TECHNICAL NOTE

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The Computer-Assisted Postmortem Identification (CAPMI) System: Sorting Algorithm Improvements

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ABSTRACT: Refinements to the original Computer-Assisted Postmortem Identification (CAPMI) software algorithms and general data handling were suggested as a result of observations made following the Gander plane crash of 1985. The presence of highly fragmented and scattered remains following most plane crashes suggested that changes to procedure might improve CAPMI performance for use in these types of disasters. A total of 162 ante- and postmortem dental records which had been used successfully to identify victims of the Gander disaster were coded for anonymity and used for this investigation. Changes in data construction and management were made to CAPMI, according to concepts which were thought might improve system performance, and tested. Although most tested techniques improved CAPMI performance, the data suggested that replacement of "virgin" chartings with "data unknown" results in improved performance of CAPMI largely independent of other factors. Of 162 possible record matches, the original algorithm successfully listed the true record match in the top 20 possibilities 74% of the time; the tested variations on the original algorithm yielded results across a range of 38 to 83% successes, with most techniques performing better than the original algorithm. Results of this investigation have been incorporated into improved CAPMI procedures and software.

KEYWORDS: odontology, computers, human identification

The Computer-Assisted Postmortem Identification system (CAPMI) was described previously [*1*]. The system was first used to facilitate victim identification from the December 1985 Gander, Newfoundland crash of a chartered DC-8 transporting 101st Airborne (Air Assault) Division troops from Egypt to Fort Campbell, Kentucky. CAPMI was helpful, but since other evidence (fingerprints, medical radiographs and physical examinations) was also

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used to guide forensic investigators to correct record matches during the investigation, it was not possible to evaluate objectively the performance of CAPMI at that time.

CAPMI software was designed to perform repetitive and time-consuming record-by-record comparisons of all possible ante- and post-mortem records so that forensic science examiners may more efficiently concentrate their efforts on making positive identifications. The first-generation CAPMI program used at Gander prioritized and listed records based upon the maximum number of tooth matches between the postmortem record of interest (in the *key* file or database) and electronic dental records which had been previously entered in the antemortem database (the *object* file). This process is termed a *sort;* the request of a sort is called an *inquiry*. When an investigator initiates an inquiry, the computer compares all possible record matches and the sort produces a listing of all possible record matches based upon the number of tooth-by-tooth "matches," "mismatches," and "possibles." Possible record matches were listed *(prioritized)* in order of decreasing likelihood of matching the record of interest. CAPMI also tallied the numbers of correct tooth-by-tooth "mismatches" and "possibles" for each inquiry. Subsequent upgrades to CAPMI have preserved these features. The original estimations of system capability were based on the anticipated availability of a victim's entire dental record, however. At Gander it became clear that the victim fragmentation typical in high energy mass disasters would require different techniques to optimize the *selectivity* of incomplete data sets.

Selectivity is a term used to describe the relative capabilities of a decision system such as CAPMI. A highly selective CAPMI system is desirable, ideally resulting in consistently high prioritizations of correct ante- and post-mortem record matches. Selectivity has two components, *sensitivity* and *specificity.* As in many decision systems, sensitivity and specificity can be adjusted. Usually, however, changes made to improve one of these components are generally at the expense of the other. The goal for CAPMI is to assure that correct record matches are consistently listed among the top several possibilities for each sort (that is, to be highly sensitive), while simultaneously assuring that there is a minimal number of "most likely" record matches at the top of each prioritized list (that is, to be maximally specific).

Practicing dentists typically perform highly detailed examinations on their patients. Unfortunately, as examinations become more discerning, the likelihood of subjective interpretative disagreements increases; for example, one dentist may note subtle mineralization changes indicative of dental caries, yet another may not. In clinical environs, such disagreements may mean little, yet for the forensic science examiner using computer assistance, such discrepancies may complicate efforts to identify fatalities. CAPMI is designed to avail itself of the very high degree of specificity characteristic of each human dentition while limiting the effect of discrepancies expected when detailed examinations are performed by different dentists. However, since CAPMI is intended only to make positive identifications easier for the investigator—not to replace him or her—the theoretical loss of some specificity helps assure a minimal number of charting discrepancies, thereby assuring an acceptable level of sensitivity.

The use of less detailed dental data limits charting discrepancies, thus minimizing the number of tooth-to-tooth mismatches. In CAPMI, if both ante- and post-mortem records are accurate and complete, the correct record match for each inquiry will always place first (or tied for first if the oral state is not unique in the population) in the prioritized listing of possible record matches produced by the program. Sufficient amounts of highly specific dental data are retained for use by CAPMI to limit the number of ties. Incomplete records, inaccurate records, unknown changes in a fatality's dentition during the interval between ante- and postmortem charting, or some combination of these, may result in the displacement of the correct record down the list.

The experience at Gander suggested that software which relied on chartings of complete dentitions, including virgin teeth, would limit CAPMI's selectivity in circumstances in which variable amounts of postmortem data were available for each fatality. It was also thought that using just a few restored teeth in a single quadrant might offer improved selectivity compared with the original sorting scheme. Other examiners wondered if the already simplified anatomic characterization of restorations required by CAPMI might still be needlessly complex. Indeed, such observations suggested that the selectivity of CAPMI might be optimized by changes in data construction, combined with different sorting concepts.

Purpose

The purpose of this investigation was to examine all available Gander crash data, after victim identifications were complete, to determine the hypothetical effectiveness of modifications to CAPMI for use in future disasters. An additional goal was to identify flaws in the original software or utilization procedures or both which may have caused certain true matches of ante- and post-mortem records to appear lower on the prioritized lists than theoretically expected. Thus, the purpose was not only to assess the effectiveness of CAPMI, but also to examine possible improvements which would optimize the order in which the victims' records appear on the prioritized lists of suggested record matches.

Methods

Data on 162 fatalities with both ante- and post-mortem records were used for this retrospective study. Anonymity was protected by coding names and Social Security numbers. These positive identifications served as the baseline for accuracy assessments in this investigation.

Worksheets completed by forensic science investigators at the Gander disaster identification site were manually compared with the electronic ante- and post-mortem dental records used by CAPMI. The worksheets were a compilation of ante- and postmortem data from all known sources and represented the best diagnosis of the dental state of each victim immediately before death and at the time of postmortem examination. After comparison of the worksheets and the electronic records, it was noted that there were both ante- and post-mortem dental records which had not been entered in a CAPMI database at the time of the crash investigation. (This was most likely due to the prompt positive identification of an occasional victim whose associated records were then not forwarded for data entry.) Such records were added to the databases for the purpose of this investigation. Worksheet chartings were compared with both electronic records and raw data submitted by dentists who had provided past care to the victims. Discrepancies were tallied and characterized.

For the purpose of this investigation, discrepancies noted between worksheets and electronic records were corrected in the database; errors made by forensic science examiners and treating dentists were left uncorrected. This approach was used to simulate how CAPMI would be used for similar identification problems in the future. At such time, worksheets would be read in an error-free fashion by optical mark-reading devices, thereby eliminating keying errors as a source of database mischartings. It was assumed that the use of optical mark-read forms would not improve examiner accuracy. The data manipulation methods evaluated follow.

Master Sort—All data were used in the same manner as at Gander. These results served as a standard by which to judge the effectiveness of the other data handling methods. Prioritized listings were generated based upon the highest number of tooth-by-tooth matches, including virgin teeth match-ups.

Lower Jaw Only Sort—All postmortem records were changed to include lower jaw data only. All upper teeth were charted as if no information were available; a "/" was used to indicate no information available for a specific tooth. The slash results in a "possible" tally for that tooth when a sort is conducted. This technique was used to judge the effectiveness of CAPMI under the circumstances in which only a mandible is recovered. Prioritized listings were generated based upon the highest number of tooth-by-tooth matches.

Upper Jaw Only Sort—Same changes were made as described in procedure No. 2 above except only upper jaw data were used.

Trimmed Sort—Postmortem records were changed so that each virgin tooth entry (V) was replaced by a "/." This approach eliminates the inadvertent weighting given to the often trivial tooth-by-tooth virgin matches in the Master Sort because a "/" results in a "possible" score for that tooth. Prioritized listings were generated based upon the highest number of tooth-by-tooth matches.

Logical Sort—Only those groupings of restored teeth which seemed (empirically) likely to be near-unique in a victim population of this size were used for the comparisons. Typical groupings consisted of several molar and premolar teeth. Each postmortem virgin tooth entry was replaced by "/", and prioritized listings were generated based upon the highest number of tooth-by-tooth matches.

Stratified Sort—This sort was constructed to test the combined effect of two observations: First, it was thought an improved degree of specificity could be achieved by prioritizing according to the maximum number of tooth-by-tooth matches on teeth possessing relatively uncommon but easily detected restorative work; and second, it was felt that such improvements could be achieved without significant loss of sensitivity. Teeth in both ante- and postmortem databases were categorized by restorative state; those with crowns were placed in Group M3, those with simple or complex non-crown restorations in Group M2, and the remainder in Group M1. Sorts generated lists prioritized according to the number of highly selective M3 matches. If more than one antemortem record had an equal number of M3 matches to the postmortem record in question, these antemortem records were further prioritized by the number of M2 matches and so on. Each virgin tooth in the postmortem database was replaced by a "/" as described in Lower Jaw Only Sort above.

Two-Step Sort—This sort was also designed to test a comparison using only a minimal amount of unambiguous and easily obtained dental data. Only one of three possible entries were used for any tooth, that is, "restored" (M), "missing" (X), or "possible" (/). It was thought a beneficial improvement in specificity could be achieved by first prioritizing according to the *minimum number of mismatches* in teeth likely to be present and unrestored in most people, that is, the incisor, canine, and premolar teeth. As in the Stratified Sort, it was felt that this could be achieved without significant loss of selectivity. The Two-Step Sort listed according to two rules: First, records were prioritized into groups by the minimum number of mismatched teeth in the premolar and anterior areas alone, followed by a prioritization by the number of tooth-by-tooth matches within each of these groups now including all teeth. The Two-Step Sort thereby generated a listing of records with no non-molar mismatches prioritized by the number of all-teeth matches followed by records with one non-molar mismatch (also prioritized by the number of all-teeth matches) and so on.

Inquiries were made on a record-by-record basis using each sorting technique, attempting to match each individual postmortem record to the correct antemortem record contained in the database of 162. For the purpose of this study, an inquiry which resulted in the correct post- to antemortem record match appearing in the first 20 antemortem possibilities (including ties for 20th) on the prioritized list was deemed a *success*. See Table 1 for excerpted sample of one such inquiry. While arbitrarily selected, it was felt that appearing in the first 20 records on a prioritized list represented a significant improvement over manual sorting methods. Ranking of a record in the top 20 by a sort was the basis for placement into 1 of 6 groups. If an inquiry resulted in a correct record having (or tied for) the best performance, that result was categorized in Group 1. If an inquiry resulted in a correct record having (or tied for) the second highest level of performance, that inquiry was scored in Group 2, and so on. *If an inquiry resulted in more than 20 records tied for the highest level of performance, that inquiry was deemed unsuccessful.* The comparative number of successes for each sorting technique and the distribution of successes across the six groups was reported. Those records which failed to succeed (place in the top 20) using any technique were individually reevaluated to assess reasons for non-success.

TABLE 1—*Excerpt of CAPMI report generated by Logical Sort method described in test. In this actual data, genuine record match was that of Victim D140, which placed in a group tied for second highest performance along with Victims D085 and D026. This inquiry was thus scored in Group 2 for comparison purposes (see Table 2).*

Patient	Number of Matches	Number of Mismatches	Number of Possible	Rank
D229	2	0	30	1
D140	2	1	29	2
D085	2	1	29	3
D026	2	1	29	4
D252	2	2	28	5
D241	2	2	28	6
etc.				

Results

The results using the seven techniques are given in Table 2. The Trimmed, Logical, Lower Jaw Only, and Upper Jaw Only all performed better than the control Master Sort. The Two-Step and Stratified Sorts did not perform as well as the control. Indeed, the Stratified Sort results are shown for only the first 65 postmortem record inquiries because it quickly became obvious that this technique was relatively unsuccessful and required much more computer processing time than did the other sorts. Of the 162 individual records used in this simulation, 156 were successful with 1 or more techniques. The 6 records which were unsuccessful were based on small jaw and tooth fragments with minimal restorative or other distinguishing features.

Characterization of suspected sources of charting error revealed almost no mistakes in charting by forensic science examiners. A few errors as a result of mistakes in keying data into the computer were detected and corrected. The majority of discrepancies were found in care provider records used to compile the antemortem database. These errors sometimes resulted in theoretical incongruities (for example, an ostensibly restored maxillary right first molar appearing as a virgin tooth on a radiograph at a later time). This left forensic science examiners with no choice but to make educated guesses when compiling antemortem records for the identification task.

TABLE 2—*Performance of tested CAPMI techniques (see text for explanation of Groups). The total percentage of successful inquiries for each technique are included in the data shown in* **bold** *type. The Master Sort represents the original CAPMI sorting algorithm. Analyses suggested the Trimmed Sort to be best for larger air crash scenarios because it had both the highest number of successes and Group 1 placements. The Stratified Sort was discontinued after 65 inquiries because of its excessive processing time requirements and poor performance up to that point.*

Sort %	Group 1, %	Group 2, %	Group 3, %	Group 4, %	Group 5, %	Group 6, %	Total, %	Not in Top 20, %
Master	88 (54)	11 (7)	9 (6)	8 (5)	3 (2)	1 (0.5)	120 **(74)**	42 (26)
Lower	86 (53)	36 (22)	6 (4)	1 (0.5)	0 (0)	0 (0)	129 **(80)**	33 (20)
Upper	87 (54)	18 (11)	9 (6)	4 (2)	0 (0)	0 (0)	118 **(73)**	44 (27)
Trimmed	99 (61)	24 (15)	10 (6)	1 (0.5)	1 (0.5)	0 (0)	134 **(83)**	28 (17)
Logical	86 (53)	33 (20)	12 (7)	1 (0.5)	0 (0)	0 (0)	132 **(81)**	30 (19)
Stratified	18 (28)	3 (5)	4 (6)	0 (0)	0 (0)	0 (0)	25 **(38)**	40 (62)
Two-Step	80 (48)	19 (12)	7 (4)	2 (1)	0 (0)	0 (0)	108 **(67)**	54 (33)

Discussion

Because the goal of CAPMI has been to facilitate victim identifications by deprioritizing most non-matches, the original program was designed with an emphasis requiring users to enter only unequivocal dental data. It was suspected that such an approach would permit a high level of sensitivity while still providing ample specificity.

This simulation study demonstrated that the original procedure for the use of CAPMI (represented by the Master technique above) suffers in comparison with some of the less specific (but more sensitive) data sorting methods tested in this study. The Trimmed Sort results suggest strongly that CAPMI selectivity can be improved by charting each virgin tooth as a "/" (rather than as a "V") for most likely applications. It is reasonable to suggest that the improved performance of the Logical, Lower Jaw Only, and Upper Jaw Only Sorts compared with the control Master Sort were due primarily to the substitution of "possible" for "virgin" entries. The Trimmed Sort not only garnered the highest percentage of successes, but also the greatest incidence of Group 1 successes.

It seems counter-intuitive that the total absence of an entire arch (as in the Lower Jaw Only and Upper Jaw Only Sorts) in a postmortem record reduces selectivity only slightly, yet this study demonstrates that to be true, thereby further emphasizing the high degree of selectivity possible with only a few teeth.

This investigation further demonstrates that attempts to improve selectivity even more by simplifying dental charting as tested by the Stratified and Two-Step Sorts were unsuccessful. This is so, despite the performance improvements expected by substituting "/" for "V." The performance of the Two-Step Sort, while clearly inferior to the Trimmed Sort, serves to again demonstrate the remarkable sorting power of even very rudimentary dental data.

The victims in the Gander crash were all fairly young and had fewer restorations than would be expected in a civilian disaster cohort. It was observed and stands to reason that victims with the greatest number of restored tooth surfaces in antemortem records tend to be the easiest to identify and are most likely to be prioritized at the top of a sort—often untied with other records. This reasoning suggests CAPMI could be of even greater aid in domestic civilian disaster identification taskings since victims are likely to be older and have more dental work in their mouths.

The six sets of remains which were not matched successfully regardless of technique shared common features; they were highly fragmented and had minimal or no restorative work in place. These cases demonstrated the intuitive fact that there is a threshold amount of data, below which sorting by simplified criteria may become nonproductive. By the rules of this simulation, it might appear these six cases would require handling in the traditional fashion by the forensic examiner looking at each possible antemortem dental record one at a time. However, when viewed outside of the stringent criterion required for success in this study, sorts for these six records were not necessarily failures in the strictest sense. Sorts using these six records provided prioritized lists which essentially eliminated 70% of the possible antemortem matches—a significant improvement over no prioritization sorting at all.

The relatively high rate of charting errors noted on raw antemortem dental records suggests improved charting accuracy in clinical practice is a desirable goal. Many times forensic examiners can obviate preexisting charting errors by careful scrutiny of all available antemortem data, yet in certain circumstances the presence of a single seemingly minor error may profoundly confound the forensic odontologist who is trying to assist in making a positive identification.

Several observations made while reviewing the sorts are of interest. Using the presence or absence of dental caries as a sorting criterion seems to be of no net value. This is probably due to the frequently subjective nature of this diagnosis—especially when based upon data gleaned from sources other than the typical clinical environment. Radiographic interpretation of caries can be highly subjective, especially in a younger population of U.S. residents who often have no caries or only small sites suggestive of dental demineralization. Indeed, even an unequivocal diagnosis of caries from an antemortem radiograph may be misleading due to difficulty of detecting caries while performing the manual manipulation typical of postmortem examinations. Yet, while caries are generally not helpful as a facilitator for sorting programs, a single carious tooth may indeed provide the singular unique match which permits a positive identification, once the examiner has narrowed his or her search by the use of CAPMI or some other sorting protocol and is comparing ante- and postmortem radiographs.

Sorting by using a highly specific yet chartable dental characteristic (for example, a root canal and crown on tooth No. 32) in a particular set of remains may yield a high ranking position in a sort early in the forensic science process. This technique can be expeditiously accomplished by entering the highly specific datum or data and charting each remaining tooth as a "/". If the situation is indeed rare and the antemortem database contains the record match, the correct record will be listed very high by the sort, thereby facilitating rapid positive identification by forensic science investigators.

A significant change in CAPMI was suggested by the Trimmed Sort which eliminated the designation of "V" from the coding format. The substitution of "/" yielded a higher ranking of true matches in most cases. The use of virgin teeth as discriminators is only of value when the antemortem database consists of essentially complete records and when the antemortem record in question has data for most teeth (>26).

Data-entry errors were not found to be widespread in this investigation. In any event, as a matter of convenience and efficiency, forensic science examiners using CAPMI can now enter examination data onto optical mark-read forms or touchscreen devices which permit error-free data transposition into CAPMI by eliminating the previous requirement to manually enter data via a keyboard. Such techniques cannot compensate for inadequate or incorrect data or both sometimes maintained by dentists who treated potential victims in life.

Conclusions

The data gathered from the Gander, Newfoundland, air disaster of 1985 supplied actual ante- and post-mortem databases and solutions for testing the accuracy of potential improvements to the CAPMI system. Data were transformed and manipulated to test various hypotheses about the relative sorting value of certain types of dental data in such a scenario. A change in the design of the CAPMI system was a result. The substitution of the code for "data unknown" for "virgin" improved the performance of CAPMI in the simulations described herein. It is likely that this change to CAPMI or any like system would be advantageous for use in any disaster in which a high degree of victim fragmentation occurs.

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Reference

[1] Lorton, L., Rethman, M., and Friedman, R., "The Computer-Assisted Postmortem Identification (CAPMI) System: A Computer-Based Identification Program," *Journal of Forensic Sciences*, Vol. 33, No. 4, July 1988, pp. 977-984.

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