more credence to the idea that performance will increase with increased experience. Of the remaining three, two were made by professionals with a highest degree of MA/MS and the other was made by a PhD, with a qualifying statement.

The participants in this study were provided with no information regarding the age, sex, or ancestry of the cadavers used for the radiographs. This was intentional because this study was designed to test the participants' ability to compare details visible on the x-ray films and it was not expected to have an effect on the participants' ability to correctly match the simulated antemortem and postmortem images of the same individuals (Koot *et al.* 2005; Weiler *et al.* 2000). Several of the participants indicated on their data sheets that they would need additional information to consider any of their matches to be positive identifications, which is an important clarification to make. While for the purposes of this study, the matches are being considered "identifications," they could not possibly be positive identifications unless all of the biological information associated with the missing person and the decedent also matched.

Problematic Cases

The majority of the errors and non-matches that were committed by the participants in this study involved *Unknown D* or *Unknown E*. *Unknown D* was misidentified 3 times, not identified 4 times, and several of the participants noted at the bottom of their data sheets that they would not consider their correct match of *Known 20* to *Unknown D* a positive identification. *Unknown E* was not matched 1 time and was mismatched by 2 participants—one of whom was a PhD who has been practicing for greater than 20 years and has extensive casework experience, and qualified his/her incorrect answer by saying that it was "not something I would consider a positive identification without further study." These two cases are revisited in more detail below.

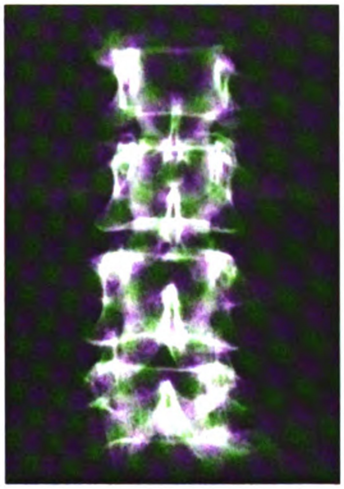
Problematic Case: Unknown D

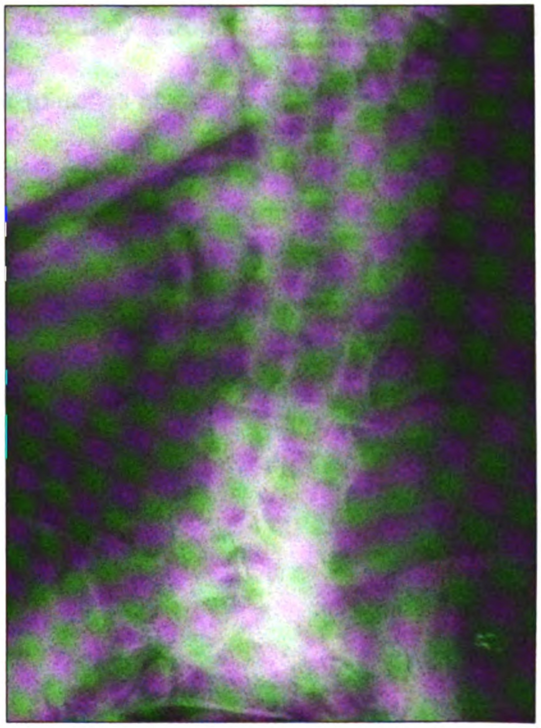
Because *Unknown D* proved to be problematic for so many of the participants, the images were revisited to evaluate what the problem might have been. There are three immediately obvious factors that likely resulted in the participants' misidentification of *Unknown D* or unwillingness to match *Unknown D* to *Known 20*, and which likely speak to problems inherent in any x-ray comparison. First, the skeletal structures in the simulated antemortem image were obscured due to the fact that the cadaver's abdomen was intact at the time of x-ray. The dense organs and collection of embalming fluid in the abdomen led to a radiographic "antemortem" image that appears to be underexposed. This is unfortunately one of the limitations of a study, like this one, that involves cadaver tissue. The potential for the visual obstruction of skeletal features by internal organs and soft tissue is often a factor when comparing antemortem and postmortem radiographs because many clinical x-rays are taken for diagnostic purposes concerning soft tissues.

Second, the orientation of the vertebrae in the simulated postmortem image is not exactly matched to that of the simulated antemortem image. Though the vertebrae are aligned as closely as the researcher could make them, they are not quite perfect, which

may have hindered participants from making a match. A third potential complication involved in this identification is that the cadaver used for *Unknown D/Known 20* had a congenital defect that resulted in the individual only having 4 lumbar vertebrae. The cadaver's 4th and 5th lumbar vertebrae were fused as one vertebra with bifid transverse processes. This was not clear on the simulated antemortem image and the existence of only 4 lumbar vertebrae in the image was not explained to the participants, who may have been focusing on non-corresponding details as a result (see *Figure 3*).

Figure 3: Unknown D (left) and Known 20 (right). This illustration shows the difference in orientation between the two images and the poor image quality of Known 20.





Due to the problematic nature of *Known 20*, the accuracy rates were reexamined to evaluate the performance of the study participants in cases where the images are conducive to making matches. When *Unknown D/Known 20* is removed from consideration, the number of misidentifications among the total sample of participants drops from 4% (5/125) to 3% (3/100), the number of cases where participants declined to make a match drops from 4.8% (6/125) to 1% (1/100), and the accuracy rate of the total sample increases from 91.2% to 96%. Among individual groups the difference is even more dramatic. The overall accuracy rate among professional forensic anthropologists increases from 91.3% (73/80) to 95.3% (61/64); instances of misidentification decrease from 5% (4/80) to 3.1% (2/64) and cases where participants declined to make matches decrease from 3.8% (3/80) to 1.6% (1/64) . Accuracy among PhDs increases from 92.3% (60/65, including misidentifications and non-matches as incorrect answers) to 96.2% (50/52), and to 98% (50/51 attempted matches) when the non-matches are removed from consideration. Among graduate students, accuracy increases from 91.1% (including misidentifications and non-matches as incorrect answers) to 97.2% (only one misidentification and no non-matches). See *Table 3,* on the following page.

Table 3: Participant Performance, Excluding Unknown D/Known 20

Subject	# Correct (True Positives) Total Possible = 5	# Incorrect	False Positives (Misidentifications)	No Identification Attempted	Accuracy
Graduate Students					
1	4	0	0	0	1.00
2	3	1	2	0	0.75
3	4	0	0	0	1.00
9	4	0	0	0	1.00
10	4	0	0	0	1.00
11	4	0	0	0	1.00
19	4	0	0	0	1.00
20	4	0	0	0	1.00
25	4	0	0	0	1.00
Total:	**35**	**1**	**2**	**0**	**0.972**
	35/36 (97.2%)	1/36 (2.8%)	1/36 (2.8%)	0/36 (0%)	
Professionals					
4	4	0	0	0	1.00
5	4	0	0	0	1.00
6	4	0	0	0	0.67
7	4	0	0	0	1.00
8	3	1	1	0	0.80
12	4	0	0	0	1.00
13	4	0	0	0	1.00
14	4	0	0	0	1.00
15	4	0	0	0	1.00
16	3	1	0	1	0.60
17	3	1	1	0	0.60
18	4	0	0	0	0.80
21	4	0	0	0	1.00
22	4	0	0	0	1.00
23	4	0	0	0	1.00
24	4	0	0	0	1.00
Total:	**61**	**3**	**2**	**1**	**0.91**
	61/64 (95.3%)	3/64 (4.7%)	2/64 (3.1%)	1/64 (1.6%)	
Group Total:	**96**	**4**	**3**	**1**	**0.96**
	96/100 (96%)	4/100 (4%)	3/100 (3%)	1/100 (1%)	

Problematic Case: Unknown E

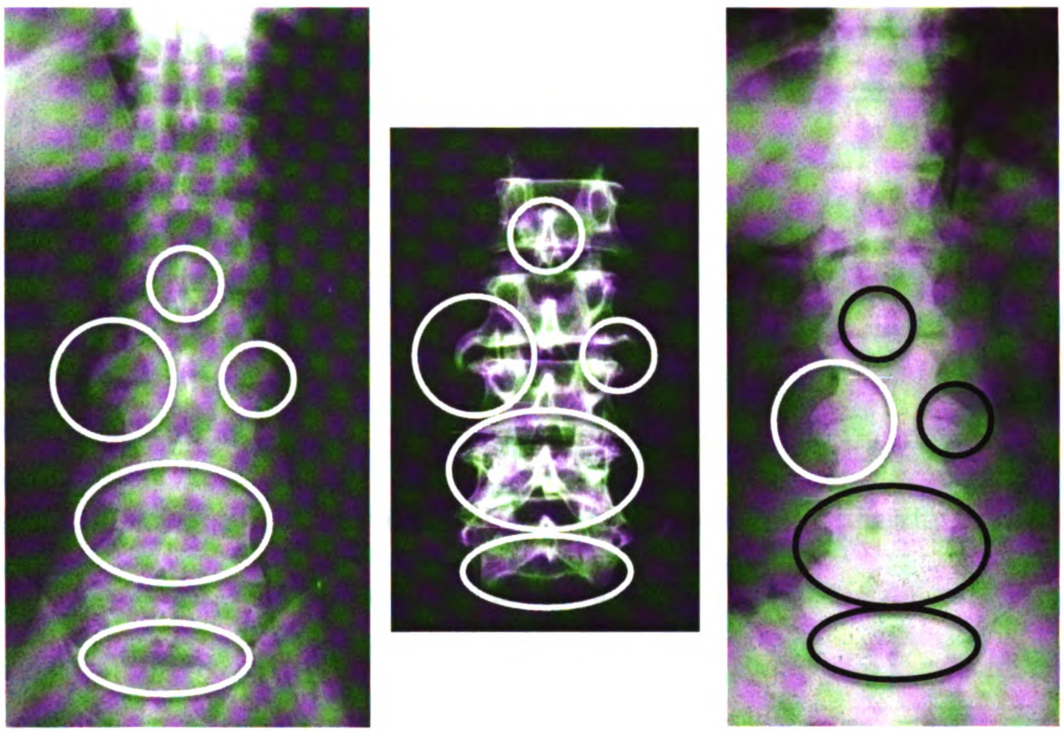
The extent of osteophyte development was the most often cited criterion for making a match between *Unknown E* and *Known 3* (having been cited a total of 28 times by 24 of the 25 participants). Both of the participants who mismatched *Unknown E* suggested that its "antemortem" match was *Known 15*, and both of them cited osteophyte development among their primary criteria.

It is probable that the two participants who mismatched *Unknown E* with *Known 15* focused primarily on the extensive osteophyte development between L2 and L3 along the right side of the vertebral column. Similar osteophyte development is visible in the images of both *Known 3* and *Known 15*. When other features are taken into consideration, however, it becomes apparent quickly that *Known 15* cannot be a match for *Unknown E*. *Figure 4* (page 45) presents images of *Known 3*, *Unknown E*, and *Known 15*. The large white circles in all 3 images indicate the similar osteophyte development along the right side of the vertebral column. Other similarities between *Known 3* and *Unknown E* are also circled in white, while black circles highlight some examples of differences between *Known 15* and *Unknown E*. Though the osteophyte development along the right side of the vertebral column may be similar, there are marked differences between other features, for example: spinous process contours, expressions of osteophyte development, contours of the vertebrae, and the intervertebral spaces.

This case was not missed nearly as frequently as *Unknown D/Known 20*, and there do not appear to be any problems with the quality of the images or the orientation of the vertebrae, so the participants' performance was not reevaluated as it was for

Unknown D/Known 20.

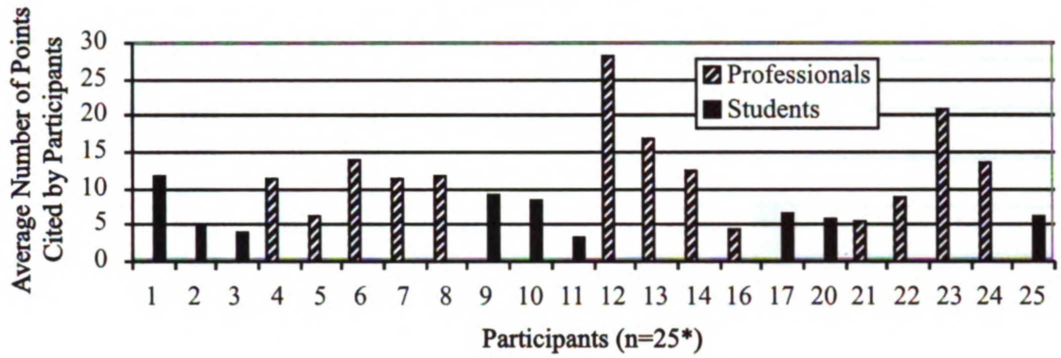
Figure 4: Known 3 (left), Unknown E (center), and Known 15 (right). With the three images side-by-side, the similarities between Known 3 and Unknown E and the differences between Unknown E and Known 15 become apparent.



Features

The number of points cited per identification ranged from 3 to 15. All students cited an average of less than 10 points of similarity when comparing the x-ray sets, while the overwhelming majority of professionals cited an average of greater than 10 points per identification. This may indicate that the professionals have more knowledge of terminology or they may be looking for more subtle details than the students, who generally have less experience (see *Figure 5*, on the following page).

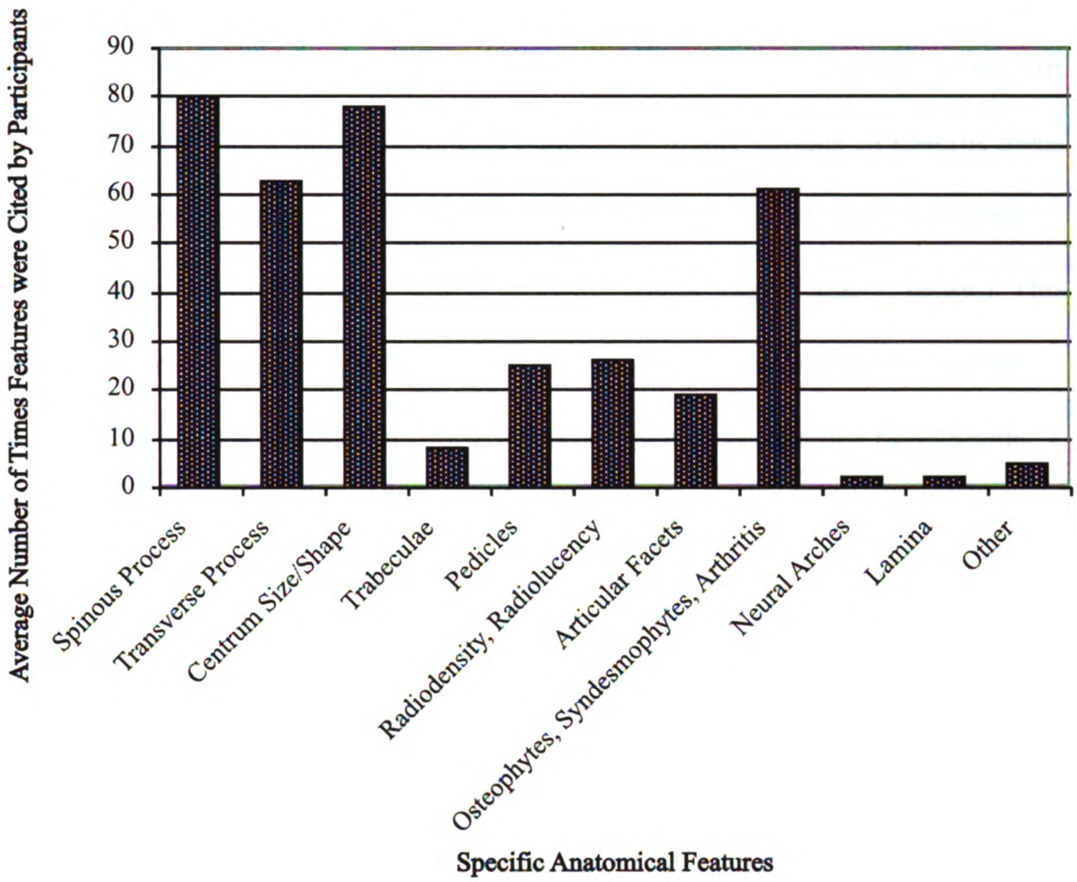
Figure 5: Bar chart showing the average number of points of similarity cited by students and professionals



*Participants #15, #18, and #19 are missing from this graph. Participant #15 did not provide an answer for how many points he/she cited for each identification; Participants #18 and #19 answered "Multiple" and "Many," respectively, and their answers could not be quantified.

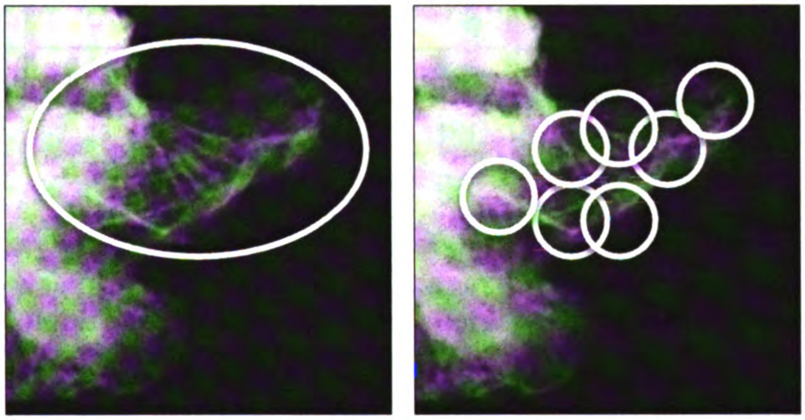
The most frequently cited criterion used for making matches was the Spinous Process (size, shape, orientation), which was cited a total of 134 times by the 25 participants. The centrum (size, contour) and transverse processes (contour, trabeculae) followed closely, having been cited 117 and 96 times, respectively. The fourth most frequently cited features were age related changes, such as osteophytic lipping, syndesmophyte development, and arthritis, terms that are often used interchangeably. These features were cited a total of 79 times by the 25 participants (See *Figure 6*, on the following page).

Figure 6: Bar chart showing the number of times each type of vertebral feature was cited by participants



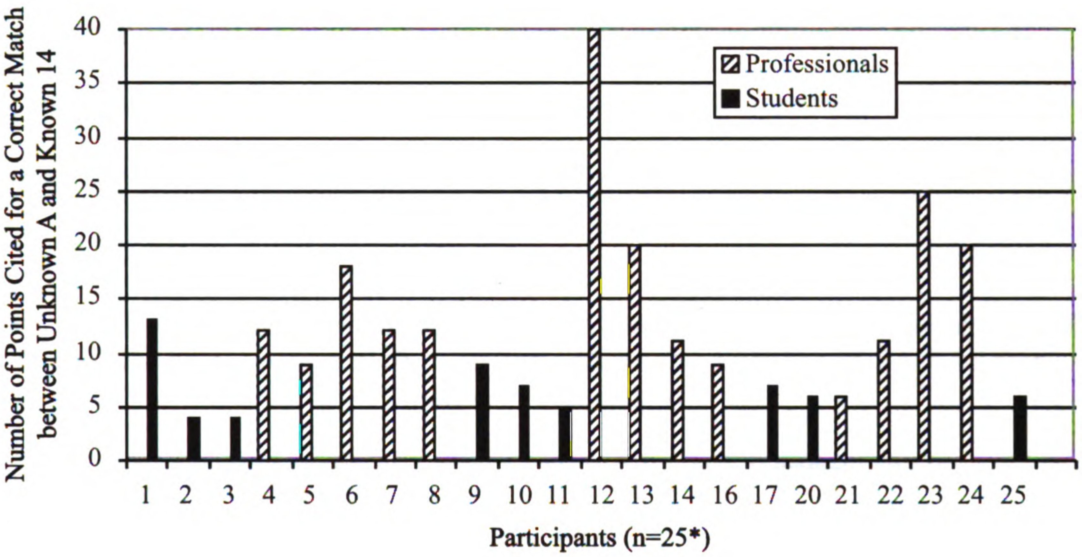
Correct answers were achieved using anywhere from 2 to over 40 points of similarity. In cases where the participants responded that no identification was possible, no points of similarity were ever noted. For incorrect answers where misidentifications resulted, anywhere from 3 to 11 points of similarity were noted. This brings up three important issues. First, a number of participants interpreted some of the terminology in the open-ended questions on the data sheets differently. Participants were asked, "How many points of similarity did you find when making this match?" and "Which specific anatomical features did you find most useful in making this identification?" Several participants noted that there was some confusion with regard to what was meant by "point" of similarity (see Appendix G for the participants' answers to the questions on the data sheets). For example, "point of similarity" could either refer generally to the left transverse process of L2, or the same term could refer to any number of specific areas of radiolucency/density or specific locations along the contour of the same transverse process, thereby greatly increasing the number of "points" (see *Figure 7*, below). This is likely the reason for the large discrepancies between the number of points used by participants in making the matches between the *Known* and *Unknown* radiographs.

Figure 7: A "point" may refer to the contour of a bony feature, or it may refer to any number of smaller details contained within the larger feature.



The graph below provides an example of one of the sample cases in this study that was matched correctly by all 24 participants. You can see that while everyone arrived at the same conclusion, the number of points cited ranged from 4 to almost 40.

Figure 8: All participants answered the match between Unknown A and Known 14 correctly. Note the large disparity among the numbers of points cited by participants.

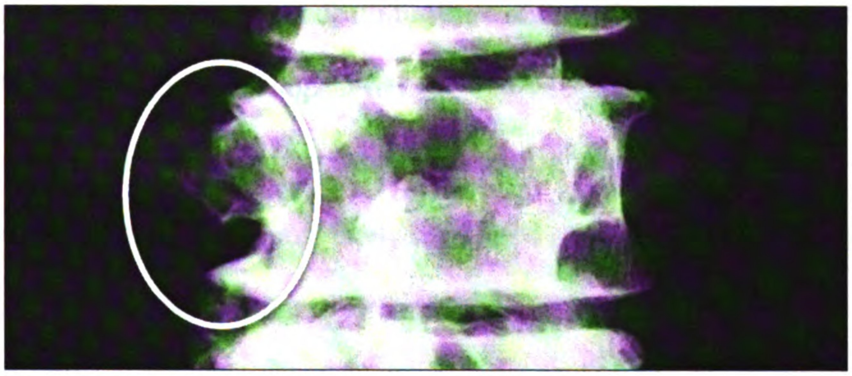


*Participants #15, #18, and #19 are missing from this graph. Participant #15 did not provide an answer for how many points he/she cited for each identification; Participants #18 and #19 answered "Multiple" and "Many," respectively, and their answers could not be quantified.

It is problematic that misidentifications occur at all, especially when they are based on up to 11 points of similarity. In the cases where this occurred, it appears as though the observers are paying attention to the minute details or to potential non-individualizing age-related characteristics, without considering larger or more discriminating features. For example, when *Unknown E* was misidentified, it appears as though the participants were focusing on osteophyte development, while ignoring overall shape and proportions of the vertebral column (see *Figure 4* on page 45).

A third problem that is notable regarding the "points" of identification is a lack of standardization in terminology among the study participants. The terms, "arthritis," "syndesmophyte," and "osteophyte" were repeatedly used by different researchers to describe the same features. For example, the feature pictured in the illustration below (*Figure 9*) was described by one participant as "arthritic activity," by a second participant as "syndesmophytes," and by a third participant as "osteophytes." These terms refer to very different skeletal conditions that can have very different etiologies; however they are used interchangeably by participants in this study. It will be important in the future to standardize not only methods but terminology as well.

Figure 9: The terms, syndesmophyte, osteophyte, and arthritis were used interchangeably to describe bony changes of the vertebral column (the vertebra shown is L3 from Unknown C/Known 9)



Limitations

There are some limitations to this study that may have an impact on the success and failure of matches and on the strength of the conclusions that are able to be drawn from this research. First, because of the difficulty in generating a sample of antemortem radiographs of the abdomen for which a subsequent postmortem image can be made, this study made use of cadavers to simulate the ante- and postmortem conditions. Image quality varies substantially across the simulated antemortem set of radiographs, which is mainly due to the condition of the bodies at the time of x-ray (see Appendix A). Several of the bodies were missing the majority of their internal organs, which enabled the x-ray beam to penetrate the skeletal structures with relative ease. The bodies with more intact abdominal cavities posed somewhat of a problem because of the increased density of the tissues due to postmortem changes and the embalming process.

Second, the average age at death for the cadavers that were used for this study is 77 years. Though this does not appear to have hindered anyone's ability to make matches between the radiographs, it is a factor that must be considered, especially when discussing which criteria were most likely to be used in a correct match. The age-related changes that compose the fourth most frequently cited features, would not be present to such an extent in a younger population. Because all of the x-rays were taken of deceased individuals, there is no potential for skeletal changes between the time the "antemortem" and "postmortem" images were taken. According to Sauer *et al.* (1988), positive identifications can still be made after up to 2.5 decades have passed between the antemortem and postmortem x-rays. In other words, skeletal features can remain very constant for a considerable length of time, so the fact that there is no time depth in this study does not necessarily diminish the quality of the conclusions.

There were also constraints placed on the quality of the information collected for this study because of the way the data sheets were designed. There are two items that could be changed in the future if this study is repeated or if a similar study is conducted which may strengthen the conclusions that can be made. First, the participants should have been asked how much time it took them to make each identification. Three of the participants, all of whom answered all 5 of the identification questions correctly, revealed through personal communication that they spent 30 minutes, 2 hours, and over 10 hours making the identifications. Because all 3 of them scored 5/5, it is not believed at this time that the time people spend making the identifications necessarily has any bearing on their ability to correctly match x-ray pairs, but it would have been a more thorough study if this information had been systematically collected. The other methodological change that should be made would be to include at least one simulated postmortem image for which there is no corresponding simulated antemortem image. The accuracy and error rates presented in this study are somewhat weakened by the absence of potential for true negatives (correctly indicating that a particular image cannot be matched) and false negatives (incorrectly indicating that a particular image cannot be matched). The way this study was constructed, it left no potential for statistical analysis of specificity and sensitivity values, which would have added greatly to any statements made regarding the accuracy and error rates achieved by the participants.

Another important limitation to this study is that the participant pool was small and was selected from a nonrandom self-selected group of volunteers. In order to obtain a better idea of whether this group of participants is representative of forensic anthropologists in general, it would be necessary to have a much larger sample. It is unfortunate that not all of the individuals who had initially volunteered to participate were able to contribute to this study.

Finally, this study does not test the participants' ability to make positive identifications; it is an evaluation of their ability to correctly match radiographic images to one another. In order to accurately determine a positive identification of an unknown decedent, an observer would need critical information regarding the biological profile—age, sex, ancestry, and stature—of both the decedent and the individual to whom the antemortem records correspond. Information concerning the circumstances of death—for example, location of the body, any identification present, time since death or disappearance—are also helpful in narrowing down the list of missing persons who could potentially be identified as the decedent. The single PhD who mismatched *Unknown E* and qualified his/her statement that he/she would not consider it a positive identification without further study was alluding to the fact that the study did not simulate an actual scenario because participants in this study were not provided with any of the information mentioned above. None of the matches that were made during the course of this study would be considered positive identifications in an actual forensic case.

This brings up an interesting issue. It is possible that participants may have felt compelled to provide an answer to each question because they were aware that there was a correct answer possible for each of the radiograph matches. As a result, some of the participants may have made judgement calls, knowing there was a correct answer, that they would not have made in a testing situation that was more representative of the conditions of an actual forensic case. This may have led to an inflated number of incorrect matches and a deflated number of non-identifications, and may account for many of the errors committed by the participants. While this study did not replicate an actual forensic case scenario, which may weaken any statements made regarding positive identification specifically, it is the process of matching radiographic images to one another to positively identify an unknown decedent that is in need of validation. The research design for this project is appropriate for such an evaluation.

Chapter 6: Conclusions

The primary goal of this study is to validate the utility in comparing lumbar spine radiographs as part of the positive identification process. Professionals were expected to perform generally well on the x-ray comparison test that was set up for this study, as they are the ones who would be the most likely to be asked to testify in court. They were the main objects of the study; the graduate students were included mainly as a comparative sample. Therefore, the overall high accuracy rate among professionals was not surprising. Ideally, none of the professionals would have answered incorrectly, but would have erred on the side of caution and chosen not to make a match where they were not confident that it was correct. In no instance should a positive identification be made where the investigator is unsure of his/her conclusion. This is an issue that should not be taken lightly by the scientific community. Conservative science is good science, and it is problematic that any misidentifications occurred at all in the course of this study. That said, this study has shown that comparing radiographs of the lumbar spine for identifying unknown decedents is generally a robust technique, with an overall accuracy rate of over 90%. When only professionals evaluated and only attempted matches are considered (removing the non-identifications from the analysis), the accuracy rate increases to 98%.

The ability for observers to correctly match radiographs of the same individual is greatly affected by the quality of the images with which they are provided, and like the conclusions presented by much of the earlier research concerning radiograph comparison, orientation of the vertebrae and angle of the x-ray beam are critical for this type of analysis. The detrimental effect of a problematic image became apparent in this study when the problematic case (*Unknown D/Known 20*) was eliminated so that the materials included only comparisons made using high-quality antemortem images that show a large number of bony anatomical features. When the problematic case was eliminated from consideration when evaluating the participants' results, the overall accuracy rate increases substantially from 91% to 96%.

In this study it was important to separate out the actual incorrect answers (the misidentifications) from the non-identifications. Though the relationship is not statistically significant, trends observed during the course of this study indicate that observers who have more experience are less likely to attempt a match that is negatively impacted by confounding factors, such as poor image quality. They are more likely to err on the side of caution and decline to make a match, rather than present a conclusion of which they are not certain.

As previous validation studies (Hogge *et al.* 1994; Koot *et al.* 2005) concerning radiographs of other regions of the body have demonstrated, and as was expected in the present study, it does appear that individuals with more training or experience with examining radiographs were more successful overall than those with little-to-no experience. Those with more experience also cited more specific points of similarity when making matches, likely because they have more knowledge of which features are most individualizing and because they may generally have more knowledge of anatomical features and terminology than those with less experience. This study shows that significant relationships exist between the participants' performance and their level of education, years of experience, and number of radiograph cases, which is consistent with the findings of previous researchers. Among the most experienced participants (n = 8)—those who have earned their PhDs, have been practicing for more than 20 years and have had experience with more than 30 radiograph cases—six answered all of the matching questions correctly, one scored 3/5 (both non-identifications), and one scored 3/5 (1 non-identification, 1 misidentification). To revisit a point made in Chapter 5, the participant who made one misidentification is the only participant who provided an incorrect answer but qualified it, saying that he/she would not consider it an identification without further study. It is that qualifier, left out by less experienced observers who answered at least one question incorrectly, which distinguishes this experienced participant from those with less experience. It was also noted in Chapter 5 that when the entire sample of study participants is taken into account, the only significant relationship between any of the independent and dependent variables exists between *Number of Radiograph Cases* and *Score out of 5*, indicating that the participants with more experience comparing radiographs outperformed those with less radiograph comparison experience.

The anatomical features most commonly relied upon to correctly match the antemortem and postmortem images were the spinous processes, transverse processes, and centrum shape/contour. In combination, these features are highly reliable. Less reliable are the patterns of radiolucencies and radiodensities (the appearance of which is highly susceptible to the orientation of the vertebrae and of the x-ray beam), and the osteophytes/syndesmophyte development. The five misidentifications that were made in this study all cited such age-related changes among the primary criteria used to make the identifications. This study has shown that it is important to be mindful of gross structures as well as smaller details when comparing radiographs of the spine, and to take into consideration as many features as possible when deciding on whether the decedent can be positively identified or excluded.

Unfortunately, this study also reaffirms the NAS report's condemnation of the forensic sciences for their lack of standardization. It is important for forensic anthropologists to continue to work toward a standardization in terminology and methods. Results from this study show that terms such as "osteophytes," "syndesmophytes," and "arthritis" were used by different participants to explain the same structures, which is problematic because the terms themselves are not interchangeable. If forensic anthropology is to continue improving standardization in methods, techniques, and record keeping, maintaining consistent terminology will be critical.

Despite the problem with terminology, the majority of the participants—students and professionals alike—consistently relied on a handful of vertebral features to arrive at correct matches between radiographs of the same individual. This is an indication that although there is a lack of consistency in terminology, there is a generally accepted practice for comparing radiographs among forensic anthropologists. The disparities between the number of specific anatomical features cited by the participants is something to be considered, however. The professional anthropologists who participated in this study cited more points than students, and it appears as though the difference (See Appendix G) is mainly because professionals recorded more detailed summaries of their observations on their data sheets. This does not mean that students did not examine the same features; they may have simply not known how to write as precisely, using specific terminology, as their professional counterparts. If standardization is to be achieved for the practice of comparing medical and dental radiographs for positive identification, it will be necessary to outline best practices for recording such information.

This study has shown that the lumbar spine is a reliable region of the body from which positive identifications can be made using comparisons of antemortem and postmortem radiographs if the comparison is carried out by a well-trained, experienced observer. It has also identified some problems with the standardization of terminology and methods used by forensic anthropologists when making such identifications. For that reason, it may serve as a basis from which best practices and standards can be developed for the field of forensic anthropology, specifically with regard to comparative radiography.

APPENDICES

APPENDIX A

Cadaver Information

Cadaver Information

The chart on the following page is a list of the cadavers that were used for the radiographs in this study. The cadaver ID numbers assigned by the MSU Willed Body Program, their causes of death, and their date of death have not been included in order to protect the identities of the individuals who donated their bodies to the Willed Body Program. The fifth column in the chart describes the type of dissection for each body in the sample. This column is relevant because the depth of dissection and the amount of soft tissue and organs that are intact or removed have an impact on radiograph quality. Bodies that have been dissected to the Intermediate or Deep levels are missing many, if not all, of their organs and are more likely to produce clear radiographic images of the bony features of the spine. Those that have been dissected only superficially (in many cases, meaning that only the skin and subcutaneous fat have been removed) or to the viscera still contain organs and are the bodies that tend to yield obscured or cloudy simulated antemortem radiographic images.

The abbreviations used in the chart are as follows:

LAM	Limbs Anterior Muscles	**TAM**	Thorax Anterior Muscles
LAV	Limbs Anterior Viscera	**TAD**	Thorax Anterior Deep
LPM	Limbs Posterior Muscles	**TPI**	Thorax Posterior Intermediate
LPV	Limbs Posterior Viscera		
TAI	Thorax Anterior Intermediate	**TPS**	Thorax Posterior Superficial

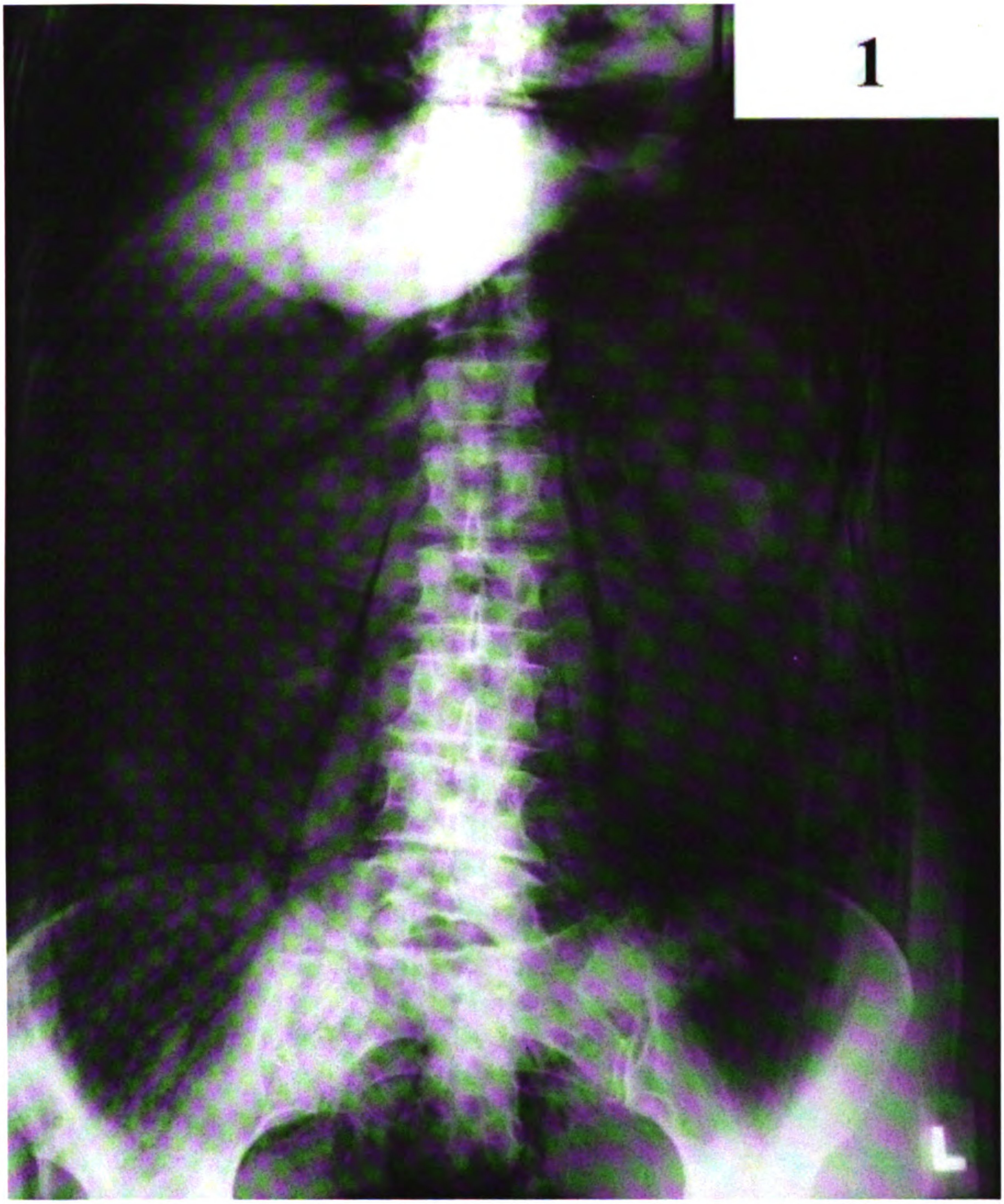
Table 4: Cadaver Information

Specimens Available for X-ray	Age at Death	Sex	Year of Death	Type of Dissection	X-rayed for "AM" sample	X-rayed for "PM" sample	Used for "AM" Sample	Used for "PM" Sample
1	84	F	2004	TAM	Yes	Yes	*Known 14*	*Unknown A*
2	90	F	2005	LAV	Yes	Yes	*Known 10*	*Unknown B*
3	59	M	2004	LAV	Yes	Yes	*Known 3*	*Unknown E*
4	83	M	2005	LAM	Yes	No	*Knowns 2 & 19*	No
5	74	M	2005	LAM	Yes	No	*Known 4*	No
6	59	F	2005	LAV	Yes	Yes	Not used—damaged during maceration	Not used—damaged during maceration
7	83	M	2004	LPM	No—too large	No	No	No
8	79	M	2004	LPV	Yes	No	Not used—lamenectomy	Not used—lamenectomy
9	58	F	2005	TPS	Yes	Yes	*Known 5*	No
10	73	M	2004	TAI	Yes	No	No	No
11	82	M	2004	TAD	Yes	No	*Known 18*	No
12	86	F	2004	TAI	Yes	Yes	*Known 20*	*Unknown D*
13	71	F	2004	TAD	Yes	No	*Known 6*	No
14	63	M	2006	TAI	Yes	No	*Known 11*	No
15	90	M	2005	LAM	Yes	No	No	No
16	88	F	2005	TAM	Yes	No	*Known 17*	No
17	74	F	2006	TAI/LAV	Yes	No	*Known 1*	No
18	83	M	2005	LAM	Yes	No	No	No
19	73	M	1998	LAM	Yes	No	*Known 15*	No
20	62	F	2000	LAV	Yes	No	*Known 16*	No
21	87	M	2005	TAM	Yes	No	*Known 8*	No
22	97	F	2005	TAM	Yes	No	No	No
23	63	M	1987	TAM	Yes	No	No	No
24	91	M	2006	TAM	Yes	No	No	No
25	77	F	2005	TPI	Yes	No	*Known 9*	*Unknown C*
26	93	F	2006	TAD	Yes	No	*Known 7*	No
27	50	F	2006	TAD	Yes	No	*Known 12*	No
28	75	F	2006	TAI	Yes	No	*Known 13*	No

APPENDIX B

Simulated Antemortem Radiograph Images

Figure 10: Simulated Antemortem Image #1

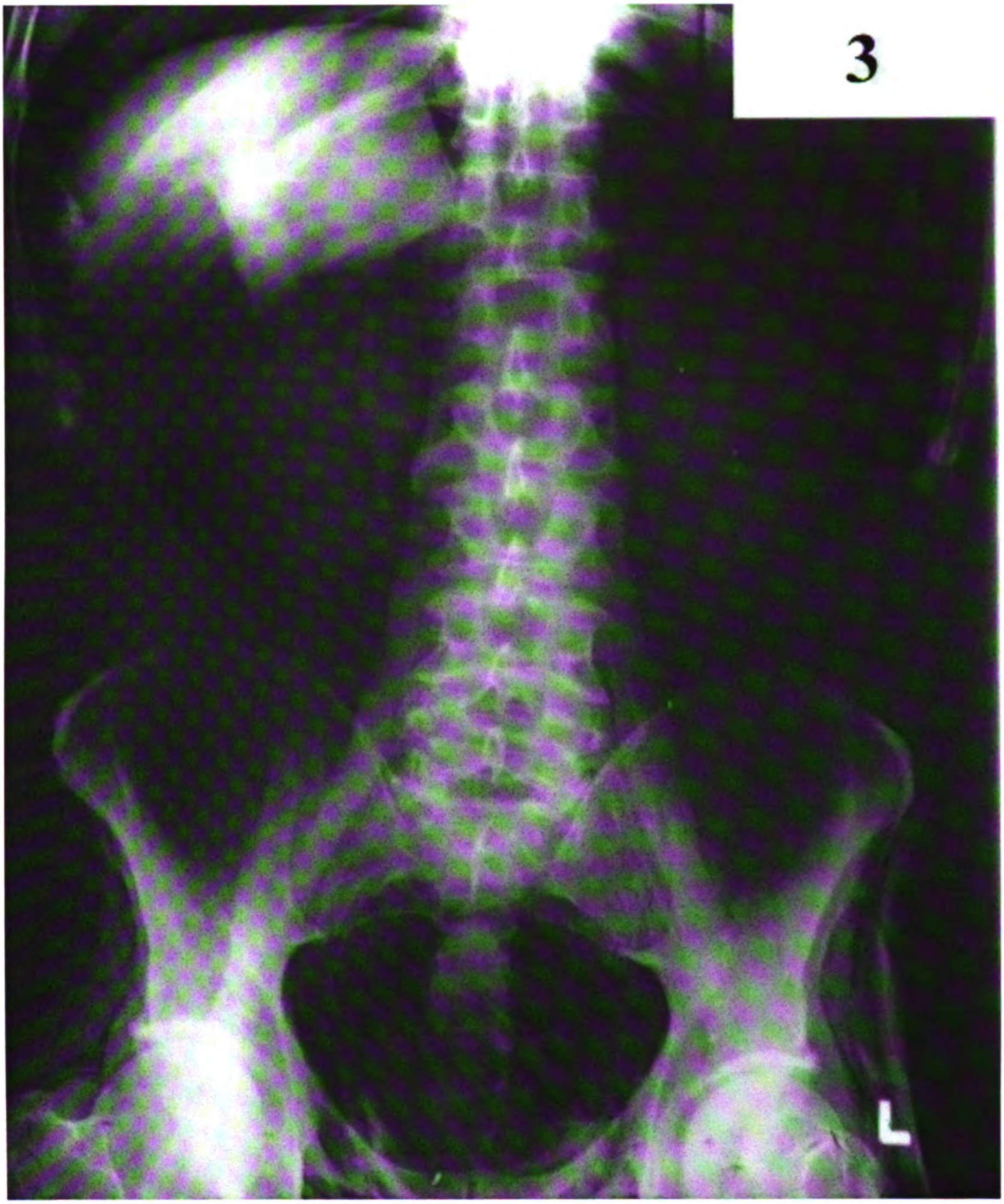


kVp 75 @ mAs 48
Not a match for any of the simulated postmortem images

Figure 11: Simulated Antemortem Image #2

kVp 75 @ mAs 40
Not a match for any of the simulated postmortem images
*This is an x-ray from the same cadaver as Simulated Antemortem Image #19

Figure 12: Simulated Antemortem Image #3

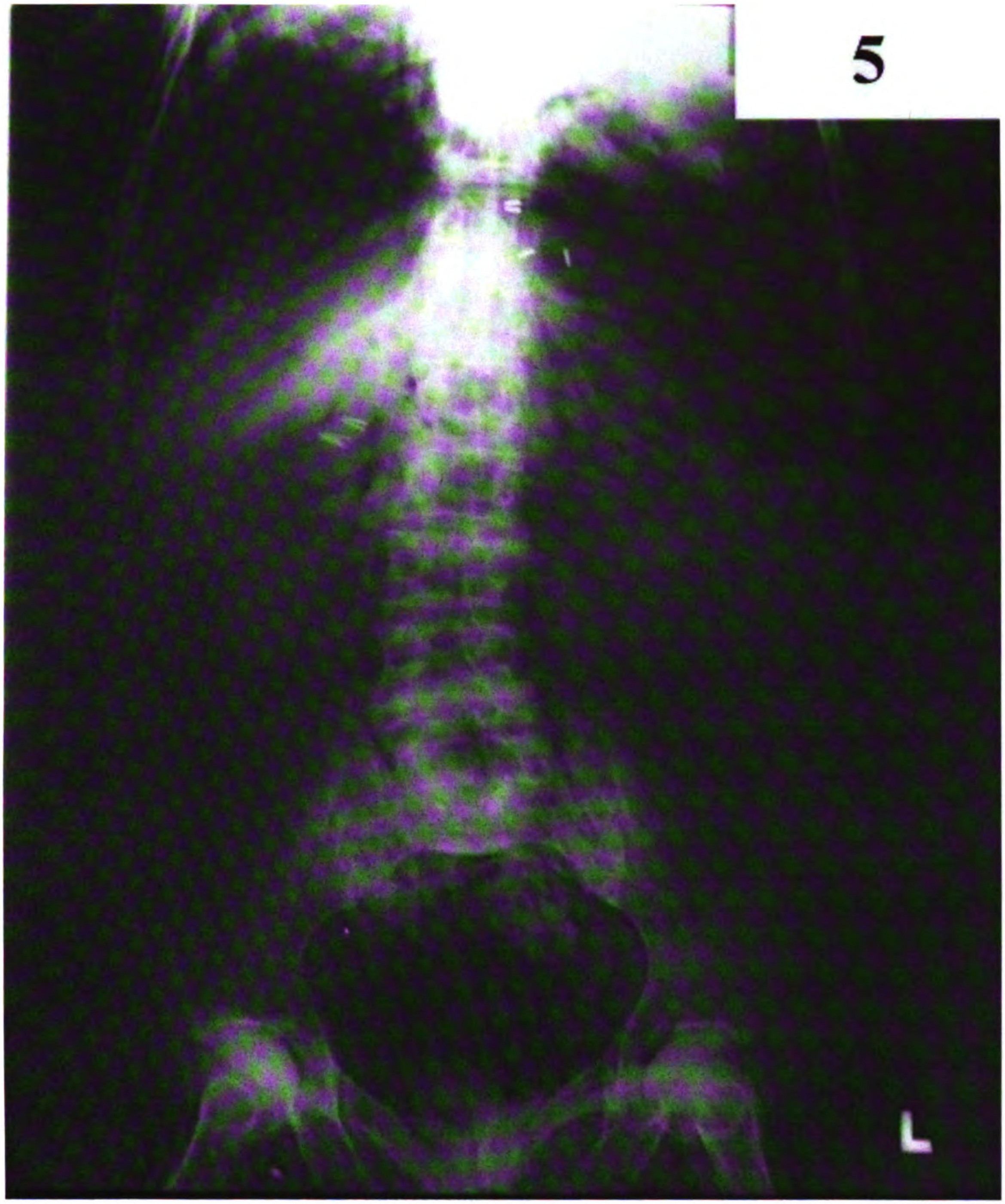


kVp 75 @ mAs 20
"Antemortem Match" for *Unknown E*

Figure 13: Simulated Antemortem Image #4

kVp 75 @ mAs 64
Not a match for any of the simulated postmortem images

Figure 14: Simulated Antemortem Image #5



kVp 70 @ mAs 20
Not a match for any of the simulated postmortem images

Figure 15: Simulated Antemortem Image #6

kVp 70 @ mAs 20
Not a match for any of the simulated postmortem images

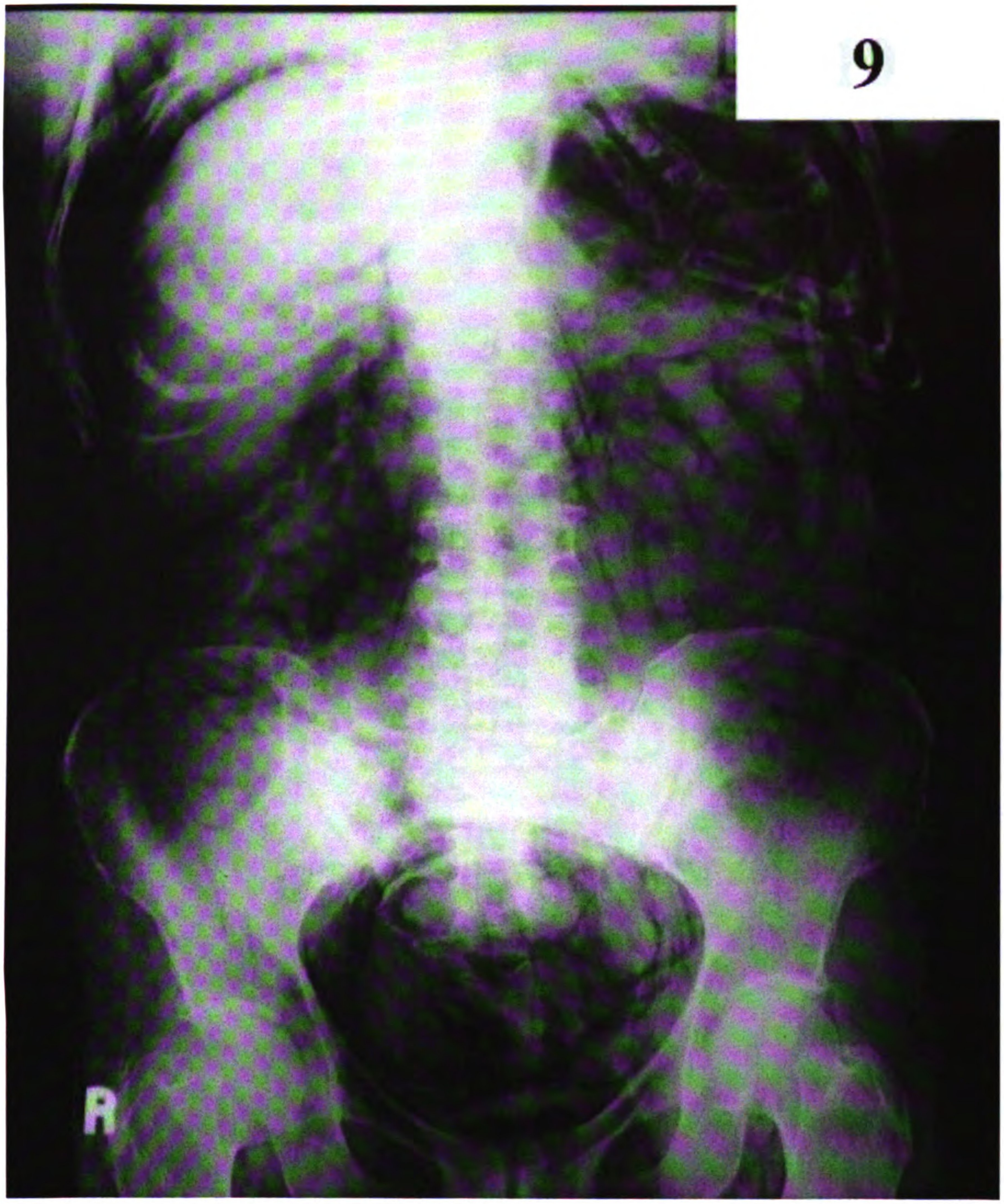
Figure 16: Simulated Antemortem Image #7

kVp 75 @ mAs 32
Not a match for any of the simulated postmortem images

Figure 17: Simulated Antemortem Image #8

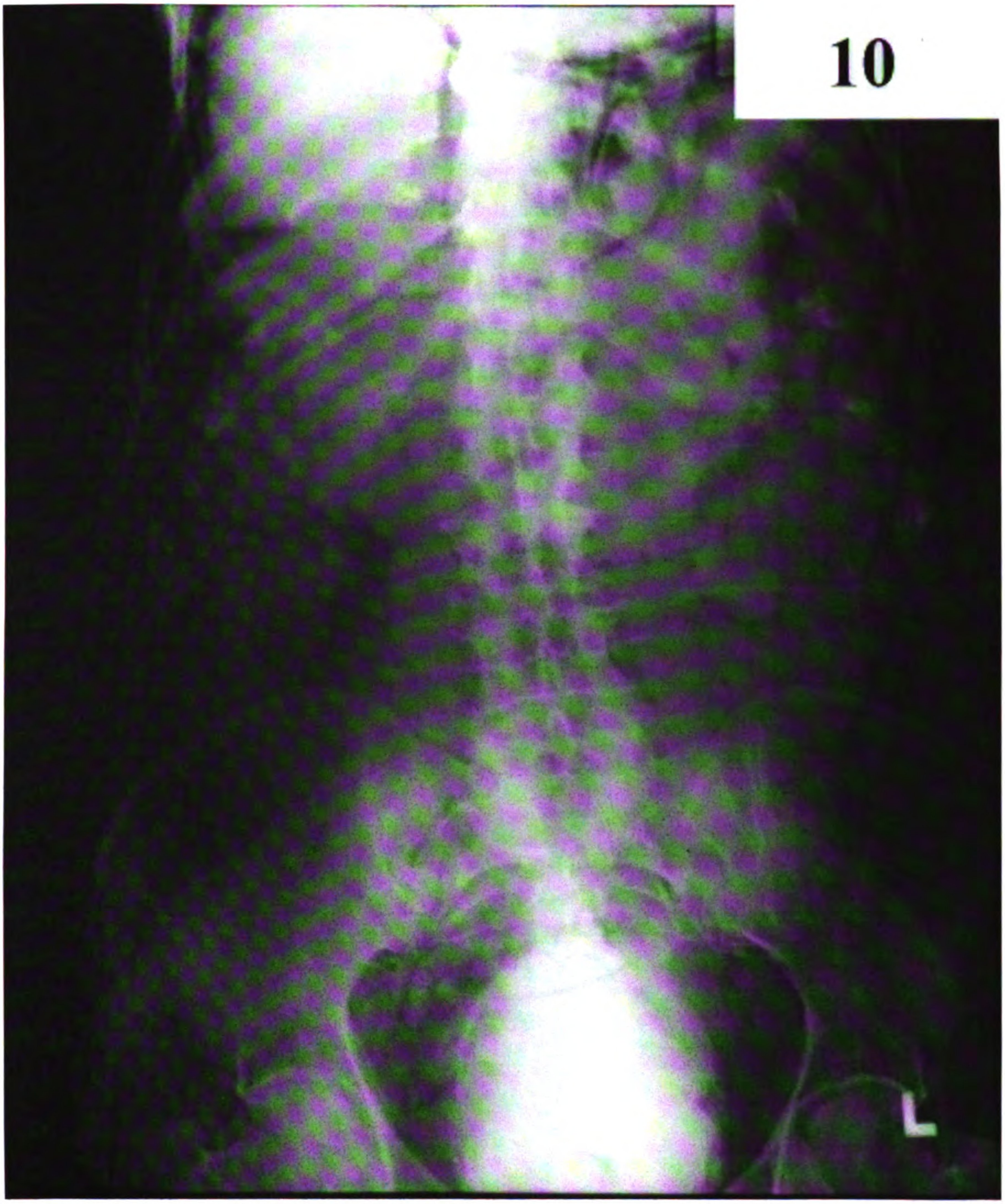
kVp 75 @ mAs 80
Not a match for any of the simulated postmortem images

Figure 18: Simulated Antemortem Image #9



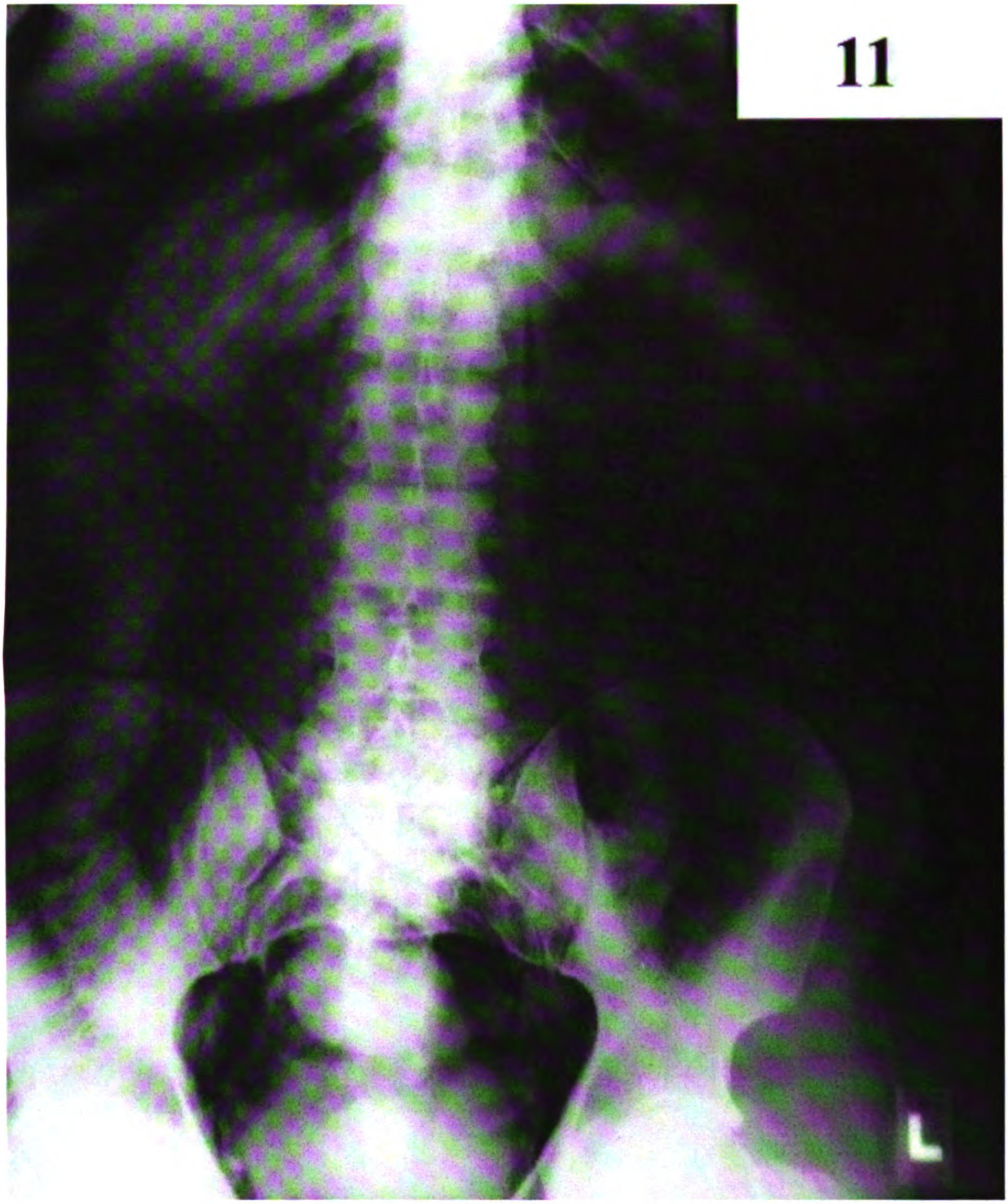
kVp 75 @ mAs 32
"Antemortem Match" for *Unknown C*

Figure 19: Simulated Antemortem Image #10



kVp 75 @ mAs 20
"Antemortem Match" for *Unknown B*

Figure 20: Simulated Antemortem Image #11

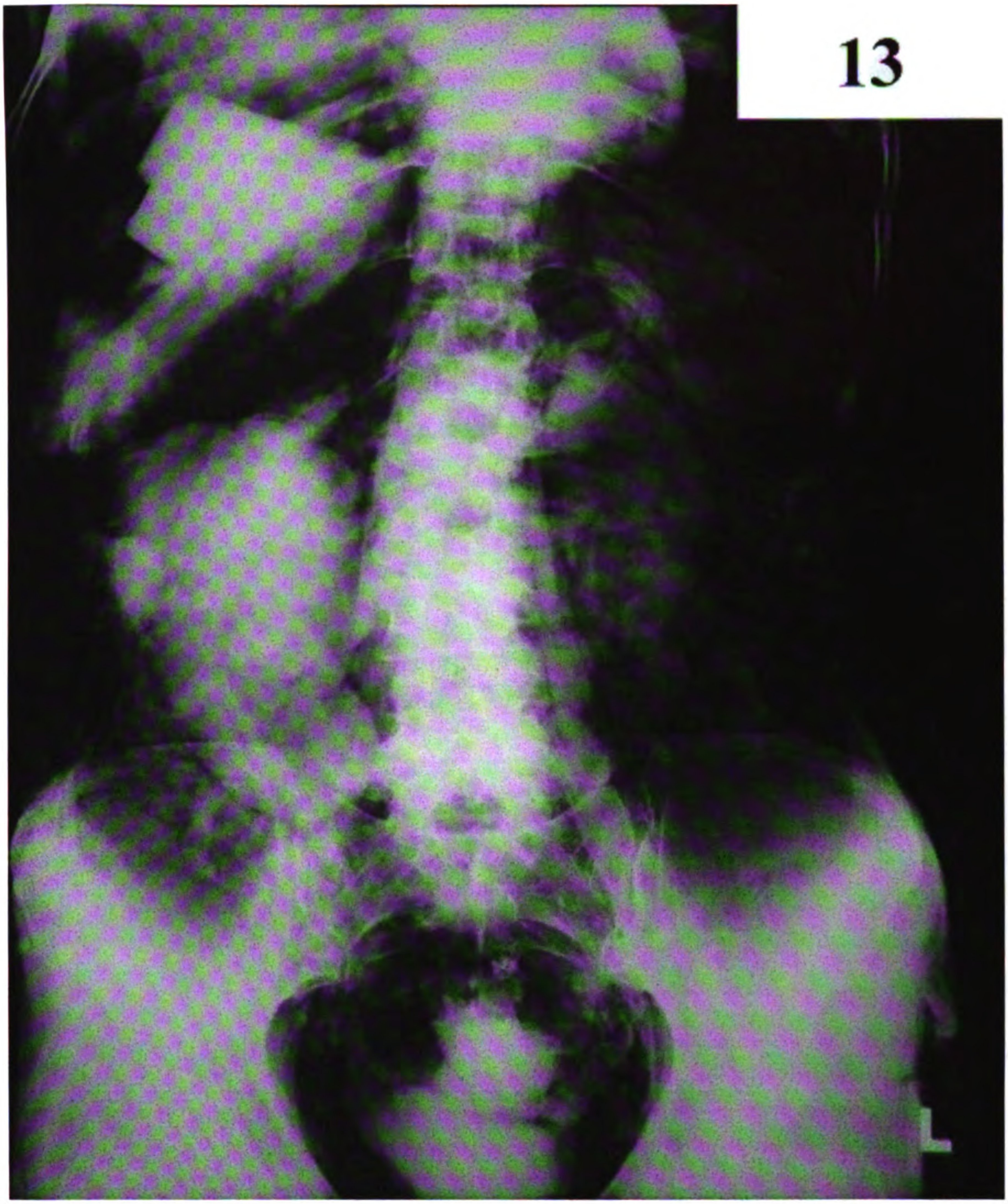


kVp 70 @ mAs 64
Not a match for any of the simulated postmortem images

Figure 21: Simulated Antemortem Image #12

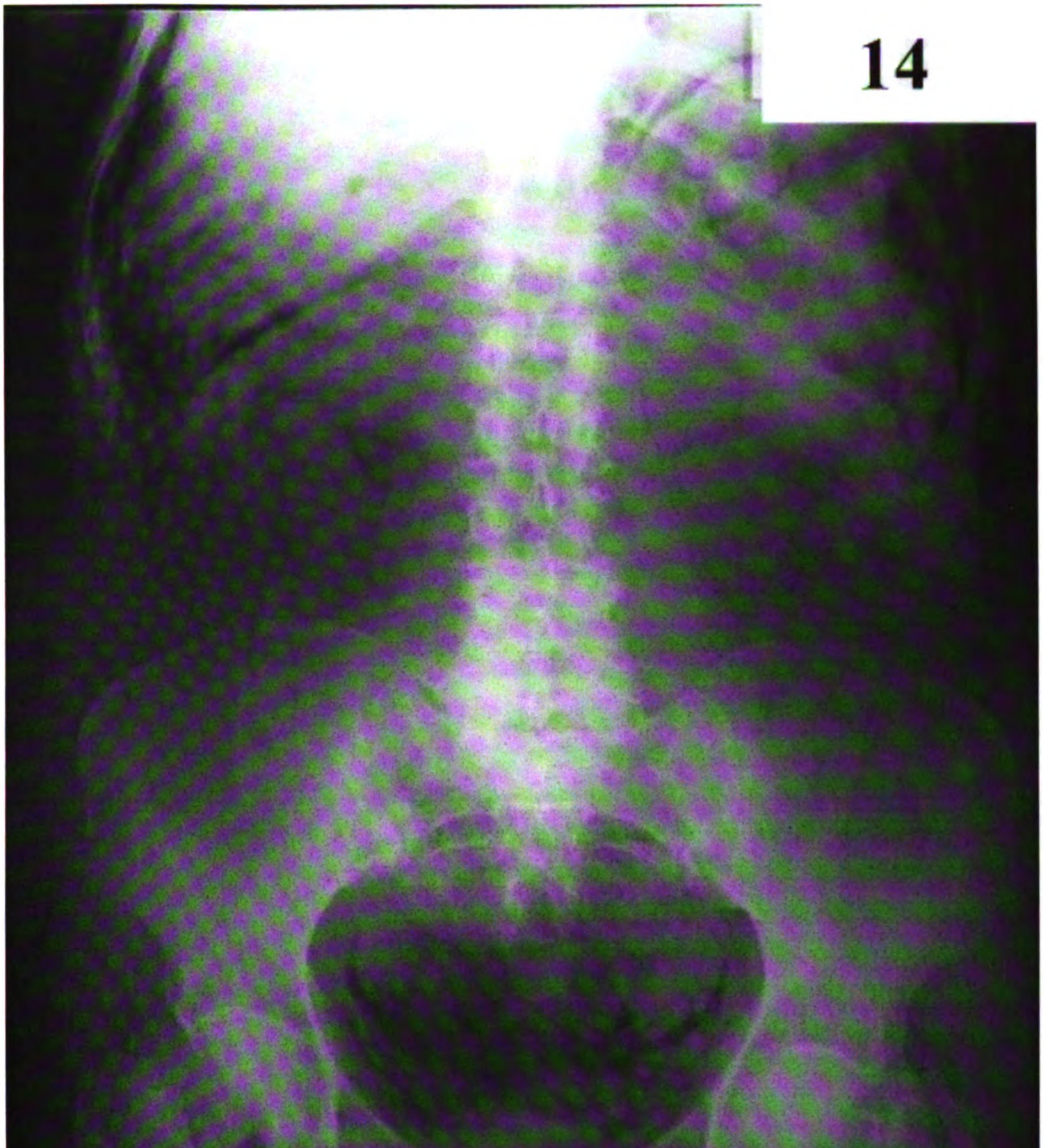
kVp 75 @ mAs 24
Not a match for any of the simulated postmortem images

Figure 22: Simulated Antemortem Image #13



kVp 70 @ mAs 24
Not a match for any of the simulated postmortem images

Figure 23: Simulated Antemortem Image #14



kVp 75 @ mAs 24
"Antemortem Match" for *Unknown A*

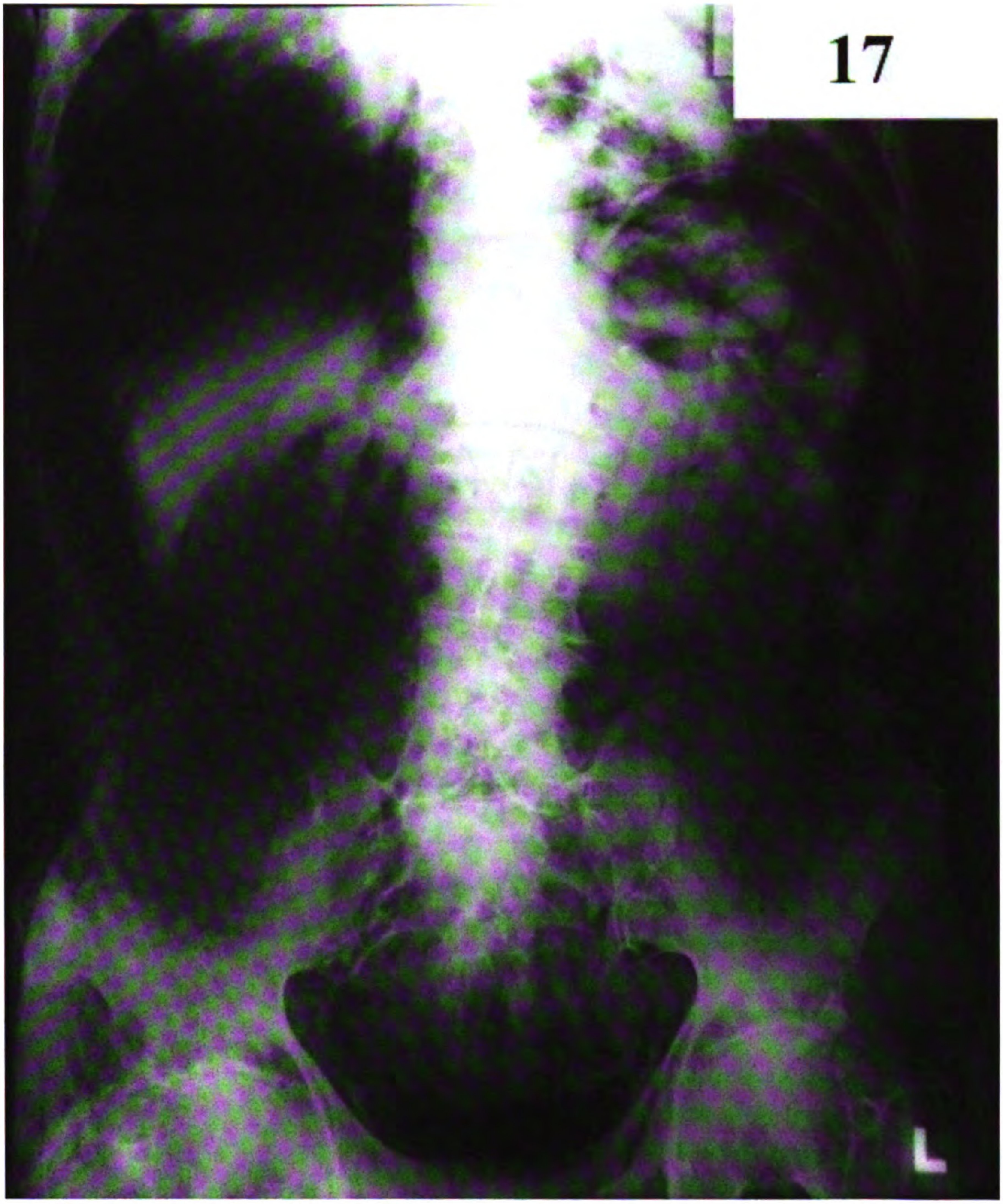
Figure 24: Simulated Antemortem Image #15

kVp 90 @ mAs 64
Not a match for any of the simulated postmortem images

Figure 25: Simulated Antemortem Image #16

kVp 75 @ mAs 20
Not a match for any of the simulated postmortem images

Figure 26: Simulated Antemortem Image #17



kVp 75 @ mAs 64
Not a match for any of the simulated postmortem images

Figure 27: Simulated Antemortem Image #18

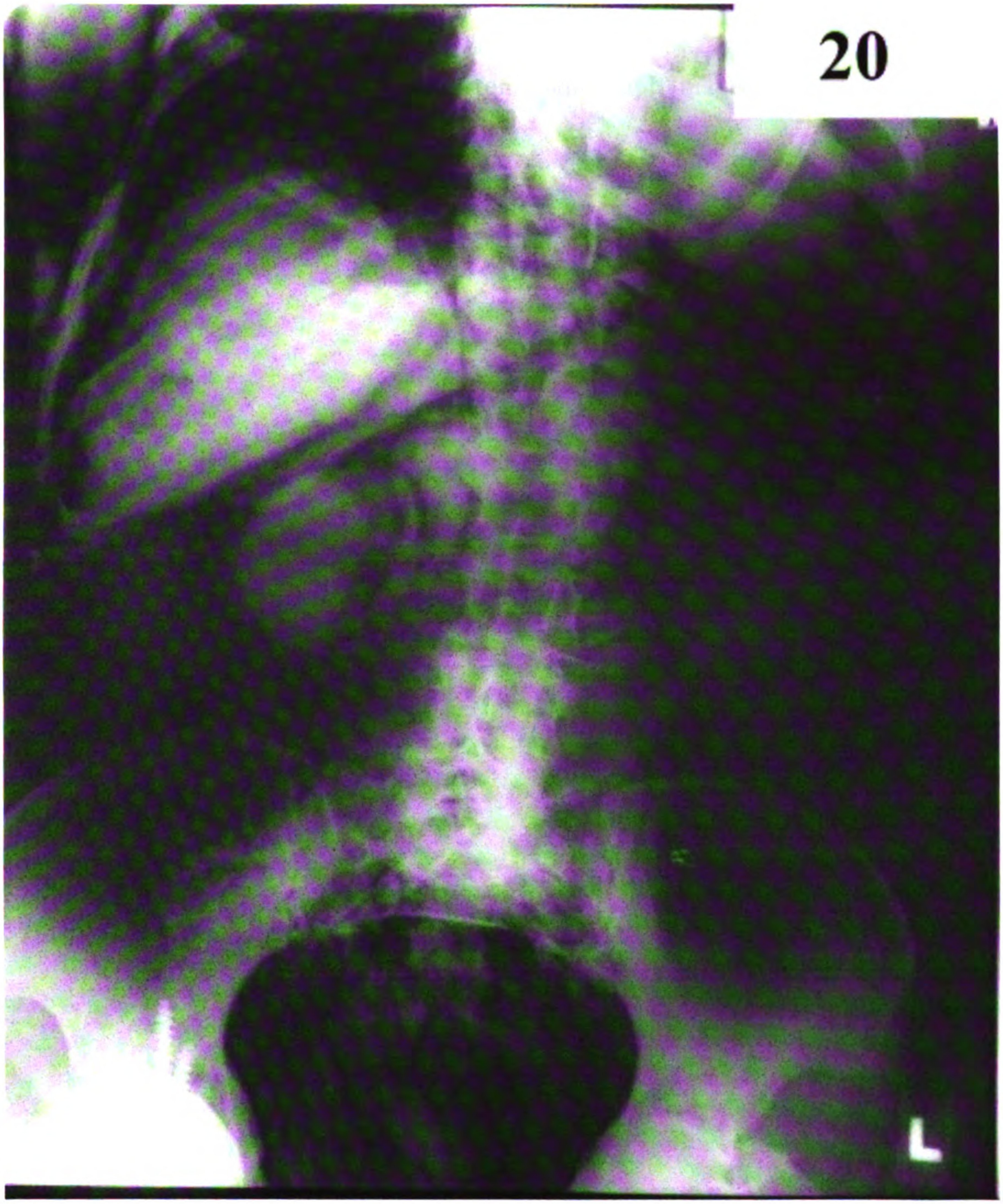
18

kVp 70 @ mAs 24
Not a match for any of the simulated postmortem images

Figure 28: Simulated Antemortem Image #19

kVp 75 @ mAs 48
Not a match for any of the simulated postmortem images
*This is an x-ray from the same cadaver as Simulated Antemortem Image #2

Figure 29: Simulated Antemortem Image #20

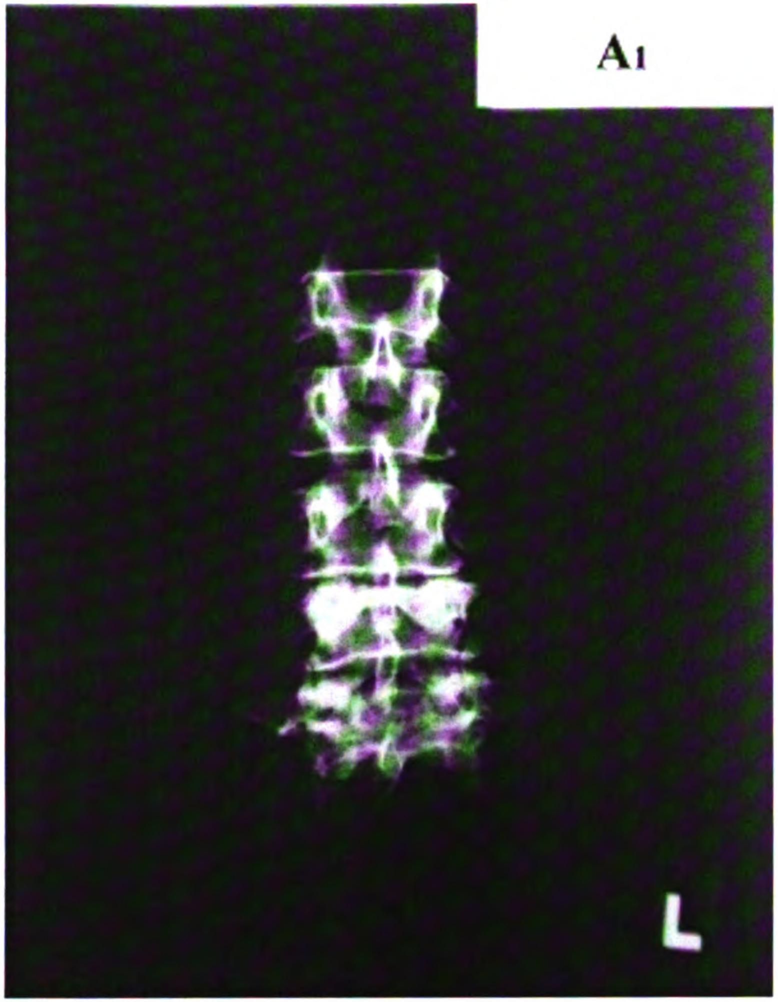


kVp 75 @ mAs 40
"Antemortem Match" for *Unknown D*

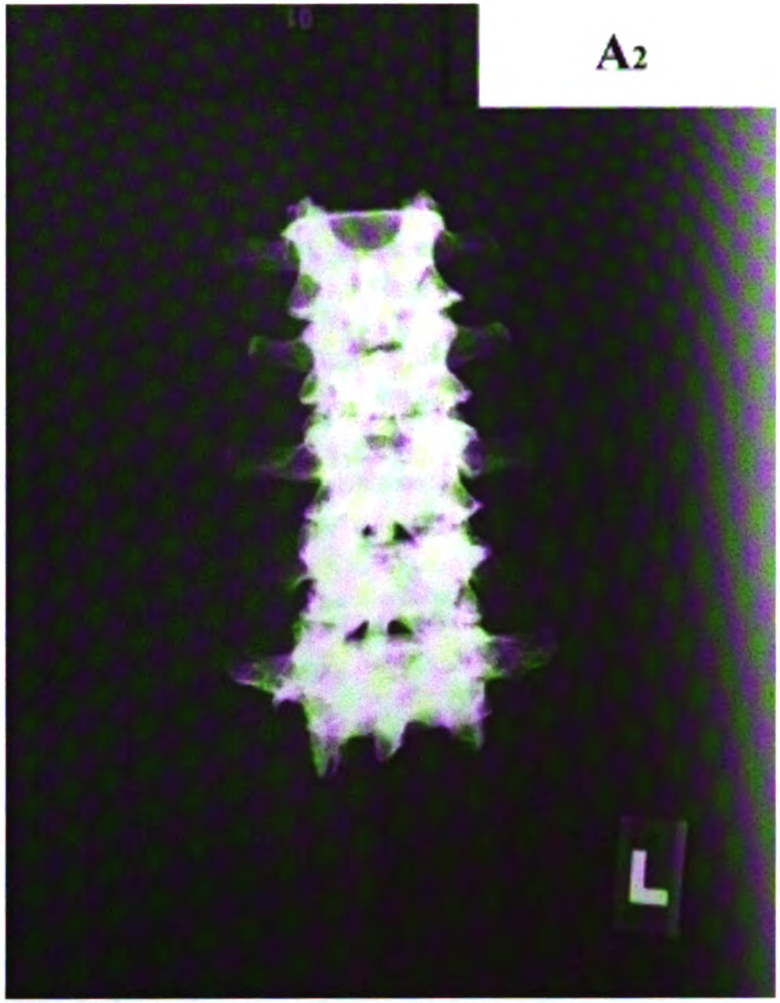
APPENDIX C

Simulated Postmortem Radiograph Images

Figure 30: Simulated Postmortem Images A1 and A2

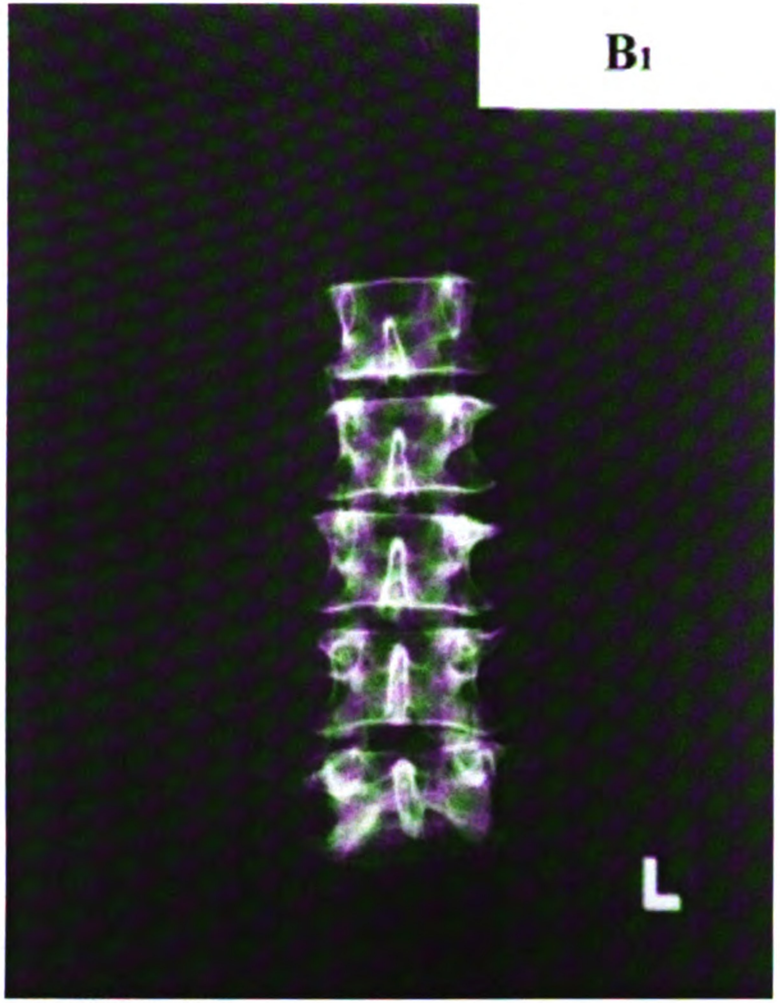


kVp 65 @ mAs 5
"Postmortem Match" for *Known 14*

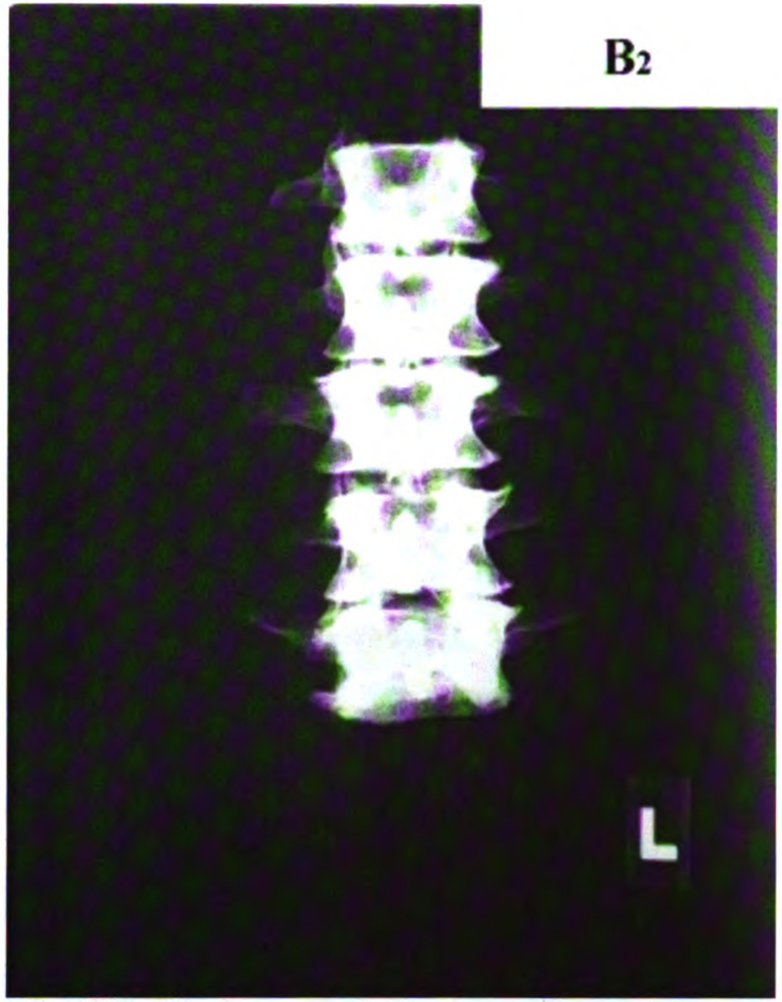


kVp 55 @ mAs 4
"Postmortem Match" for *Known 14*

Figure 31: Simulated Postmortem Images B1 and B2

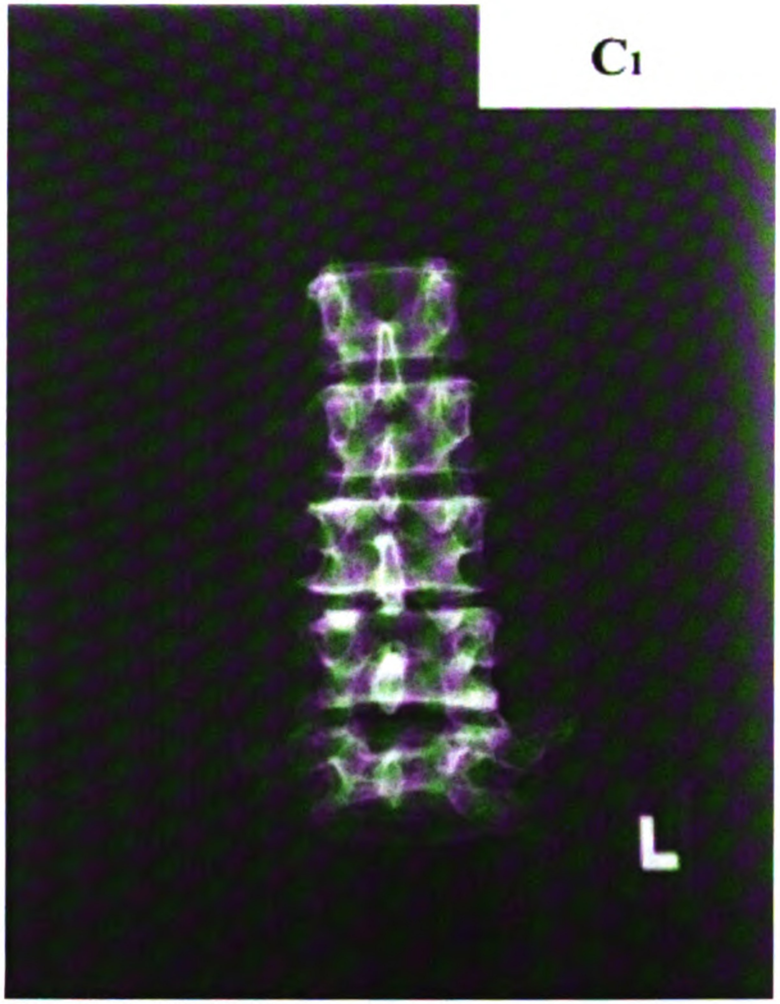


kVp 65 @ mAs 5
"Postmortem Match" for *Known 10*

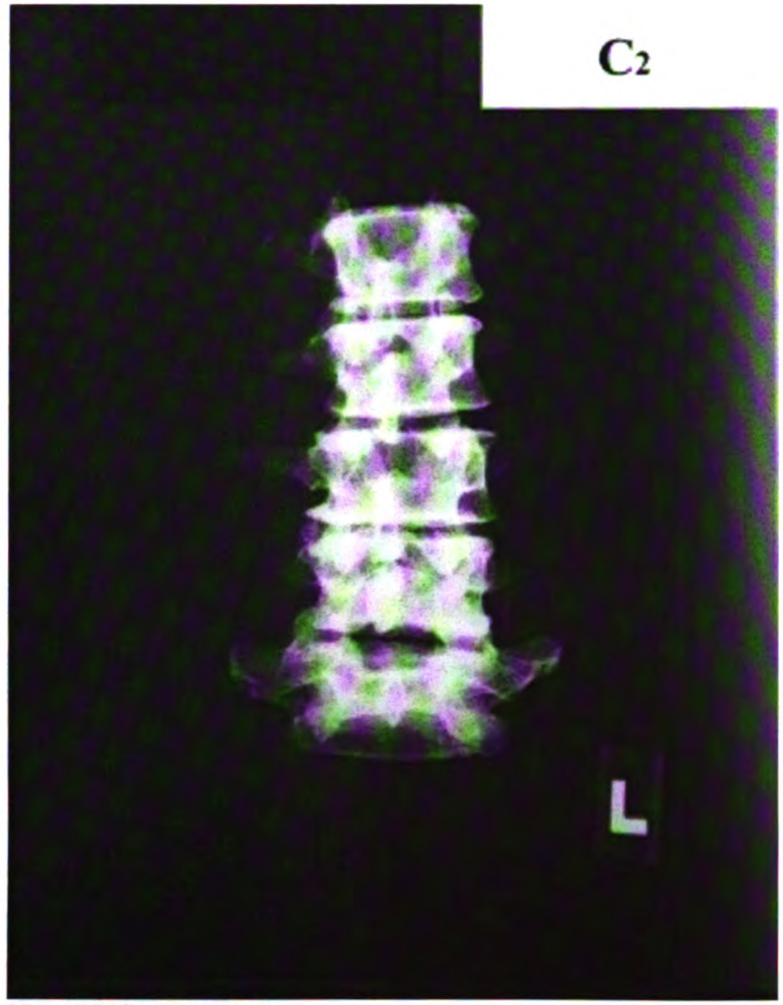


kVp 55 @ mAs 5
"Postmortem Match" for *Known 10*

Figure 32: Simulated Postmortem Image C1 and C2

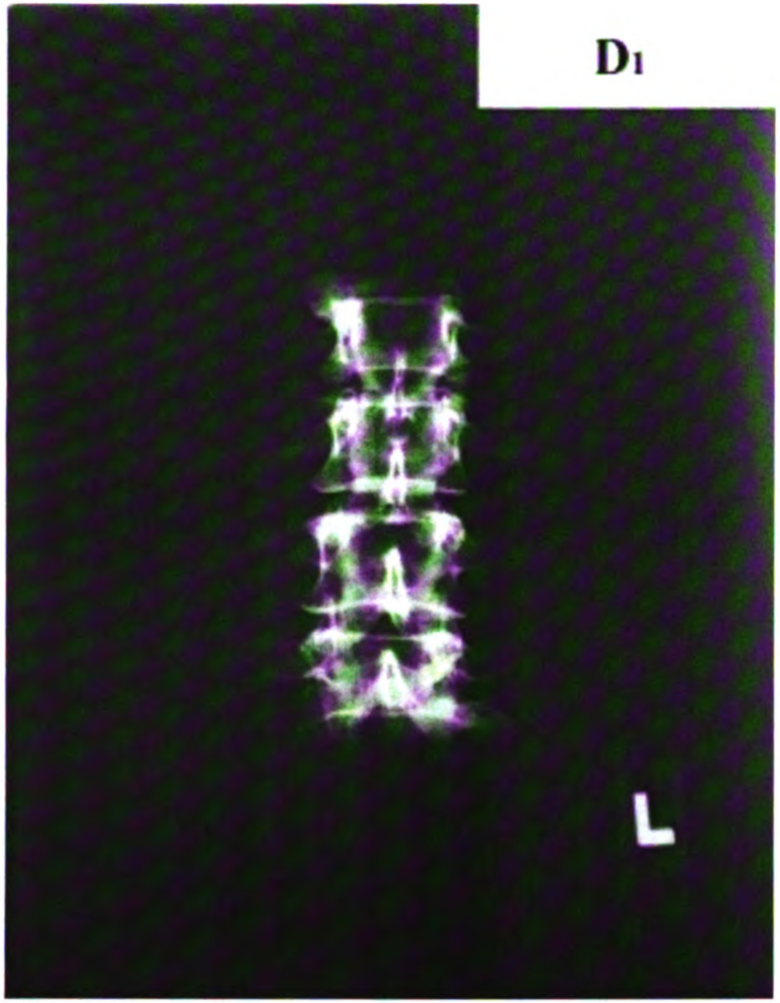


kVp 65 @ mAs 5
"Postmortem Match" for *Known 9*

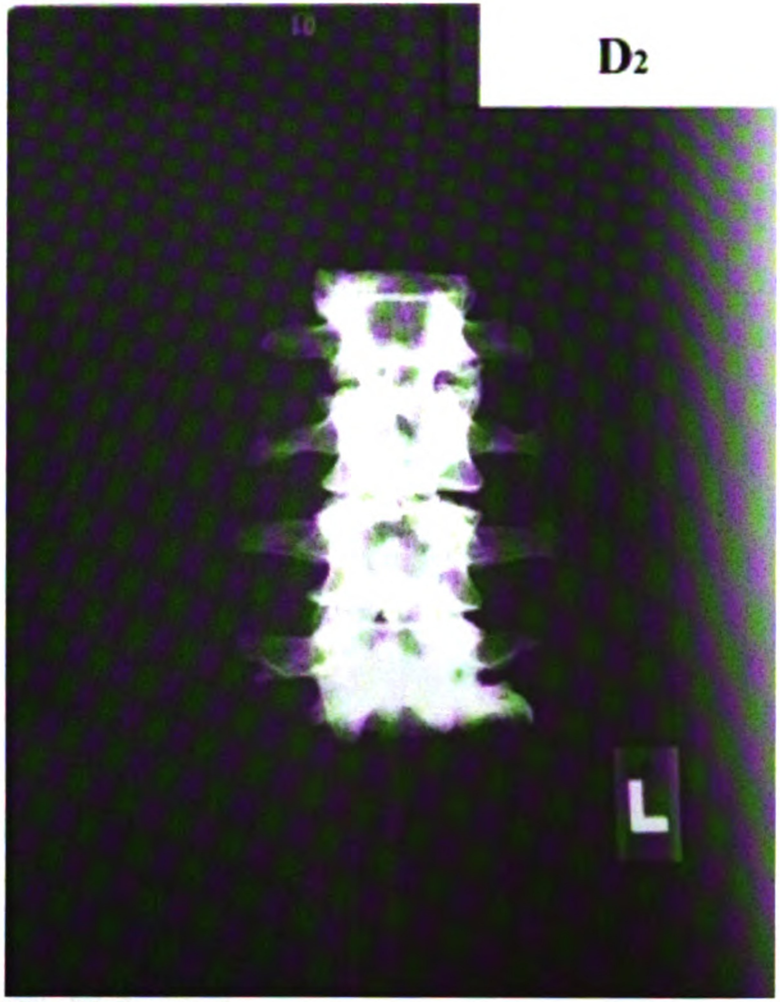


kVp 55 @ mAs 4
"Postmortem Match" for *Known 9*

Figure 33: Simulated Postmortem Images D1 and D2

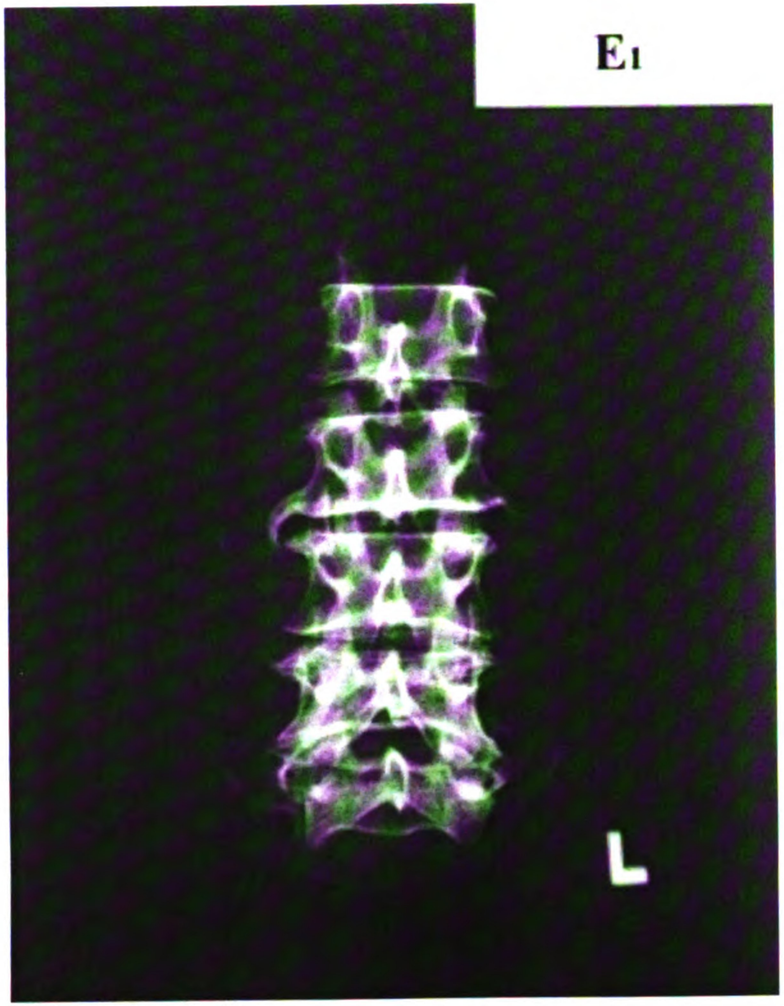


kVp 65 @ mAs 5
"Postmortem Match" for *Known 20*

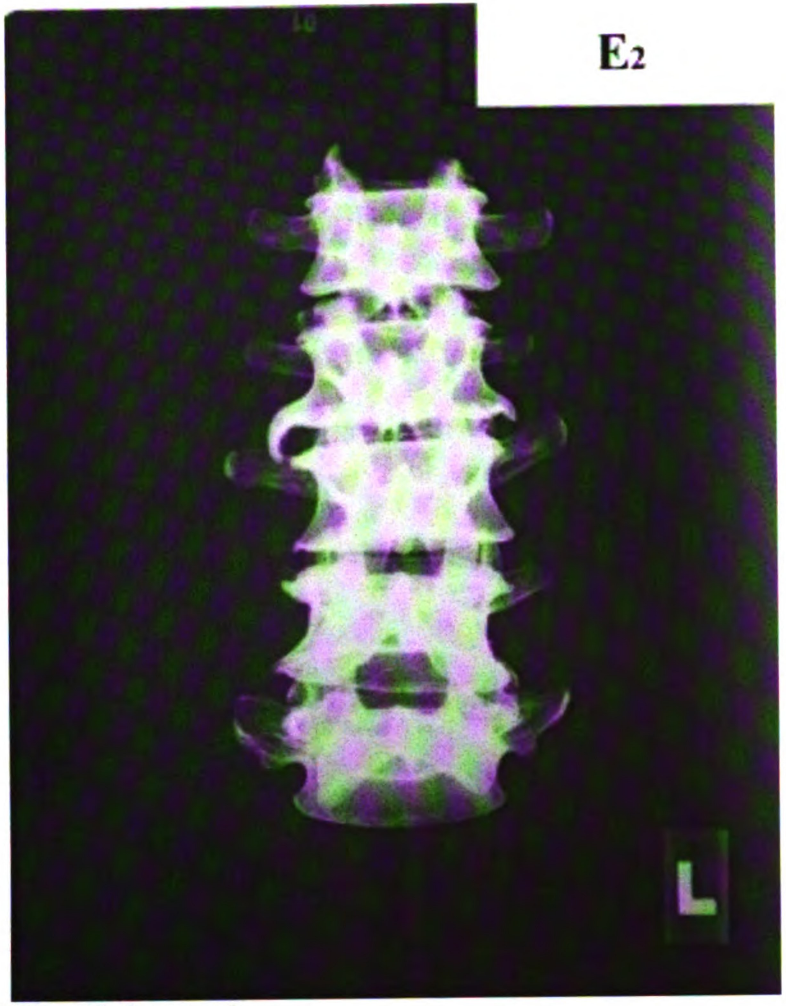


kVp 55 @ mAs 4
"Postmortem Match" for *Known 20*

Figure 34: Simulated Postmortem Images E1 and E2



kVp 65 @ mAs 5
"Postmortem Match" for *Known 3*



kVp 55 @ mAs 5
"Postmortem Match" for *Known 3*

APPENDIX D

Sample Data Sheets

Positive Identification through the Comparison of Abdominal X-rays, focusing on the Bony Features of the Lumbar Spine: A Validation Study

DATA SHEET PART 1 PERSONAL INFORMATION

Please circle the answer that best describes you, or fill in the blanks where it is appropriate.

1. What is the highest degree you hold? **a**. BA/BS **b**. MA/MS **c**. Ph.D.

2. Are you still a graduate student? **a**. Yes **b**. No
   - a. If yes, what is your expected degree? **a**. MA/MS **b**. Ph.D.
   - b. How many years have you been in graduate school? __________
   - c. Are you ABD? **a**. Yes **b**. No
   - d. Which of the following best describes the type of program in which you are enrolled?
     - **a**. Forensic Anthropology **b**. Biological Anthropology **c**. Human Biology
     - **d**. Physical Anthropology **e**. Bioarchaeology **f**. Other: ____________

3. How many years have you been practicing Forensic Anthropology? (*Please answer this question only if you have finished your graduate education and are working in the field*)
   a. 1-5 **b**. 6-10 **c**. 11-15 **d**. 16-20 **e**. greater than 20 years

4. Approximately how many cases have you worked on that involved comparing antemortem and postmortem radiographs?
   a. 0 **b**. 1-5 **c**. 6-10 **d**. 10-20 **e**. 20-30 **f**. greater than 30 cases

5. Were any of those comparisons made between radiographs of the spine? **a**. Yes **b**. No
   If yes, approximately how many? ________________

6. Do you work primarily: **a**. Within Academia **b**. Outside of Academia

7. Which characteristics do you generally tend to focus on when comparing radiographs of the human body?

____

____

____

Positive Identification through the Comparison of Abdominal X-rays, focusing on the Bony Features of the Lumbar Spine: A Validation Study

DATA SHEET PART 2 IDENTIFICATIONS

The postmortem radiograph marked "**A**" corresponds to antemortem radiograph #: _______

How many points of similarity did you identify? _______

Which specific anatomical features were most important to making this match?

____

____

____

The postmortem radiograph marked "**B**" corresponds to antemortem radiograph #: _______

How many points of similarity did you identify? _______

Which specific anatomical features were most important to making this match?

____

____

____

The postmortem radiograph marked "**C**" corresponds to antemortem radiograph #: _______

How many points of similarity did you identify? _______

Which specific anatomical features were most important to making this match?

____

____

____

The postmortem radiograph marked "**D**" corresponds to antemortem radiograph #: _______

How many points of similarity did you identify? _______

Which specific anatomical features were most important to making this match?

____

____

____

The postmortem radiograph marked "**E**" corresponds to antemortem radiograph #: _______

How many points of similarity did you identify? _______

Which specific anatomical features were most important to making this match?

____

____

____

Please feel free to list any additional comments in the space provided below or on the reverse side of this form.

APPENDIX E

Results from Contingency Tables

Table 5: Results from Contingency Tables

Independent Variable	Dependent Variable	Contingency Coefficient	Significance	Retain/Reject Null Hypothesis
Highest degree (Total Sample, n=25)	Score out of 5	.550	.369	Retain Null Hypothesis
	Score out of 4	.233	.838	Retain Null Hypothesis
	Error/Non-error (5)	.056	.962	Retain Null Hypothesis
	Error/Non-error (4)	.149	.753	Retain Null Hypothesis
	Number of features	.519	.231	Retain Null Hypothesis
Student/Professional (Total Sample, n=25)	Score out of 5	.496	.148	Retain Null Hypothesis
	Score out of 4	.155	.736	Retain Null Hypothesis
	Error/Non-error (5)	.100	.617	Retain Null Hypothesis
	Error/Non-error (4)	.021	.918	Retain Null Hypothesis
	Number of features	**.574**	**.013**	**Reject Null Hypothesis**
PhD/Not PhD (Total Sample, n=25)	Score out of 5	.435	.323	Retain Null Hypothesis
	Score out of 4	.226	.511	Retain Null Hypothesis
	Error/Non-error (5)	.017	.930	Retain Null Hypothesis
	Error/Non-error (4)	.137	.490	Retain Null Hypothesis
	Number of features	.400	.241	Retain Null Hypothesis
Number of radiograph cases (Total Sample, n=25)	Score out of 5	**.658**	**.039**	**Reject Null Hypothesis**
	Score out of 4	.292	.676	Retain Null Hypothesis
	Error/Non-error (5)	.270	.373	Retain Null Hypothesis
	Error/Non-error (4)	.246	.448	Retain Null Hypothesis
	Number of features	.492	.318	Retain Null Hypothesis
Any radiograph cases involving the spine (Total Sample, n=25)	Score out of 5	.455	.218	Retain Null Hypothesis
	Score out of 4	.265	.437	Retain Null Hypothesis
	Error/Non-error (5)	.154	.464	Retain Null Hypothesis
	Error/Non-error (4)	.252	.221	Retain Null Hypothesis
	Number of features	.334	.497	Retain Null Hypothesis
Number of radiograph cases involving the spine (Total Sample, n=25)	Score out of 5	.575	.331	Retain Null Hypothesis
	Score out of 4	.484	.135	Retain Null Hypothesis
	Error/Non-error (5)	.244	.483	Retain Null Hypothesis
	Error/Non-error (4)	.303	.313	Retain Null Hypothesis
	Number of features	.444	.556	Retain Null Hypothesis
Highest degree (Students, n=9)	Score out of 5	.302	.638	Retain Null Hypothesis
	Score out of 4	.302	.343	Retain Null Hypothesis
	Error/Non-error (5)	.302	.343	Retain Null Hypothesis
	Error/Non-error (4)	.302	.343	Retain Null Hypothesis
	Number of features	.302	.343	Retain Null Hypothesis
Years in graduate school (Students, n=9)	Score out of 5	.302	.638	Retain Null Hypothesis
	Score out of 4	.302	.343	Retain Null Hypothesis
	Error/Non-error (5)	.302	.343	Retain Null Hypothesis
	Error/Non-error (4)	.302	.343	Retain Null Hypothesis
	Number of features	.302	.343	Retain Null Hypothesis

Table 5: Results from Contingency Tables (Continued)

Independent Variable	Dependent Variable	Contingency Coefficient	Significance	Retain/Reject Null Hypothesis
Expected degree (Students, n=9)	Score out of 5	.302	.638	Retain Null Hypothesis
	Score out of 4	.302	.343	Retain Null Hypothesis
	Error/Non-error (5)	.302	.343	Retain Null Hypothesis
	Error/Non-error (4)	.302	.343	Retain Null Hypothesis
	Number of features	.302	.343	Retain Null Hypothesis
Type of program (Students, n=9)	Score out of 5	.447	.895	Retain Null Hypothesis
	Score out of 4	.243	.905	Retain Null Hypothesis
	Error/Non-error (5)	.243	.905	Retain Null Hypothesis
	Error/Non-error (4)	.243	.905	Retain Null Hypothesis
	Number of features	.500	.392	Retain Null Hypothesis
ABD/Not ABD (Students, n=9)	Score out of 5	.213	.827	Retain Null Hypothesis
	Score out of 4	.141	.686	Retain Null Hypothesis
	Error/Non-error (5)	.141	.686	Retain Null Hypothesis
	Error/Non-error (4)	.141	.686	Retain Null Hypothesis
	Number of features	.281	.408	Retain Null Hypothesis
Number of radiograph cases (Students, n=9)	Score out of 5	.555	.406	Retain Null Hypothesis
	Score out of 4	.447	.325	Retain Null Hypothesis
	Error/Non-error (5)	.447	.325	Retain Null Hypothesis
	Error/Non-error (4)	.447	.325	Retain Null Hypothesis
	Number of features	.500	.223	Retain Null Hypothesis
Any radiograph cases involving the spine (Students, n=9)	Score out of 5	.386	.455	Retain Null Hypothesis
	Score out of 4	.368	.236	Retain Null Hypothesis
	Error/Non-error (5)	.368	.236	Retain Null Hypothesis
	Error/Non-error (4)	.368	.236	Retain Null Hypothesis
	Number of features	.302	.439	Retain Null Hypothesis
Number of radiograph cases involving the spine (Students, n=9)	Score out of 5	.386	.455	Retain Null Hypothesis
	Score out of 4	.368	.236	Retain Null Hypothesis
	Error/Non-error (5)	.368	.236	Retain Null Hypothesis
	Error/Non-error (4)	.368	.236	Retain Null Hypothesis
	Number of features	.156	.635	Retain Null Hypothesis
Highest degree (Professionals, n=16)	Score out of 5	.511	.130	Retain Null Hypothesis
	Score out of 4	.302	.447	Retain Null Hypothesis
	Error/Non-error (5)	.177	.473	Retain Null Hypothesis
	Error/Non-error (4)	.290	.226	Retain Null Hypothesis
	Number of features	.452	.342	Retain Null Hypothesis
Years practicing professionally (Professionals, n=16)	Score out of 5	.608	.404	Retain Null Hypothesis
	Score out of 4	.453	.658	Retain Null Hypothesis
	Error/Non-error (5)	.368	.474	Retain Null Hypothesis
	Error/Non-error (4)	.414	.347	Retain Null Hypothesis
	Number of features	.592	.634	Retain Null Hypothesis

Table 5: Results from Contingency Tables (Continued)

Independent Variable	Dependent Variable	Contingency Coefficient	Significance	Retain/Reject Null Hypothesis
Work primarily within or outside of academia (Professionals, n=16)	Score out of 5	.463	.225	Retain Null Hypothesis
	Score out of 4	.245	.599	Retain Null Hypothesis
	Error/Non-error (5)	.092	.712	Retain Null Hypothesis
	Error/Non-error (4)	.213	.383	Retain Null Hypothesis
	Number of features	.407	.462	Retain Null Hypothesis
Number of radiograph cases (Professionals, n=16)	Score out of 5	**.586**	**.039**	**Reject Null Hypothesis**
	Score out of 4	.216	.676	Retain Null Hypothesis
	Error/Non-error (5)	.345	.142	Retain Null Hypothesis
	Error/Non-error (4)	.151	.541	Retain Null Hypothesis
	Number of features	.492	.318	Retain Null Hypothesis
Any radiograph cases involving the spine (Professionals, n=16)	Score out of 5	.511	.130	Retain Null Hypothesis
	Score out of 4	.302	.447	Retain Null Hypothesis
	Error/Non-error (5)	.177	.473	Retain Null Hypothesis
	Error/Non-error (4)	.290	.226	Retain Null Hypothesis
	Number of features	.334	.497	Retain Null Hypothesis
Number of radiograph cases involving the spine (Professionals, n=16)	Score out of 5	.602	.241	Retain Null Hypothesis
	Score out of 4	.469	.414	Retain Null Hypothesis
	Error/Non-error (5)	.316	.459	Retain Null Hypothesis
	Error/Non-error (4)	.316	.459	Retain Null Hypothesis
	Number of features	.444	.556	Retain Null Hypothesis

APPENDIX F

Results from Nonparametric Statistical Tests

Table 6: Results from Nonparametric Statistical Tests

Independent Variable	Dependent Variable	Significance Test	Significance	Retain/Reject Null Hypothesis
Highest degree (Total Sample, n=25)	Score out of 5	Kruskal-Wallis	.279	Retain Null Hypothesis
	Score out of 4	Kruskal-Wallis	.528	Retain Null Hypothesis
	Error/Non-error (5)	Mann-Whitney U	.871	Retain Null Hypothesis
	Error/Non-error (4)	Mann-Whitney U	.463	Retain Null Hypothesis
	Number of features	Kruskal-Wallis	.135	Retain Null Hypothesis
Student/Professional (Total Sample, n=25)	Score out of 5	Kruskal-Wallis	.166	Retain Null Hypothesis
	Score out of 4	Kruskal-Wallis	.746	Retain Null Hypothesis
	Error/Non-error (5)	Mann-Whitney U	.624	Retain Null Hypothesis
	Error/Non-error (4)	Mann-Whitney U	.920	Retain Null Hypothesis
	Number of features	**Kruskal-Wallis**	**.030**	**Reject Null Hypothesis**
Number of radiograph cases (Total Sample, n=25)	Score out of 5	Kruskal-Wallis	.195	Retain Null Hypothesis
	Score out of 4	Kruskal-Wallis	.432	Retain Null Hypothesis
	Error/Non-error (5)	Mann-Whitney U	.169	Retain Null Hypothesis
	Error/Non-error (4)	Mann-Whitney U	.301	Retain Null Hypothesis
	Number of features	Kruskal-Wallis	.220	Retain Null Hypothesis
Any radiograph cases involving the spine (Total Sample, n=25)	Score out of 5	Kruskal-Wallis	.246	Retain Null Hypothesis
	Score out of 4	Kruskal-Wallis	.261	Retain Null Hypothesis
	Error/Non-error (5)	Mann-Whitney U	.295	Retain Null Hypothesis
	Error/Non-error (4)	Mann-Whitney U	.119	Retain Null Hypothesis
	Number of features	Kruskal-Wallis	.495	Retain Null Hypothesis
Number of radiograph cases involving the spine (Total Sample, n=25)	Score out of 5	Kruskal-Wallis	.214	Retain Null Hypothesis
	Score out of 4	Kruskal-Wallis	.119	Retain Null Hypothesis
	Error/Non-error (5)	Mann-Whitney U	.246	Retain Null Hypothesis
	Error/Non-error (4)	Mann-Whitney U	.145	Retain Null Hypothesis
	Number of features	Kruskal-Wallis	.505	Retain Null Hypothesis

Table 6: Results from Nonparametric Statistical Tests (Continued)

Independent Variable	Dependent Variable	Significance Test	Significance	Retain/Reject Null Hypothesis
Highest degree (Students, n=9)	Score out of 5	Kruskal-Wallis	.670	Retain Null Hypothesis
	Score out of 4	Mann-Whitney U	.371	Retain Null Hypothesis
	Error/Non-error (5)	Mann-Whitney U	.371	Retain Null Hypothesis
	Error/Non-error (4)	Mann-Whitney U	.371	Retain Null Hypothesis
	Number of features	Mann-Whitney U	.371	Retain Null Hypothesis
Years in graduate school (Students, n=9)	Score out of 5	Kruskal-Wallis	.670	Retain Null Hypothesis
	Score out of 4	Mann-Whitney U	.371	Retain Null Hypothesis
	Error/Non-error (5)	Mann-Whitney U	.371	Retain Null Hypothesis
	Error/Non-error (4)	Mann-Whitney U	.371	Retain Null Hypothesis
	Number of features	Mann-Whitney U	.371	Retain Null Hypothesis
Expected degree (Students, n=9)	Score out of 5	Kruskal-Wallis	.670	Retain Null Hypothesis
	Score out of 4	Mann-Whitney U	.371	Retain Null Hypothesis
	Error/Non-error (5)	Mann-Whitney U	.371	Retain Null Hypothesis
	Error/Non-error (4)	Mann-Whitney U	.371	Retain Null Hypothesis
	Number of features	Kruskal-Wallis	.371	Retain Null Hypothesis
Type of program (Students, n=9)	Score out of 5	Kruskal-Wallis	.386	Retain Null Hypothesis
	Score out of 4	Mann-Whitney U	.490	Retain Null Hypothesis
	Error/Non-error (5)	Mann-Whitney U	.490	Retain Null Hypothesis
	Error/Non-error (4)	Mann-Whitney U	.490	Retain Null Hypothesis
	Number of features	Mann-Whitney U	.759	Retain Null Hypothesis
ABD/Not ABD (Students, n=9)	Score out of 5	Kruskal-Wallis	.846	Retain Null Hypothesis
	Score out of 4	Mann-Whitney U	.705	Retain Null Hypothesis
	Error/Non-error (5)	Mann-Whitney U	.705	Retain Null Hypothesis
	Error/Non-error (4)	Mann-Whitney U	.705	Retain Null Hypothesis
	Number of features	Mann-Whitney U	.439	Retain Null Hypothesis

Table 6: Results from Nonparametric Statistical Tests (Continued)

Independent Variable	Dependent Variable	Significance Test	Significance	Retain/Reject Null Hypothesis
Number of radiograph cases (Students, n=9)	Score out of 5	Kruskal-Wallis	.459	Retain Null Hypothesis
	Score out of 4	Mann-Whitney U	.221	Retain Null Hypothesis
	Error/Non-error (5)	Mann-Whitney U	.221	Retain Null Hypothesis
	Error/Non-error (4)	Mann-Whitney U	.221	Retain Null Hypothesis
	Number of features	Mann-Whitney U	.414	Retain Null Hypothesis
Any radiograph cases involving the spine (Students, n=9)	Score out of 5	Kruskal-Wallis	.497	Retain Null Hypothesis
	Score out of 4	Mann-Whitney U	.264	Retain Null Hypothesis
	Error/Non-error (5)	Mann-Whitney U	.264	Retain Null Hypothesis
	Error/Non-error (4)	Mann-Whitney U	.264	Retain Null Hypothesis
	Number of features	Mann-Whitney U	.655	Retain Null Hypothesis
Number of radiograph cases involving the spine (Students, n=9)	Score out of 5	Kruskal-Wallis	.497	Retain Null Hypothesis
	Score out of 4	Mann-Whitney U	.264	Retain Null Hypothesis
	Error/Non-error (5)	Mann-Whitney U	.264	Retain Null Hypothesis
	Error/Non-error (4)	Mann-Whitney U	.264	Retain Null Hypothesis
	Number of features	Mann-Whitney U	.655	Retain Null Hypothesis
Highest degree (Professionals, n=16)	Score out of 5	**Kruskal-Wallis**	**.030**	**Reject Null Hypothesis**
	Score out of 4	Kruskal-Wallis	.470	Retain Null Hypothesis
	Error/Non-error (5)	Mann-Whitney U	.487	Retain Null Hypothesis
	Error/Non-error (4)	Mann-Whitney U	.241	Retain Null Hypothesis
	Number of features	Kruskal-Wallis	.379	Retain Null Hypothesis
Years practicing professionally (Professionals, n=16)	Score out of 5	Kruskal-Wallis	.071	Retain Null Hypothesis
	Score out of 4	Kruskal-Wallis	.702	Retain Null Hypothesis
	Error/Non-error (5)	Mann-Whitney U	.297	Retain Null Hypothesis
	Error/Non-error (4)	Mann-Whitney U	.930	Retain Null Hypothesis
	Number of features	Kruskal-Wallis	.621	Retain Null Hypothesis

Table 6: Results from Nonparametric Statistical Tests (Continued)

Independent Variable	Dependent Variable	Significance Test	Significance	Retain/Reject Null Hypothesis
Work primarily within or outside of academia (Professionals, n=16)	Score out of 5	Kruskal-Wallis	.252	Retain Null Hypothesis
	Score out of 4	Kruskal-Wallis	.618	Retain Null Hypothesis
	Error/Non-error (5)	Mann-Whitney U	.720	Retain Null Hypothesis
	Error/Non-error (4)	Mann-Whitney U	.398	Retain Null Hypothesis
	Number of features	Kruskal-Wallis	.498	Retain Null Hypothesis
Number of radiograph cases (Professionals, n=16)	Score out of 5	**Kruskal-Wallis**	**.049**	**Reject Null Hypothesis**
	Score out of 4	Kruskal-Wallis	.693	Retain Null Hypothesis
	Error/Non-error (5)	Mann-Whitney U	.155	Retain Null Hypothesis
	Error/Non-error (4)	Mann-Whitney U	.554	Retain Null Hypothesis
	Number of features	Kruskal-Wallis	.688	Retain Null Hypothesis
Any radiograph cases involving the spine (Professionals, n=16)	Score out of 5	Kruskal-Wallis	.151	Retain Null Hypothesis
	Score out of 4	Kruskal-Wallis	.470	Retain Null Hypothesis
	Error/Non-error (5)	Mann-Whitney U	.487	Retain Null Hypothesis
	Error/Non-error (4)	Mann-Whitney U	.241	Retain Null Hypothesis
	Number of features	Kruskal-Wallis	.578	Retain Null Hypothesis
Number of radiograph cases involving the spine (Professionals, n=16)	Score out of 5	Kruskal-Wallis	.168	Retain Null Hypothesis
	Score out of 4	Kruskal-Wallis	.233	Retain Null Hypothesis
	Error/Non-error (5)	Mann-Whitney U	.271	Retain Null Hypothesis
	Error/Non-error (4)	Mann-Whitney U	.234	Retain Null Hypothesis
	Number of features	Kruskal-Wallis	.644	Retain Null Hypothesis

APPENDIX G

Participant Answers to Data Sheet Questions

Table 7: Participant Answers to Data Sheet Questions

Subject	ID1	ID2	ID3	ID4	ID5	Question 7	Final Question
1	Spinous processes, transverse processes, centra	Spinous processes, centra, articular facets	Spinous processes, outline of centra, spinous processes	Unique spinous processes of L5, spinous processes, centra outlines	Osteophytic lipping on L2, spinous processes, articular facets, centra	Spinous processes, pedicles, transverse processes, trabeculae, outline of centra	No answer
2	Shape of spinous processes on L5, L4, L2; shape of body L3	Shape/angle of spinous process L5; shape of body L4 and spinous process, inferior margin; shape of body L3	L3 lipping on body; radiopacity on L1 and L2; shape of body L2; shpae of body L1	Spinous process L1; spinous process L2; shape of body L3; lipping L3	Lipping on L2; shape of spinous process L5, shape of spinous process L4, shpae of body L4; shape of spinous process L3	Shape, angles	No answer
3	Shape of lumbar bodies (especially L3 and L4); shpae of spinous processes especially L4); shape of transverse process of L5 (has a distinct shape on the left side)	Shape of lumbar bodies (especially L2-L4); osteophytic lipping of L2-L5; spinous processes (especially L5); transverse proceses of L5; pedicles of L3 and L4 on right side.	Morphology of bodies (especially L3 and L4); morphology of spinous processes (especially L4 and L5); osteophytic lipping on L3; trabecular bone structure of right spinous of L3	Morphology of body of L2; spinous processes; pedicles (especially L3)	Osteophytic lipping (especially L2-L4)—L2 has very distinct osteophytes; shape of spinous processes (especially L1) and pedicles (especially L2); morphology of bodies (especially L3)	Bony morphology of trabeculaer structure and any unique structures, fractures, etc. Within the vertebrae: shape of centrum, spinous processes, transverse processes.	Letter D most difficult to identify

Table 7: Participant Answers to Data Sheet Questions (Continued)

Subject	ID1	ID2	ID3	ID4	ID5	Question 7	Final Question
4	All 5 verts lined up well in this comparison. 1. L1 transverse process shape; 2. L2 left shape on lateral mass; 3. L2 density of left lower body on outturned point (osteophytes); 4. L3 downward slope of both right and left SAP lateral margins; 5. body shape outline L3; 6. L3 density of inferior proximal left transverse process; 7. L4 density of top half of body; 8. L4 body shape outline; 9. L4 upper left dense projection; 10. L5 transverse process outline and small lines of density	1. the osteophytes on left L4 superior—curves up; 2. L4-L5 on left remodeled osteophytes into "lip" configuration; 3. L3 superior left border very dense with osteophytes shelf; 4. spinous process outline L3-L5 strong; 5. L3 upper right corner small focal dense area; 6. body shape outline and transverse process morphology is similar L3 (right), L1 (left and right); 7. L2 has a bell shape to left side of the body (could call it shouldering)	Flat surface of left side of L4 and less so on L 3 was used to screen Antemortem—L1 not visualized well and not used (underexposed) L500large facet superior right, dense lines on body, also 3 separate, individual dense lines on transverse processes (left and right) L4—left wall of body is flat—I looked for this first L3—as L4 the area extending across upper body forms a pattern that matches; v-shaped density inferior side of right transverse process *includes pictures that I could not type here*	Bifurcation on right transverse process of L5 (or L4 since there are only 4) body outline shapes of L4 and L3 (or L2/L3)	Large osteophytes on L2 (right) that hangs inferiorly and curves into L3. This was the most distinctive feature. Transverse processes were not visible in underexposed AM radiograph. L4/L5 articular facet area of overlap on right, loose heart shape with dense dot at bottom on right (opposite side) a large dense area at bottom	Any anomalies if present. In verts—transverse processes, body margins and spacing, 1st rib costal articular ossifications, lower c-spine spinous process outline, small trabeculae in hands, frontal sinuses in heads. Areas of density and lack of density—these make patterns that line up if the angle is the same.	The exposure on film #5 is so bad, I would not use it (ordinarily)

Table 7: Participant Answers to Data Sheet Questions (Continued)

Subject	ID1	ID2	ID3	ID4	ID5	Question 7	Final Question
5	Facet shape; contour of vertebral bodies; shape of transverse processes; shpae of spinous processes	Osteophyte development; shape of transverse processes; facet shape; contour of vertebral bodies	Osteophytes on superior and inferior endplates of L3; contour of vertebral bodies	Contour of body; transverse processes	Osteophytic development; shape of spinous processes; facet shape	Frontal sinus, dentition—primarily features in cranium and mandible.	"D" was difficult…I never would have called D/20 and ID.
6	Transverse processes (especially L5 left, L3 right, L1 left and right); curvature of lateral borders; areas of radiodensity (especially along superior and inferior borders); spinous processes	Especially superior left osteohpyte on L4 (with line of radiodensity). Also transverse processes (L5 left and right, L1 right, L3 right); radiodensity along superior and inferior borders of L3 and L4	L4's truncated transverse processes; areas of radiodensity along superior and lateral borders of L3 (especially right superior corner)	L1 right transverse process; superior and inferior borders of L3 and L4; radiotranslucency between L3 and L4	Spinous processes; radiodense superior and inferior borders; osteophytes	Clavicle morphology	Thanks and good luck!
7	Body margin L2 and L3; spinous process morphology L5; transverse process morphology L1, L2, L3	Lipping on L3 and L4; Body margin L2, L3, L4; transverse process morphology L1, L3, L5; spinous process morphology L1 through L5	Body margins L3 and L4; Transverse prcess L2, L3, L5; spinous process L2 through L4	Body margin L2 and L3; Transverse process L4 and L5; spinous process L5	Body margin L2 through L4; Lipping on L2; spinous process L1 through L5	Margins of cortical bone; Trabecular bone pattern	Used spinous process morphology to do initial sorting of AM radiographs

Table 7: Participant Answers to Data Sheet Questions (Continued)

Subject	ID1	ID2	ID3	ID4	ID5	Question 7	Final Question
8	Processus spinosus on all lumbar vertebrae; Processus tansversus on L1 and L5; Concavity on vertebral bodies	Processus spinosus; processus transverses on L1 and L5; Concavity on vertebral bodies; osteopohytes on e.g. L5, L4	Processus transverses on L3, L5; especially small part on L3 right side; superior border on left side of L3 body	Processus transverses, processus spinosus	Osteophytes and lipping	No answer	No answer
9	Spinous processes, shape of vertebral body L3-L2, pedicles of L4-L3	Spinous processes, shape of vertebral bodies, osteophytic lipping, pedicles, transverse processes	L3 body lucency and trabeculae, L3 lipping, pedicles, L4 trabeculae, spinous processes	Spinous processes, shape of vertebral bodies, pedicle L2, osteophytic lipping L1	Osteophytic lipping, pedicles, spinous processes, outline of vertebral body, outline of neural arch L5	Spinous processes, pedicles	No answer
10	Spinous processes, pedicles, contour of margins	Spinous processes, pedicles, contour of margins, lipping	Margins, spinous processes, pedicles	Lipping, pedicles, margins, contour of transverse processes	Spinous processes, pedicles, contour of margins, lipping	For non-dentals: spinous processes, pedicles, trabecular patterns, bony contours and margins, relationship of bones to one another	No answer
11	Transverse processes of L5, osteophytes of L2, spinous processes of L4	Osteophytes of L3 and L4; transverse processes of L5; spinous processes of L3, L4 and L5	Osteophytes of L3 and L4	I was unable to confidently match this radiograph to any others	Osteophytes of L2 and L3; superior articular process of L1	Both general bone shape/morphology and trabecular patterns	No answer

Table 7: Participant Answers to Data Sheet Questions (Continued)

Subject	ID1	ID2	ID3	ID4	ID5	Question 7	Final Question
12	Everything. Cross section shape; posterior spines; shape transverse processes; shape pedicles; shape/contour vertebral body (right side-left side), osteophytes (presence, absence, shape); shape body "corners," lines or areas increased density or decreased density	Same as above—everything visible.	Same as above—everything visible.	Probable—Cannot Exclude. Transverse processes of L5 are distincitive. However many other "points" are not as clear as I would like them to be for a "positive" ID—so I would not exclude and try for more antemortem films.	Same as A, B, C—in addition: L2 lower left "corner" has distinctive large osteophytes. All other points must "match" however, as these do. One point is not enough.	Depends on what I have to look at. Contours (external and internal), internal buttressing, foramina, density/lack of density, cross sections posterior spines, shapes and contours. Everything	The number of points of similarity depends entirely on HOW you count them—i.e. the left side of the vertebral body in its totality as "L." Or count the contour, shape, density of upper and lower left "corners" as well as body side shape which would = "3."
13	Body (lat) contours, spine cross-sections, pedicle cross-sections	Body (lat) contours, spine cross-sections, pedicle cross-sections	Body (lat) contours	*Not Positive, Cannot be excluded* Body (lat) contours, spine cross-sections	Body (lat) contours—expecially osteophytes, spine cross-sections	Everything—contours (outline), internal structure (density, etc.), pathology	Depends on definition of points "Antemortem" #2, #19 appear to be the same individual

Table 7: Participant Answers to Data Sheet Questions (Continued)

Subject	ID1	ID2	ID3	ID4	ID5	Question 7	Final Question
14	Shape of spinous processes on L1-L5, inferior shape of arch outline on L4, L3 articular facets on right side, lipping on L3 (left and right sides), L4 right side body shape	L2-5 spinous process outlines (and some microstructure), left transverse process on L5=general outline w/ dip on caudal surface, L4=lippoin g on superior body, L4 shape of vertebral body, L4=shape of aticular facet	L5-left transverse process general outline and microstructure, L4-spinous process outline, very short transverse processes, L3-very slight lipping, articular process outline on left, L2-outline of articualr facets, vertebral body and transverse process	There are some similarities, but the angle is not quite the same on ante- and postmortem. D-bifurcated right transverse process on the right side (may also be on #20, but not great exposure)	Spinous process shape, patterns oflipping particularly right side of L2, L4 caudal outline under spinous process, outlines of articular facets	General outlines, microstructure (if it can be seen), idiosyncratic/unique characters, pathology, etc.	#19 and #2 (great one!) I would not feel comfortable making a positive ID on "D"

Table 7: Participant Answers to Data Sheet Questions (Continued)

Subject	ID1	ID2	ID3	ID4	ID5	Question 7	Final Question
15	Transverse process contour and angle, (entire) centra margins	Transverse process contour and angle, (entire) centra margins, and osteophytes	Transverse process contour and angle, (entire) centra margins, and osteophytes	Transverse process contour and angle, (entire) centra margins, and osteophytes	Transverse process contour and angle, (entire) centra margins, and osteophytes	Important is the alignment of all surface contours/outlines. Attention has to be paid to angle as they (between ante and post) WILL NOT be identical. That is, a main caveat when making conclusions--so rotating between films is critical. Hence, a solid knowledge of lumbar anatomy is critical. Two other things to consider are shrinkage of the intervertebral disc in the postmortem specimen from drying, distance differences from the core. Yet, slight tilting, as mentioned above, is the greatest attribute. Lucencies cannot be compared,	ONLY in conjunction when all else is matching. Then one MIGHT rely on spinous process densities. Positive identifications from lumbar morphology must rely on a suite of congruent structures and not a SINGLE transverse process contour or centra margin. The most important guide to remember for the forensic anthropolgist is that radiographs are a RECORD OF DENSITY. Postmortem specimens lack some of the paravertebral soft tissue calcifications and … that may well occlude surface detail. CANNOT rely on trabeculation.

Table 7: Participant Answers to Data Sheet Questions (Continued)

Subject	ID1	ID2	ID3	ID4	ID5	Question 7	Final Question
16	Spinous processes of L1-L5; Left transverse process of L1, Body contours of L2-L4	Spinous process of L5; superior and inferior borders of L5 neural arch; osteophytic "beaking" of superior left body; body contours of L1-L5; transverse process contours of L1 *I would not a positive ID based on film #10, however	(not 100% confident) Left transverse process of L5; body contours L2-L4; trabecular patterning and contours of left transverse process of L5	None—could not find a match	None—could not find a match	1. Anomalies, 2. Pathologies, 3. Past medical intervention, 4. Bone contours, 5. Healed/partially healed trauma/unhealed trauma, 6. Non-biological defects, e.g. foreign bodies	Film # 5: staples visible, L lower torhacics and R upper lumbar 2&19: same individual; note incomplete fusion of L5 spinous process 17: fusion (of long standing) of L4 and L5 (block vertebrae) 18: three wires in T12 (right side); one wire in T11-T12 space
17	Centrum size and shape mostly. Would not make this a positive ID without additional study.	Centrum size and morphology. Close to positive ID.	Centrum size and shape, density details.	Radiograph has anatomical similarity to #s 4, 3, 6, and 20. #8 cannot be excluded due to poor visibility of structures.	The large osteophyte, size and shape of centra; although there are points of similarity, I would not call this a positive ID without additional study.	Those which can be clearly seen ad those that are known to be highly variable.	No answer.

Table 7: Participant Answers to Data Sheet Questions (Continued)

Subject	ID1	ID2	ID3	ID4	ID5	Question 7	Final Question
18	Shape of spinous processes throughout lumbar spine and several of the transverse processes, particularly the 5th left	Osteophytic activity on the bodies of the 3rd and 4th lumbar verts, spinous process shape and radiopacity throughout	Arthritic activity in 3rd lumbar vert, spinous process shape throughout	Arthritic development/degeneration throughout column, spinous process shape	Beaking on second inferior right margin, spinous process shape and radiopacity throughout column	Frontal sinus, dental radiographs	No answer
19	Transverse processes L5; spinous processes (all)	Transverse processes L5; Body L4 and L3; spinous processes L5 and L4	Body L4; Left transverse process L5	Unable to determine enough points of similarity to match antemortem and postmortem radiographs	Arthritic lipping L2; spinous processes; superior articular facets	N/A	No answer
20	Spinous processes of L1, L2, L4; left transverse process of L1; right transverse process of L5, L1; left superior edge of L4 vertebral body is much further out than inferior edge of L3	Left superior border of L4 (hook shape); spinous processes of L3-L5; transverse processes of L3 (right) and L5 (right and left, especially right)	Spinous processes L2, L4, L5; lamina of L5 (very thin posteriorly); shape and size of right and left transverse processes of L5	General shape of spinous processes; right transverse processes of L2, L4, L5; general size and shpae of bodies	Large hook on right inferior body of L2; general size of all verts; shape of both superior articular facets of L2; shape of spinous processes on L1, L2, L4 and L5	None. I have not compared radiographs before. But I have observed professors and other graduate students focusing on the shape and size of the spinous processes when examining radiographs of the spine.	Known #2 and #19 are the same individual D was the most difficult to match. Even now I am not thrilled with the match but I felt that it was the best available. C took a while to decide as well but I am not quite happy with that match.

Table 7: Participant Answers to Data Sheet Questions (Continued)

Subject	ID1	ID2	ID3	ID4	ID5	Question 7	Final Question
21	I used similar and different features. Size and shape of L5 transverse process and trabeculae; spinous process size and shape (primarily); all transverse process shapes; unusual shape right pedicle in L3; density L2 centrum corner	Transverse processes (size/shape) matched; spinous processes; L4 osteophyte superior (left) centrum; L3 osteophyte superior (left) centrum; L2 small osteophytes superior (left) centrum; L3 osteophyte inferior (left) centrum	Spinous processes (size/shape); L5 left/right transverse processes; L3 lucencies left side centrum; L3 osteophyte superior (left) centrum; L1 triangulr shaped spinous process	L2 narrowed centrum (illustration showing side-side narrowing; pinched appearance); indentation along lower inferior border of L3; L5 left transverse process; L5 right transverse process; downward sloping (right side) transverse process L3	All spinous processes; pedicles same size and shape; osteophytes on L2 and L3; osteophytes (right) on superior centrum; L4 shape of inferior arch	Size and shape comparisons—I use the external features and internal (densities, lucencies, trabecualer pattern) where possible. I tend to look for unusual or unique features.	I relied most heavily on the "1" series (e.g. A1)—not sure you needed the "2" series; I used tehm only a few times. I think it's a useful study, but a few of the films were poor quality and difficult to find landmarks such as L5 or T12. All in all good. Took me 3 1/2 hours to complete. But thanks!!
22	L1, 3, 5-transverse processes; L1, 2, 3, 4 spinous processes; L1, 2, 3, 4 body morphology (lateral margins)	L1, 3, 5 transverse processes; L3, 4, 5 spinous processes; L 2, 3, 4 body morphology (inferior margins); radiolucencies; syndesmophytes	L2, 3, 5 transverse processes; L3 body radiolucencies; syndesmophytes	4 verts (L2-L5); L3 right mamillary process; L 3, 4, 5 transverse processes; L2, 3, 4 body morphology (lateral), L2 (inferior margin); radiolucencies	L1-5 spinous processes; L1-4 body morphology; trabecular patterns; syndesmophytes	Any and all osseous/dental features; surgical and dental implants; medical intervention	Films #5, 7, 8, 9, and 13 are suboptimal and would be of no comparative value here. I was able to exclude many films, and given that y assumption is that each of the 5 "postmortem" films has a numbered match, some of my conclusions are made more easily due to this. D-20 was most difficult. Thanks for the challenge.

Table 7: Participant Answers to Data Sheet Questions (Continued)

Subject	ID1	ID2	ID3	ID4	ID5	Question 7	Final Question
23	Generically, the shape and densities of the spinous processes, body, pedicles, and transverse processes	As above for "A" but in addition: shpae of inferior/superior border of lamina, and osteophytes on left side of L3 and L4	As for "A," but in addition: osteophytes on right side of L3 and L4. Especially telling in this case weret he L5 transverse processes and pedicle outlines of L1-L4.	As above for "A," but in addition: distinctive morphology of transverse processes of most inferior vertebra on postmortem film (probably L5), and lipping of L3/L4 bodies at right, inferior aspects. In addition: the translucency visible on the left transverse process of L3.	As above for "A,' but in addition: shpae of lamina borders, large osteophytes on inferior aspects of L2 body and lipping at right lateral aspects of L3 and L4 bodies.	I try to use all, or as many characters as possible. Those available typically depend on the case. None are therefore focused on, but several may be used in an opportunistic fashion. Generically, bone shape and densities (=structure) are used. What anatomical regions of the bone to be used depend on which bone is the subject of the investigation and what antemortem x-ray views are available.	"Points of Similarity": I am not sure what you are referring to here as a "point." Morphological similarities have numerous levels at which they can be described. For example, similar appearance ofa transverse process could be described as one point or broken down into details (many points that could be almost indefinitely numbered depending on the definition), i.e. similarity of border regions, similarity of trabecular patterns or even single trabecule, etc.

Table 7: Participant Answers to Data Sheet Questions (Continued)

Subject	ID1	ID2	ID3	ID4	ID5	Question 7	Final Question
24	L5 transverse processes, spinous processes, outline of vertebral bodies especially L3, superior/inferior articualr processes/facets	Spinous processes, outline of ertebral bodies expecially L4, superior/inferior articular processes (facets)	(most difficult due to poor antemortem quality) *Unique "rolled" look to sujperior edge of L3, body outlines especially osteophytic development, spinous processes, superior edges of vertebral bodies	Unique transverse process (bifid), articulations between vertebrae, spinous processes	Osteophytic activity, outlies of vertebral bodies, spinous processes especially L5, superior/inferior articular facets	Unique trabeculation, unusual morphology, spinous processes, sinuses, overall shapes of bone or features if unique or unusual	I looked for unique features in each postmortem and then hunted through antemortem for match. Afterwards I looked for a minimum of 10 correspondences between ante-and post. Radiograph #8 is really unusable due to poor quality. Might be interesting to know how long each participant took to make matches.
25	I looked at the shape of the lateral margins of the vert bodies and areas of radiopaciites on the transverse processes. I also looked at the shape of the upper articular facets.	Again, I looked at the shape of the lateral margins of the vert bodies and the superior and inferior margins to the vert bodies. I also used the shape/outline of the spinous process. Areas of radiotranslucency and radiopacity was not helpful (slightly different angle).	I looked specifically at the outline of the vert body and shape of the lateral edges. I also looked at shape of visible transverse processes and areas of radiotranslucency.	I looked particularly at the shape of the transverse processes—especiallt the 4/5 lumbar vert. I also looked at the lateral borders of the vert bodies of the upper 2 verts. (This one was slightly difficult ☺).	I looked at the osteophytic development, particularly on the 2nd lumbar vert. I also looked at the shape of the spinous process outlines and the intervertebral space between the 4th and 5th lumbar vert.	Trabecular bone patterns, areas of radiotranslucenc y/radiopaque, outlines/shapes of bony features, evidence for pathologies/path ological changes to the bone.	No answer.

APPENDIX H

Features Cited by Participants when Making Matches between Radiographs

Table 8: Features Cited by Participants when Making Matches between Radiographs

ID #1—*Unknown A/Known 14*

Feature	General	L1	L2	L3	L4	L5
Spinous Processes	1, 18, 19, 21, 23, 24, 3, 5, 6, 8, 9, 10, 12, 11	20, 22, 14, 16	2, 22, 14, 16	22, 14, 16	2, 20, 22, 3, 14, 11, 16	2, 21, 7, 14, 16
Transverse Processes	1, 21, 23, 5, 6, 12, 15	20 (L/R), 22, 4, 6 (L/R), 7, 8	7	22, 6(R), 7	No one used L4 specifically	18(L), 20(R), 21, 22, 24, 3, 4, 6(L), 8, 11
Centrum (contour, shape)	1, 23, 24, 3, 5, 6, 8, 10, 12, 11, 15, 17, 25	22	22, 7, 9, 16	2, 3, 22, 24, 7, 9, 16	20, 22, 3, 4, 14, 16	No one used L5 specifically
Trabeculae	No one cited Trabeculae generally	No one used L1 specifically	No one used L2 specifically	No one used L3 specifically	No one used L4 specifically	21, 4 (TP)
Pedicles	23, 10, 12, 11	No one used L1 specifically	No one used L2 specifically	21, 9	9	No one used L5 specifically
Radiodensities	25	No one used L1 specifically	Centrum: 21, 4, 6, 12	TP(L): 4	4	No one used L5 specifically
Radiolucencies	12, 25	No one used L1 specifically	No one used L2 specifically	No one used L3 specifically	No one used L4 specifically	No one used L5 specifically
SAP's/IAP's	24, 5, 14, 25	No one used L1 specifically	No one used L2 specifically	4	No one used L4 specifically	No one used L5 specifically
Osteophytes (development/ lipping)	12	No one used L1 specifically	11	14	No one used L4 specifically	No one used L5 specifically
Neural Arch Contour	No one cited Neural Arches generally	No one used L1 specifically	No one used L2 specifically	14	14	No one used L5 specifically

Table 8: Features Cited by Participants when Making Matches between Radiographs (Continued)

ID #2—*Unknown B/Known 10*

Feature	General	L1	L2	L3	L4	L5
Spinous Processes	1, 18, 19, 23, 24, 3, 8, 9, 10, 12, 13, 15, 25	7	7, 14	20, 22, 4, 7, 14, 11	2, 19, 20, 22, 4, 7, 14, 11	2, 19, 20, 22, 3, 4, 7, 14, 11, 16
Transverse Processes	21, 23, 5, 9, 12, 15	22, 4, 6, 7, 8, 16	No one used L2 specifically	20, 22, 4, 6, 7	No one used L4 specifically	19, 20, 22, 6, 7, 8, 14, 11
Centrum (contour, shape)	1, 23, 24, 4, 5, 9, 10, 12, 13, 15, 17, 25	16	22, 3, 4, 7, 16	2, 19, 22, 3, 7, 16	2, 19, 20, 22, 24, 3, 7, 14, 16	16
Trabeculae	14	No one used L1 specifically	No one used L2 specifically	No one used L3 specifically	No one used L4 specifically	No one used L5 specifically
Pedicles	23, 9, 10, 12, 13	No one used L1 specifically	No one used L2 specifically	No one used L3 specifically	No one used L4 specifically	No one used L5 specifically
Radiodensities	18, 23, 12	No one used L1 specifically	No one used L2 specifically	4, 6	6	No one used L5 specifically
Radiolucencies	22, 12	No one used L1 specifically	No one used L2 specifically	No one used L3 specifically	No one used L4 specifically	No one used L5 specifically
SAP's/IAP's	1, 24, 5	No one used L1 specifically	No one used L2 specifically	No one used L3 specifically	14	No one used L5 specifically
Osteophytes (development/ lipping)	5, 9, 10, 12, 15	No one used L1 specifically	21, 3	18, 21, 23, 3, 7, 11	18, 21, 23, 3, 4, 6, 7, 8, 11	4, 8, 16
Neural Arch Contour	No one cited Neural Arches generally	No one used L1 specifically	No one used L2 specifically	No one used L3 specifically	No one used L4 specifically	16
Syndesmophytes	22	No one used L1 specifically	No one used L2 specifically	No one used L3 specifically	No one used L4 specifically	No one used L5 specifically
Lamina	No one cited Lamina generally	No one used L1 specifically	No one used L2 specifically	23	23	No one used L5 specifically

Notes:

Participant #16 answered correctly, but indicated that he/she is uncertain of the match

Participant #25 noted that radiotranslucency and radiopacity were not useful because of a slightly different angle between the radiographs

Table 8: Features Cited by Participants when Making Matches between Radiographs (Continued)

ID #3—*Unknown C/Known 9*

Feature	General	L1	L2	L3	L4	L5
Spinous Processes	1, 18, 21, 23, 24, 3, 9, 10, 12	21	20, 7	7	20, 3, 7, 14	20, 3
Transverse Processes	23, 12, 14, 25	6	22, 7	22, 7, 8	6	19, 20, 21, 22, 23, 7, 8, 14, 13, 16, 15
Centrum (contour, shape)	1, 23, 24, 3, 5, 10, 12, 14, 13, 15, 17, 25	2	2, 16	24, 3, 7, 8, 16	19, 3, 4, 7, 16	No one used L5 specifically
Trabeculae	No one cited Trabecula e generally	No one used L1 specifically	No one used L2 specifically	SP: 3	9	TP: 14, 16
Pedicles	23, 10, 12	23	23, 9	23, 9	23	No one used L5 specifically
Radiodensities	No one cited Radiodens ities generally	2	2	4, 6, 9	No one used L4 specifically	4
Radiolucencies	25	No one used L1 specifically	No one used L2 specifically	21, 22, 9	No one used L4 specifically	No one used L5 specifically
SAP's/IAP's	No one cited SAP's/IA P's generally	No one used L1 specifically	14	14	No one used L4 specifically	4
Osteophytes (development/ lipping)	24, 12, 15	No one used L1 specifically	No one used L2 specifically	2, 18, 21, 23, 24, 3, 5, 9, 14, 11	23, 11	No one used L5 specifically
Neural Arch Contour	No one cited Neural Arches generally	No one used L1 specifically	No one used L2 specifically	No one used L3 specifically	No one used L4 specifically	No one used L5 specifically
Lamina	No one cited Lamina generally	No one used L1 specifically	No one used L2 specifically	No one used L3 specifically	No one used L4 specifically	20
Syndesmophytes	22	No one used L1 specifically	No one used L2 specifically	No one used L3 specifically	No one used L4 specifically	No one used L5 specifically

Notes:
Participant #2 answered incorrectly (misidentification)
Participant #16 made a correct match, but noted that he/she is, "not 100% confident with the match"
Participant #24 noted poor quality of the simulated antemortem image

Table 8: Features Cited by Participants when Making Matches between Radiographs (Continued)

ID #4—*Unknown D/Known 20*

Feature	General	L1	L2	L3	L4	L5
Spinous Processes	1, 18, 20, 23, 24, 3, 8, 9, 13	2	2	No one used L3 specifically	No one used L4 specifically	1, 7
Transverse Processes	23, 5, 8, 10, 15, 25	6	20	21, 22, 6	22, 6, 7, 25	20, 21, 22, 23, 24, 4, 7, 12, 14, 25
Centrum (contour, shape)	1, 20, 23, 5, 9, 10, 13, 15	25	21, 22, 3, 7, 25	2, 21, 22, 7	22	No one used L5 specifically
Trabeculae	No one cited Trabeculae generally	No one used L1 specifically	No one used L2 specifically	No one used L3 specifically	No one used L4 specifically	No one used L5 specifically
Pedicles	23, 3, 10	No one used L1 specifically	9	3	No one used L4 specifically	No one used L5 specifically
Radiodensities	23	No one used L1 specifically	No one used L2 specifically	No one used L3 specifically	No one used L4 specifically	No one used L5 specifically
Radiolucencies	22	No one used L1 specifically	22, 23	6	6	No one used L5 specifically
SAP's/IAP's	24	No one used L1 specifically	No one used L2 specifically	No one used L3 specifically	No one used L4 specifically	No one used L5 specifically
Osteophytes (development/ lipping)	18, 10, 15	9	No one used L2 specifically	2, 23	23	No one used L5 specifically
Neural Arch Contour	No one cited Neural Arches generally	No one used L1 specifically	No one used L2 specifically	No one used L3 specifically	No one used L4 specifically	No one used L5 specifically
Mamillary Process	No one cited Mamillary Processes generally	No one used L1 specifically	No one used L2 specifically	22	No one used L4 specifically	No one used L5 specifically
Number of Vertebrae	22, 23, 4	No one used L1 specifically	No one used L2 specifically	No one used L3 specifically	No one used L4 specifically	No one used L5 specifically

Notes:
Participant #2 answered incorrectly (misidentification)
Participant #6 answered incorrectly (misidentification)
Participant #11 chose not to make a match for *Unknown D*
Participant #12 believes that his/her correct answer is probably correct, cannot exclude, but would need more points—he/she only used the transverse processes of L5 to make the match
Participant #13 answered correctly, but indicated that he/she is not positive about the ID
Participant #14 noted that the angles of the radiographs were not quite the same
Participant #16 chose not to make a match for *Unknown D*
Participant #17 chose not to make a match for *Unknown D*
Participant #18 answered incorrectly (misidentification)
Participant #19 chose not to make a match for *Unknown D*, indicating that there were not enough points of similarity

Table 8: Features Cited by Participants when Making Matches between Radiographs (Continued)

ID #5—*Unknown E/Known 3*

Feature	General	L1	L2	L3	L4	L5
Spinous Processes	1, 18, 19, 21, 23, 3, 5, 6, 9, 10, 12, 14, 13, 25	20, 22, 3, 7	20, 22, 7	2, 22, 7	2, 20, 22, 7, 14	2, 20, 22, 24, 7
Transverse Processes	23, 12, 15	No one used L1 specifically	No one used L2 specifically	No one used L3 specifically	No one used L4 specifically	No one used L5 specifically
Centrum (contour, shape)	1, 3, 9, 10, 12, 15, 17	22, 13	22, 7	22, 3, 7	2, 22, 7	No one used L5 specifically
Trabeculae	22	No one used L1 specifically	No one used L2 specifically	No one used L3 specifically	No one used L4 specifically	No one used L5 specifically
Pedicles	21, 23, 3, 9, 12	No one used L1 specifically	3	No one used L3 specifically	No one used L4 specifically	No one used L5 specifically
Radiodensities	18, 23, 6, 12	No one used L1 specifically	No one used L2 specifically	No one used L3 specifically	No one used L4 specifically	No one used L5 specifically
Radiolucencies	12	No one used L1 specifically	No one used L2 specifically	No one used L3 specifically	No one used L4 specifically	No one used L5 specifically
SAP's/IAP's	1, 24, 5, 14	**11**	No one used L2 specifically	No one used L3 specifically	4	4
SAPs	19	No one used L1 specifically	20	No one used L3 specifically	No one used L4 specifically	No one used L5 specifically
Osteophytes (development/ lipping)	18, 23, 24, 8, 9, 10, 12, 14, 13, 15, 17, 25	No one used L1 specifically	2, 1, 19, 20, 21, 23, 3, 4, 5, 6, 7, 12, 14, 11, 25	21, 23, 3, 11	23, 3	No one used L5 specifically
Neural Arch Contour	No one cited Neural Arches generally	No one used L1 specifically	No one used L2 specifically	No one used L3 specifically	No one used L4 specifically	No one used L5 specifically
Size of Vertebrae	20	No one used L1 specifically	No one used L2 specifically	No one used L3 specifically	No one used L4 specifically	No one used L5 specifically
Syndesmophytes	22	No one used L1 specifically	No one used L2 specifically	No one used L3 specifically	No one used L4 specifically	No one used L5 specifically
Intervertebral Space	No one cited Intervertebral Space generally	No one used L1 specifically	No one used L2 specifically	No one used L3 specifically	25 (b/t 4 and 5)	25 (b/t 4 and 5)

Notes:

Participant #8 answered incorrectly (misidentification)

Participant #15 answered incorrectly (misidentification, with a qualifying statement)

Participant #16 chose not to make a match for *Unknown E*

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