

Skeletal Identification Using the Frontal Sinus Region: A Retrospective Study of 39 Cases

REFERENCE: Kirk NJ, Wood RE, Goldstein M. Skeletal identification using the frontal sinus region: a retrospective study of 39 cases. *J Forensic Sci* 2002;47(2):318–323.

ABSTRACT: The importance of identification using the frontal sinus has been previously demonstrated in case reports. In this study, 39 cases of identification using frontal sinus comparison from the Ontario Chief Coroner's Office were reviewed and differences between antemortem and postmortem radiographs examined. All cases involved decedents older than twenty years. Three cases were rejected due to poor antemortem and postmortem film quality. One subject had no frontal sinus. Thirty-five cases provided conclusive postmortem to antemortem pattern matches. Sixteen cases also yielded metric (quantitative) matches. Duration between antemortem and postmortem radiographic examinations, age, gender, and cause of death did not affect the ability to obtain a match. This is the largest study undertaken on actual cases and demonstrates the validity of frontal sinus pattern matching for forensic identification.

KEYWORDS: forensic science, frontal sinus, odontology, human identification, radiography

Located in the frontal bone, deep to the superciliary arch, the frontal sinus consists of paired loculated cavities that communicate with the nasal fossa via the infundibulum (1). The frontal sinuses are not visible at birth. They begin to develop during the second year of life and are radiographically apparent at 5 years of age. They continue to grow slowly until puberty. Subsequent rapid growth ensues until they reach their maximum size at age twenty (2,3). The anatomy of the frontal sinus remains stable throughout the course of life. Further gradual pneumatization can occur through absorption of bone from the inner walls of the sinus from atrophic changes (4,5). The configuration of the frontal sinus is controlled by environmental factors although gender, race, and disease also affect development (6,7).

It has been established in prior investigations that the radiographic pattern of the frontal sinus is both highly variable and unique to every individual (8). Morphological differences have been shown to exist within gender and racial groups as well as among monozygotic twins (9). Frontal sinus pattern matching has proven to be a useful tool for identification purposes in simulated cases and in a small number of actual forensic cases (10,11). In this study, the authors demonstrate the application of this technique using a large sample of actual cases where frontal sinus pattern matching was used to identify the deceased.

Materials and Methods

Thirty-nine cases with antemortem and postmortem views of the frontal sinus region were obtained from the radiographic archives of the Chief Coroner's Office for Ontario in Toronto Canada. Three cases were excluded from the study due to poor antemortem/postmortem film quality. One case possessed no frontal sinus and was also excluded. All subjects were past the age of twenty. The average time between antemortem and postmortem radiographic examinations and the cause of death were recorded.

Two types of radiographic film exposures were observed. The Caldwell method for views concentrated on the frontal sinus specifically and the Waters method (primarily used for evaluation of the maxillary sinuses) were used. Digital pattern tracings were made of each frontal sinus on the antemortem and postmortem radiographs using Adobe® Photoshop® 4.0 (Adobe Systems Inc., San Jose, CA) (Figs. 1, 2). Digital tracings were visually examined and superimposed. Superimposable antemortem and postmortem patterns were considered a "pattern match." The number of loculations on each side of the septum was also recorded as was any frontal sinus septum deviation, side dominance, and pathology.

Quantitative assessment of the frontal sinus was achieved by measuring the width and length of each sinus using the antemortem and postmortem radiographs. Measurements were taken using the midpoints of the two orbits as the x-axis and a perpendicular line through the midpoint of the intra-orbital distance as the y-axis. Maximum vertical and horizontal distances were documented for each sinus. An arbitrary cut-off value of 5 mm was established. Any discrepancy between antemortem and postmortem values greater than 5 mm was classified as a "metric nonmatch." If the entire perimeter of the antemortem and postmortem sinus shadows was within 5 mm when superimposed, this was defined as a "metric match."

Results

Of the 35 cases investigated, 21 (60%) were male and 14 were (40%) female. Ages ranged from 28 to 80 years with an average age of 48.5 years. The ages of the subjects did not appear to cluster along any particular age interval. Ages were dispersed among three age groupings. Twelve subjects were between 20 and 39. Fourteen placed between 50 and 59 years of age. Nine decedents were older than 60.

Cause of death varied. The majority (37%) were undetermined. Fire-related deaths accounted for a sizeable (20%) group. The remaining deaths were attributed to drugs and alcohol-related causes (17%), drowning (11%), explosion and gunshots (9%), and others (6%). In all cases, postmortem radiographs of the frontal sinus could still be exposed.

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Received 17 April 2001; and in revised form 20 June 2001; accepted 20 June 2001.



FIG. 1—Digitized radiograph showing the frontal sinus region.



FIG. 2—Enlarged view of the frontal sinus showing the corresponding digital pattern tracing. Note the multiple loculations.

The majority of radiographs were exposed using the Caldwell projection. Two antemortem radiographs were exposed using the Waters orientation. The postmortem view of one was subsequently taken using the Waters method. The postmortem view of the other was taken using the Caldwell approach. An additional postmortem Waters-oriented radiograph was taken of a subject whose antemortem film was taken using the Caldwell view (Table 1).

The time range between antemortem and postmortem radiographs averaged 35.4 months and ranged from 1 to 118 months. In one case the authors were unable to determine the date of the antemortem radiograph and the age of the individual.

The radiographic appearance of the frontal sinus region varied

greatly among the decedents. In all cases, loculation (cavity) patterns were asymmetrical. The number of loculations was highly variable and ranged from three to eighteen. The average number was 8.7 loculations per person. The number of loculations on either side of the midline appeared balanced with 4.5 loculations to the left of the midline and 4.2 to the right of the midline. Deviation of the frontal sinus with respect to the midline was also noted. The septum deviated to the left of the midline in nineteen cases and deviated to the right of the midline in sixteen (Table 2).

Irrespective of the number of arcades (arches), there appeared to be definite size distinctions in the frontal sinus to the left and right

TABLE 1—Table illustrating the demographics (gender, age, cause of death) of the study group as well as the orientation of antemortem (AM) and postmortem (PM) radiographs and the interval separating them.

Case	Gender	Age	Cause of death	Ante-mortem (AM) view	Post-mortem (PM) view	(AM)-(PM) time interval (months)
1	F	79	undetermined	Caldwell	Caldwell	92
2	M	34	undetermined	Caldwell	Caldwell	55
3	M	70	undetermined	Caldwell	Caldwell	68
4	F	80	undetermined	Caldwell	Caldwell	76
5	F	70	undetermined	Caldwell	Caldwell	118
6	M	41	undetermined	Caldwell	Waters	4
7	F	46	smoke inhalation	Caldwell	Caldwell	69
8	M	60	alcohol	Caldwell	Caldwell	11
9	M	54	undetermined	Caldwell	Caldwell	52
10	M	48	hanging	Caldwell	Caldwell	6
11	M	30	smoke inhalation	Caldwell	Caldwell	1
12	M	61	explosion	Caldwell	Caldwell	32
13	F	77	undetermined	Caldwell	Caldwell	15
14	M	51	drowning	Caldwell	Caldwell	6
15	F	66	smoke inhalation	Caldwell	Caldwell	1
16	F	57	smoke inhalation	Waters	Caldwell	48
17	M	52	undetermined	Caldwell	Caldwell	24
18	F	34	explosion	Waters	Waters	116
19	M	75	drowning	Caldwell	Caldwell	6
20	M	45	smoke inhalation	Caldwell	Caldwell	2
21	M	35	undetermined	Caldwell	Caldwell	80
22	M	36	undetermined	Caldwell	Caldwell	4
23	M	53	overdose	Caldwell	Caldwell	52
24	F	40	drowning	Caldwell	Caldwell	20
25	M	29	alcohol	Caldwell	Caldwell	43
26	M	33	gunshot	Caldwell	Caldwell	12
27	F	31	overdose	Caldwell	Caldwell	18
28	M	*	undetermined	Caldwell	Caldwell	*
29	M	26	gunshot	Caldwell	Caldwell	8
30	F	48	smoke inhalation	Caldwell	Caldwell	58
31	M	50	drowning	Caldwell	Caldwell	29
32	F	35	overdose	Caldwell	Caldwell	1
33	F	43	overdose	Caldwell	Caldwell	47
34	F	50	liver failure	Caldwell	Caldwell	7
35	M	29	smoke inhalation	Caldwell	Caldwell	44

* age of decedent and date of ante-mortem film unknown.

of the midline. The frontal sinus appeared larger to the left of the midline ("left side dominance") in 22 (63%) of the cases. Right side dominance was evident in 13 (37%) of the cases.

Of the 35 cases, eight (23%) showed radiographic evidence of pathology on antemortem or postmortem radiographs. Three subjects exhibited calcified *falx cerebris*. One case showed *hyperostosis frontalis interna*. Another had a calcified midline. Lobotomy ports were evident in one radiograph. An osteoma was observed in another. In addition, one case showed a craniotomy scar.

Measurements of the antemortem and postmortem radiographs revealed no differences between antemortem and postmortem ranges and averages for horizontal sinus width and vertical sinus height. The average width of the frontal sinus was 71.29 mm (range: 36 to 141 mm). The average height of the frontal sinus was 41.84 mm (range: 24 to 67 mm). Antemortem/postmortem differences in the width of the sinus ranged from 1 to 16 mm. The average difference was 6.06 mm. Antemortem/postmortem differences in the height of the sinus ranged from 0 to 10 mm. The average difference in sinus height was 3.40 mm.

Pattern analysis of antemortem and postmortem films revealed that in all 35 cases it was possible to superimpose antemortem and postmortem tracings and match the arcade pattern of the postmortem radiograph to the pattern on an antemortem film. Using the parameters of sinus height and width, it was also possible to match 16 (46%) of the cases quantitatively.

Discussion and Conclusion

Although differences between male and female frontal sinuses have been reported in the literature (12), gender did not appear to affect pattern-matching ability. Both male and female postmortem sinus patterns could be matched with their corresponding antemortem films. While some studies have proposed that frontal sinus height, width, and area may be larger in males than females, (13) the data indicates that there is no difference in the dimensions of male and female frontal sinuses. In this study no difference could be found in the number of male and female sinus pattern localizations as well. Due to the mixed racial make-up of the group, it is difficult

TABLE 2—Table summarizing the pattern observations found in the antemortem and postmortem radiographs. Despite apparent pathology, pattern matches were made in all cases.

Case	Number of arcades present	Loculations right of midline	Loculations left of midline	Deviation of nasal septum	Side dominance	Pathology	Pattern superimposibility
1	8	4	4	Left	Left	hyperostosis frontalis interna	Yes
2	7	3	4	Left	Right	none	Yes
3	15	8	7	Left	Left	osteoma	Yes
4	8	4	4	Right	Right	none	Yes
5	12	7	5	Left	Left	none	Yes
6	8	4	4	Left	Left	none	Yes
7	15	7	8	Right	Right	calcified falx cerebri	Yes
8	6	3	3	Left	Left	none	Yes
9	13	6	7	Right	Right	none	Yes
10	10	6	4	Right	Left	none	Yes
11	10	5	5	Right	Right	none	Yes
12	6	3	3	Right	Left	none	Yes
13	7	3	4	Right	Right	calcified falx cerebri	Yes
14	8	3	5	Right	Left	none	Yes
15	7	4	3	Left	Left	none	Yes
16	14	8	6	Right	Left	none	Yes
17	9	5	4	Left	Right	calcified midline	Yes
18	9	6	3	Right	Left	none	Yes
19	7	4	3	Left	Right	none	Yes
20	18	10	8	Right	Right	none	Yes
21	3	3	1	Right	Left	none	Yes
22	14	7	7	Right	Left	craniotomy scar	Yes
23	9	4	5	Left	Right	none	Yes
24	8	4	4	Right	Left	none	Yes
25	10	5	5	Left	Right	none	Yes
26	7	3	4	Left	Left	none	Yes
27	7	4	3	Left	Left	none	Yes
28	7	3	4	Left	Left	none	Yes
29	8	4	4	Left	Left	none	Yes
30	9	4	5	Left	Right	lobotomy ports	Yes
31	5	3	2	Right	Left	none	Yes
32	8	4	4	Left	Left	calcified falx cerebri	Yes
33	7	5	2	Left	Right	none	Yes
34	7	3	4	Left	Left	none	Yes
35	7	3	4	Right	Left	none	Yes

TABLE 3—Table summarizing the metric observations found in the antemortem and postmortem radiographs. Metric superimposability was found in 16 (46%) cases.

Case	Maximum post-mortem horizontal width (mm)	Maximum ante-mortem horizontal width (mm)	AM-PM horizontal sinus difference (mm)	Maximum post-mortem vertical height (mm)	Maximum ante-mortem vertical height (mm)	AM-PM vertical sinus difference (mm)	Metric superimposability
1	91	82	9	42	34	8	No
2	70	74	4	42	41	1	Yes
3	110	98	12	65	59	6	No
4	69	57	12	44	38	6	No
5	61	66	5	39	35	4	Yes
6	61	69	8	50	54	4	No
7	82	75	7	52	47	5	No
8	58	59	1	35	31	4	Yes
9	72	73	1	46	45	1	Yes
10	92	85	7	44	49	5	No
11	81	76	5	52	53	1	Yes
12	58	51	7	41	35	6	No
13	57	57	0	49	50	1	Yes
14	52	54	2	34	31	3	Yes
15	64	56	8	35	36	1	No
16	76	82	6	52	56	4	No
17	56	50	6	53	54	1	No
18	65	56	9	40	34	6	No
19	53	52	1	33	29	4	Yes
20	141	139	2	55	56	1	Yes
21	48	47	1	24	22	2	Yes
22	105	110	5	55	61	6	No
23	98	91	7	67	57	10	No
24	90	84	6	50	49	1	No
25	85	69	16	45	41	4	No
26	75	62	13	41	35	6	No
27	44	36	8	32	32	0	No
28	46	50	4	25	24	1	Yes
29	81	67	14	36	29	7	No
30	75	71	4	37	34	3	Yes
31	52	51	1	33	32	1	Yes
32	88	87	1	36	35	1	Yes
33	49	46	3	33	31	2	Yes
34	86	81	5	32	31	1	Yes
35	74	62	12	49	51	2	No
AVERAGE	73.29	69.29	6.06	42.80	40.89	3.40	

to conclude whether gender alone is responsible for these findings. It is more likely that gender is acting in concert with ethnicity and environmental influences in affecting the dimensions of the frontal sinus.

The data indicates that age did not appear to affect pattern-matching ability in mature frontal sinuses. Pattern matching was possible for young adults as well as the elderly. In addition, the interval between antemortem and postmortem films did not seem to impact pattern matching. One 70 year old subject (Case 5) could still be identified using antemortem and postmortem films taken almost ten years apart. Moreover, using the parameters of frontal sinus height and width, metric superimposibility of antemortem and postmortem frontal sinuses was also possible in this case. It is apparent that once mature, time-related changes to the frontal sinus are not significant enough to thwart pattern matching.

All cases investigated in the study involved decedents whose frontal sinuses had reached maturity. In assessing the viability of frontal sinus pattern matching, subjects with developing sinuses pose a challenge. The rapid growth and development of the frontal sinus prior to the age of twenty would make it difficult to match films taken at different points of development. The limitations of this technique have yet to be explored in the pre-twenty age grouping.

Cause of death of the 35 subjects identified in the study varied considerably. In all cases, the frontal sinuses presented intact and could be radiographed. In spite of traumatic episodes such as explosions (Case 12,18) and gunshots (Case 26,29), pattern identification was still possible. Further study is needed to determine to what effect trauma to the head would impact utilization of this technique. It is conceivable that even a partial pattern could be matched if it is distinct and its size is significant.

Frontal sinus pathology, evident in antemortem and postmortem films, did not affect pattern matching in the eight subjects who presented with pathological variations to the frontal sinus. In examining the sinuses for identification purposes, unique identifiable features could assist in the identification process. In fact, frontal sinus films are not regularly taken unless to aid in the investigation of a medical problem. It is therefore likely that pathological variances would be found on antemortem radiographs. This study suggests that pathological variances in the frontal sinus do not appear to affect the ability to pattern match. In fact, unique pathological markings, if present on both antemortem and postmortem films, aids identification.

Pattern matching was possible using both postero-anterior film projections. The Caldwell orientation allows for viewing of the frontal sinus, ethmoid air cells and superior portions of the maxillary sinus. The Waters view allows good visualization of the maxillary sinus and a slightly foreshortened view of the frontal sinus. In the majority (32 cases) of cases, the antemortem/postmortem projections were Caldwell-Caldwell. Pattern matching was still possible whether the antemortem/postmortem projections were Caldwell-Waters (Case 6), Waters-Caldwell (Case 16), or Waters-Waters (Case 18). No metric superimposibility was noted in any of the mixed-projection cases. It would appear to be difficult to quantify and compare dimensions taken from two differing projections. However, the small sample of mixed projections would preclude a broad generalization.

Metric quantification of frontal sinus height and width yielded matches in 16 cases. In addition to possible errors in measurement, inter-operator variability plays a role in any quantitative forensic assessment where different operators take antemortem and postmortem radiographs. Although the same x-ray technician completed the postmortem radiographs, consistency in operator tech-

nique cannot be established for the antemortem films. It is possible that an arbitrary error value of 5 mm is too small a margin to account for differences in inter-operator variability and measurement error.

The data suggests that antemortem/postmortem sinus width differences are more sensitive to error than sinus height differences. The average antemortem/postmortem sinus width difference was 6.06 mm (Table 3) while the average antemortem/postmortem sinus height difference was only 3.40 mm (Table 3). This could be attributed to errors in measurement or to a slight unnoticeable lateral shift of the head when radiographs are exposed.

While this study examined the height and width and perimeter contour of the frontal sinus in determining a "metric match," other studies have considered sinus perimeter, distance, area, and intra-orbital width in an effort to quantify the frontal sinus region (8). It may be more accurate to utilize additional parameters in order to establish metric superimposibility.

Frontal sinus pattern matching is a useful means of forensic identification. The technique can be applied in cases where antemortem frontal sinus x-rays are available and can be useful in instances when dental matching cannot be completed. The technique is especially applicable when a subject is edentulous or missing dentition due to postmortem disturbance. The uniqueness of the frontal sinus and the relative ease of pattern matching make frontal sinus pattern matching a viable adjunct for the forensic investigator.

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