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Carrie M. Kuehn,[1] *B.A.; Katherine M. Taylor,*[2] *Ph.D.; F. A. Mann,*[3] *M.D.; Anthony J. Wilson,*[3] *M.B., Ch.B.; and Richard C. Harruff,*[2] *M.D., Ph.D.*

Validation of Chest X-ray Comparisons for Unknown Decedent Identification*

ABSTRACT: Comparing skeletal structures between antemortem and postmortem chest radiographs is widely used by forensic specialists from many disciplines to positively identify unknown decedents. However, validity assessments of this method have been fairly limited. This study had three objectives: 1) to quantify the reliability of ante- and postmortem chest radiograph comparison for decedent identification; 2) to identify useful radiologic features supporting decedent identification; and 3) to recognize sources of error in decedent identification related to use of comparative radiographs. A forensic pathologist, a forensic anthropologist, and two radiologists participated in the study. Our results showed that chest radiograph comparisons proved reliable, if basic decedent information was provided, and antemortem and postmortem radiographs were adequately positioned and exposed. A "morphological approach" using normal anatomical structures for comparison may provide the most efficient method for accurate identification.

KEYWORDS: forensic science, forensic identification, chest x-ray, radiograph comparison

Identification of unknown individuals is one of the most important aspects of medico-legal death investigation. Positive identification of the deceased is necessary for an accurate death certificate to be filed, a will to be executed, benefits to be distributed, and most importantly for families to find closure. Decedent identification is also necessary for the conclusive investigation of a homicide (1). Methods of identification include fingerprints, dental radiograph comparison, axial and appendicular radiograph comparison, and in selected cases, DNA analysis. Visual identification alone is often unreliable due to thermal damage, immersion, mutilation, disarticulation, or decomposition of the remains (2).

The practice of comparing skeletal structures in antemortem and postmortem radiographs is widely used throughout the field of death investigation by forensic specialists from many disciplines including anthropology, forensic pathology, and radiology to achieve positive identification. Obtaining antemortem records requires that a presumptive identification be established either by circumstance or through a description of injuries and/or anomalies in the deceased (1,3,4). Once antemortem and postmortem radiographs are obtained, positive identification relies upon the accurate matching of skeletal features and landmarks common between the radiographs (1,3–5).

Published case reports exemplify the usefulness of various skeletal regions for decedent identification using radiographic comparisons including frontal sinuses, sphenoid bone, clavicle and scapula, thoracic and lumbar spine, ribs and costal cartilage, the pelvis and many joints (1–3, 5–15). In addition, the trabecular pattern in the wrist, distal femur, and proximal tibia can be compared accurately for identification (10,11,16,17). Although not uniformly present in a population, unique osseous features, such as previous injuries, pathological conditions, infection, developmental asymmetries, and degenerative changes may aid identification (1,2,9,18). Typically, decedent identification is based on comparison of the radiographic depiction of normal skeletal morphology and landmarks, which do not change in an adult individual unless disrupted by trauma or disease (3,5,7–9,11,12,17–20). Both the contour and internal bony structure of normal skeletal features show numerous points of radiological comparison for obtaining positive identification (5,8,9,11,15,21,22).

Widespread availability of antemortem chest radiographs enhances their utility as a basis for radiographic comparison. Chest radiographs are obtained in life more frequently than radiographs from any other postcranial region, including extremities; chest radiographs constitute up to 40% of conventional diagnostic radiographs (1,5,9,12,18). During the Noronic disaster, radiographs of the spine and chest were used for comparison more often than any other (18).

Because the majority of antemortem radiographs provided for identification to the King County Medical Examiner's Office are chest X-rays, the reliability of comparing these diagnostic films to postmortem radiographs is of practical importance. Therefore, we designed a multidisciplinary approach to test the validity of chest X-ray comparisons for unknown decedent identification.

This study had three objectives: 1) to quantify the reliability of ante- and postmortem chest radiograph comparison for decedent identification; 2) to identify useful radiologic features supporting decedent identification; and 3) to recognize sources of error in decedent identification related to use of comparative radiographs.

[1] University of Washington, Department of Anthropology, Box 353100, Seattle, WA 98195.
[2] King County Medical Examiner's Office, 325 9th Avenue, HMC Box 359792, Seattle, WA 98104.
[3] Harborview Medical Center, Department of Radiology, 325 9th Avenue, HMC Box 359728, Seattle, WA 98104.
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Materials and Methods

Radiographs for use in this study were acquired from cases that came under the jurisdiction of the King County Medical Examiner's Office in Seattle, Washington between 1995 and 1999. Cases were selected if either single antemortem or both ante- and postmortem chest radiographs were present in the radiographic file. The study used thirty sets of matching antemortem and postmortem chest films for comparison and twelve additional unmatched antemortem chest films. (One set originally included as a matching set was discovered to be a non-matching set after the study was completed. All of the performance results were subsequently corrected to take this into account.) To keep track of matching sets, each of the radiographs was randomly numbered from 1–72.

To simulate actual forensic investigation, we did not control for age or sex of the decedents, or time interval between ante- and postmortem radiographs. In addition, we did not select for radiographic positioning or quality of the ante- and postmortem radiographs. Antemortem chest radiographs may be taken either anteroposterior (AP) or posteroanterior (PA). In our study, all of the postmortem films were AP, and the antemortem positioning included 37 AP and 15 PA radiographs. The age, postmortem interval, and gender of our cases are summarized in Table 1.

Four observers (a forensic pathologist and a forensic anthropologist from the King County Medical Examiner's Office, and two radiologists from Harborview Medical Center) independently compared the radiographs without demographic information including age, sex, race, and cause of death of the decedents.

Three types of comparison tests were conducted in two separate trials (Table 2). Each of the four observers matched the same ante- and postmortem radiographs for each test. The first test, called the Group Comparison Test (GCT), consisted of three sets of eight antemortem and five postmortem radiographs. For each set, the observers were asked to select one of the eight antemortem radiographs as the unique match to each of the five postmortem radiographs. The additional antemortem radiographs precluded matching by elimination. The observers were told that they might assume that within the set, each postmortem had a matching antemortem film. The four observers recorded the radiographic features they used to match the radiographs, and noted whether or not radiographic quality affected their ability to confidently make a positive match.

The second test, the Individual Comparison Test (ICT), consisted of six sets of five antemortem and one postmortem radiograph. For each set, observers uniquely matched each postmortem radiograph to an antemortem counterpart. To test the observer confidence, there were a number of sets that had no match (Table 2). The observers were not told how many of these there might be. For each set, observers independently described the radiographic features used to make each match, and assigned a level of confidence to the match from a choice of positive, probable, possible, or no match (Table 3).

TABLE 1—*Age, postmortem interval (in years) and gender of radiographs used for comparison.*

	Mean	Min.	Max.	Females	Males
Matching Sets:				22	8
Age	53.30	21	87		
PMI	2.80	0*	12.6		
Random AM Films:				7†	4
Age	58.18	12	87		

* Person died on the same day as the AM X-ray was taken.

† Two films from the same person were used for a total of twelve random films.

TABLE 3—*Confidence level descriptions and frequency for correctly matched, mismatched, and unmatched sets of radiographs for the individual comparison and single set tests.*

Confidence Level	Description	Number Correctly Matched Sets	Number Mismatched or Unmatched Sets*
Positive	Multiple points of similarity No inconsistencies Absolute certainty	21	0
Probable	Good correspondence of features Too few matching points for positive Lack of confidence due to poor quality Most likely a match	28	5
Possible	No significant points of similarity No inconsistencies or exclusion points Lack of confidence due to poor quality	9	9
No Match	points of inconsistency Extremely poor quality Absolute certainty there is no match	NA	11
	Total†	58	27

* Unmatched sets are matching sets that were incorrectly marked as "no match;" confidence level data is not available for the 17 mismatches that occurred in the Group Comparison Tests; two additional GCT sets were marked as "no match."

† Total reflects the number of tests for which a confidence level was given; confidence was not always recorded by the observer.

TABLE 2—*Number of Antemortem and Postmortem Films, Number of Matching Sets and Non-Matching Sets and Number of Correct Answers Possible for Each Test.*

Test	AM	PM	Correct Answers Possible	Number of Matching Sets		Number of Non-matching Sets	
			Each Trial	Trial 1	Trial 2	Trial 1	Trial 2
Group Comparison Test (GCT)	8	5	15	5	5	NA	NA
Individual Comparison Test (ICT)	5	1	6	4	2	2	4
Single Set Test (SST)	1	1	10	7	8	3	2

The third test, the Single Set Test, consisted of ten sets of one antemortem and one postmortem radiograph. This test also included sets in which the films did not match, and observers did not know how many of these there might be (Table 2). For each set, observers independently assessed whether the two radiographs represented the same individual, and assigned a level of confidence from a choice of positive, probable, possible, or no match. Observers also recorded information that might have increased their certainty in the match (e.g., age, sex, time interval between radiographs, etc.).

For the second trial of these three tests, all radiographs were renumbered randomly and all test sets were composed of different combinations of ante- and postmortem radiographs than in the first trial. Otherwise the trials were identical.

The number of correct answers was determined for each observer for each test. Responses were scored incorrect for a false-positive and false-negative (errant no-match) matches.

Results

Performance

There were a total of 31 possible correct answers for each trial (Table 2). Table 4 summarizes the overall percent accuracy for the entire study (an average of Trial 1 and Trial 2) for each observer as well as the average performance for all observers combined (80% accurate). The performance of the forensic anthropologist stands out with the highest overall percent correct (92%). The two radiologists and the forensic pathologist performed similarly throughout both trials (79, 74, and 73% respectively).

Although one of the observers was unable to complete the Group Comparison Test for the second trial, our study results seem robust. If we assume that this observer got the same score for the second trial as he got on the first trial, the average percent for the overall study would be unchanged. Furthermore, if we assume that this observer got 100% correct on this test, the average percent for the overall study increases to only 82% (vs. 80%).

TABLE 4—*Summary of individual performance of observers for the group comparison test (GCT), individual comparison test (ICT), and single set test (SST) in both trials and overall performance of all observers for all tests and trials.*

Observer	% Correct Trial 1	% Correct Trial 2	Combined % Correct
Forensic Pathologist			
GCT	80%		80%
ICT	67%	67%	67%
SST	80%	70%	75%
		Total % Correct:	73%
Forensic Anthropologist			
GCT	73%	100%	87%
ICT	100%	100%	100%
SST	90%	100%	95%
		Total % Correct:	92%
Radiologist 1			
GCT	80%	87%	83%
ICT	67%	67%	67%
SST	80%	80%	80%
		Total % Correct:	79%
Radiologist 2			
GCT	87%	67%	77%
ICT	67%	50%	59%
SST	60%	90%	75%
		Total % Correct:	74%
		Overall Performance:	80%

TABLE 5—*Feature categories and frequencies of use for identification for Trial 1, Trial 2, and overall study.*

Feature Categories	Trial 1	Trial 2	Overall Study
Clavicle morphology	17	5	22
Shoulder morphology and changes*	14	3	17
Vertebral morphology	14	10	24
Rib morphology†	13	10	23
Spinous process morphology	11	11	22
Spinal degeneration‡	10	3	13
Transverse process morphology	6	1	7
Surgical hardware	6	1	7
Previous fracture	4	3	7
Other§	4	3	7

* Includes shoulder degeneration, shoulder morphology, scapular morphology, acromioclavicular joint.
† Includes rib morphology, synchondrosis, costal cartilage.
‡ Includes spinal degeneration, vertebral spondylosis, vertebral osteoarthritis.
§ Includes foreign bodies, GSW, "bone configuration," mediastinal contour, fibrous dysplasia.

Radiographic Features used for Matching

To facilitate counting the number of times a feature was used, recorded features were standardized into categories (Table 5). Radiographic features most commonly used for comparison were normal anatomical structures. For Trial 1, the most common feature reported was clavicle morphology. Shoulder, vertebral, rib, and spinous process morphology closely followed. In Trial 2, spinous process, vertebral, and rib morphology were reported most commonly. Overall, vertebral, rib, spinous process, and clavicle morphology were the most common features used for radiographic comparison.

Error and Confidence

Out of 233 possible correct answers over both trials, 187 were correct (true-positive = 154/187, true-negative = 33/187) and 46 were incorrect (false-positive = 33/46, false-negative = 13/46). Observers were conservative when assigning confidence levels to matched sets for both the Individual Comparison Test and the Single Set Test (Table 3). Sixty-three percent of the true-positive matches were given a confidence level of either probable or possible. For false-positive matches, observers showed low levels of confidence.

Understanding the sources of error that contribute to this result is important for preventing the misidentification of a deceased individual. Four sources of error were identified: 1) quality of antemortem or postmortem films (i.e., radiologic exposure); 2) orientation of the body in the films (radiologic positioning); 3) state of decomposition of the postmortem remains; and 4) the presence or absence of external information such as age, sex, time interval between films, or circumstances.

Discussion

As a means of scientific identification of unknown, deceased individuals, it is important that the method of comparing antemortem to postmortem chest radiographs be understood in terms of its applications and its limitations. Recognizing and accounting for the sources of errors in this method will minimize potential for misidentification.

The results of this study indicate that, for this sample, the method is reliable only 80% of the time, and when an error is made it is more likely to be a misidentification. Our performance result of only 80% correct is significantly different from double blind studies conducted in the past that have reported 100% accuracy. One reason for this discrepancy may be that previous double blind studies routinely compared antemortem to antemortem films (7,21). We believe that our study more closely simulates actual forensic investigation.

Standards have been published regarding the number of matching features necessary to prove a positive identification (11). It has been suggested that a minimum of four matching features be required for positive identification, however more points may be needed in some cases while in others, one unique feature may prove to be sufficient (7,11). Observers in this study felt that there should be multiple points of similarity on at least two different skeletal structures, and no inconsistencies between the films. Recorded features from our study were similar for both trials, and reveal the necessity of utilizing normal anatomical structures for comparison. We believe that for the second trial, the reported distribution of features used to match radiographs is slightly different due to incomplete data for the Group Comparison Test and/or recombination of radiographs for the second trial.

The poor quality of both ante- and postmortem films used in this study caused problems for comparison and resulted in low levels of confidence for matched sets. Many of the antemortem radiographs used in this study were originally taken for clinical diagnostic purposes, not to look at skeletal structures. Consequently, these radiographs inadequately detailed skeletal structures due to overlying soft tissue and insufficient exposure. Similarly, radiographic positioning, decompositional artifact (gaseous changes, skeletal disorganization due to loss of anatomical position), and radiographic exposure of postmortem radiographs presented significant obstacles for comparison. In addition, postmortem removal of the chest plate prior to taking the radiograph, while providing a clear view of the spinal features, makes comparison of the clavicle and ribs nearly impossible. Other trauma or mutilation could present similar problems for comparison.

All four observers commented on the lack of consistent orientation between antemortem and postmortem films. In a forensic setting, little can be done to alter the quality of an antemortem radiograph (1). Only the postmortem films can be changed in an effort to optimize comparability. Nonetheless, there are limits to improving the orientation of postmortem remains, particularly if those remains are in full rigor, decomposed, or disarticulated. In addition, it is usually not practical to take a PA postmortem chest radiograph since laying the decedent on their front does little to mimic radiographic positioning of an upright live person. Comparison of AP postmortem chest films to PA antemortem chest films is likely to remain a frequent practice.

Finally, all of the observers would have preferred access to basic information regarding the individuals' expected age, sex, and time interval between films. Typically, a tentative identification will already be available and information such as sex and age will facilitate comparison of radiographs. Only in rare cases or in mass disasters might it be necessary to compare multiple antemortem and postmortem radiographs without a tentative identification. However, radiographic positioning and exposure, and decomposition will continue to present problems, and every effort should be made to minimize their impact on comparison. For instance, taking chest radiographs both prior to and after autopsy might allow the observer to see the ribs (prior to autopsy) and the spinal column (after autopsy) clearly, avoiding complications from gaseous changes. Reproducible positioning may be a more difficult obstacle to overcome. As suggested by Sanders et al., it may be reasonable to remove one particular bone, such as the clavicle, in order to position it identically to antemortem radiographs (19). Alternatively, altering the tube angulation while taking postmortem chest radiographs may help with the comparison of AP to PA radiographs (1). Avoiding problems with orientation are the technologist's and observer's greatest challenge.

It is not unreasonable to take into account the observer's training when looking at the reliability and accuracy of chest radiographic comparison. From our results, it appears that the anthropologist had an advantage. Although it would not be prudent to make generalizations based on the results of this study, it suggests that task familiarity and training of the observer might affect the accuracy of a comparison. This is consistent with results obtained in one study that investigated the effect of medical training on the accuracy of radiographic comparison (23). On the pretest questionnaires, the radiologists and pathologist indicated they were looking for diagnostic features (hardware, fractures, degenerative changes, etc.). In contrast, the anthropologist listed features that focused on the shapes and contours of skeletal structures with less emphasis on pathology. The post-study questionnaires suggest a learning effect, in which all observers listed normal anatomical structures as features actually used for comparison. This "morphological approach" may be more effective than focusing on diagnostic features and pathology.

This study was limited in terms of the number of observers and the films available for comparison. Future studies might include a larger data set of radiographs of variable quality. In addition, representative numbers of professionals from the fields of forensic anthropology, forensic pathology, and radiology should be included to assess potential training effects. We believe that an increased awareness of the methods we use for medico-legal investigation can only augment reliability and accuracy, and improve the essential services we provide the public.

Conclusions

This study was an attempt to validate the comparison of chest radiographs for identification of unknown human remains. In addition, we set out to identify important features useful for comparison as well as factors that contribute to errors in identification. Utilizing chest radiographic comparison for identification is an important aspect of medico-legal death investigation and, for this reason, must be understood with regard to its limitations. Our study demonstrated only 80% accuracy, and identified quality of the ante- and postmortem radiographs as the major limitation. Focusing on a number of normal anatomical landmarks and skeletal structures utilizing a morphological approach to comparison, rather than relying upon diagnostic abnormalities, may provide the most straightforward and accurate method of identification.

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For additional information:
Carrie M. Kuehn, B.A.
University of Washington
Department of Anthropology
Box 353100
Seattle, WA 98195
Tel: (206) 221-5687
Fax: (206) 543-3285
E-mail: cmkuehn@u.washington.edu

For reprint requests:
F. A. Mann, M.D.
Harborview Medical Center
Department of Radiology
325 9th Avenue
HMC Box 359728
Seattle, WA 98104
Tel: (206) 731-8205
Fax: (206) 731-8560