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TECHNICAL NOTE

ANTHROPOLOGY

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The Utility of the Samworth and Gowland Age-at-Death "Look-up" Tables in Forensic Anthropology*

ABSTRACT: Accurate age-at-death estimates are crucial to forensic anthropologists when constructing biological profiles aimed at narrowing a missing-persons list and to allow for timely and efficient identification of an unknown victim. The present contribution evaluates the utility of three new age-at-death estimation techniques recently proposed by Samworth and Gowland (2007). Results indicate that, in the samples under study, the Samworth and Gowland estimates from the pubic symphysis and auricular surface perform similar to alternate phase methods. The combined method does not appear to further enhance either the precision or the accuracy of the single pubic symphysis age-at-death estimate. In conclusion, these new methods seem to be more robust to distribution deviations than originally proposed by Samworth and Gowland (2007). They are therefore suitable for immediate and reliable forensic usage in the United States and worthy of further research for their use in North American forensic contexts.

KEYWORDS: forensic science, forensic anthropology, age-at-death estimation, Samworth and Gowland method, pubic symphysis, auricular surface

Age-at-death estimates are key elements in the study of populations to infer demographics and the identification of individuals in a forensic context because these estimates can easily exclude individuals beyond the basis of sex and stature.

While age-at-death estimation techniques for skeletal samples can generally be applied to any assemblage of skeletal remains with fair performance, forensic applications require an accuracy that is not required in most bioarchaeological and seriation methodologies. These differences arise because forensic methods must have ranges that include 95% of the variation possible in a given morphological gestalt. This is because forensic applications rely much more on the age range estimates of methods for their utility, while bioarchaeological applications are more concerned with mean age-at-death estimates to elucidate their parameters. Age ranges are so key to forensic anthropology because forensic anthropologists cannot be incorrect in their age predictions, unlike bioarchaeologists who have no real legal constraints; if the age of an unknown individual falls outside of the age estimate of the remains, the individual is not likely to be identified. Thus, while bioarchaeological techniques are precise (concerned with minimizing bias/absolute mean error [AME]), these techniques are often inaccurate (an individual aged with these techniques is more likely to fall outside of the smaller confidence intervals, but be seriated correctly in relation to other individuals).

The accurate assessment of an individual's age-at-death estimation in a forensic or bioarchaeological context relies on the use of multiple age indicators whenever possible. The goal of combining these age estimates is to obtain narrower confidence intervals and a more precise mean age than provided by a single age marker. Different statistical approaches to combine multiple age estimators have been proposed, many of the most recent ones relying on applications of Bayes' theorem ([1] and references therein). However, Samworth and Gowland (1) propose a regression approach, providing two-way "look-up" tables for age-at-death prediction based on the auricular surface and pubic symphysis, alone and combined. Data in these tables were developed based on two European samples (Spitalfields, U.K. and Coimbra, Portugal). Among the advantages of the new methods proposed are age estimates that can be obtained without prior knowledge of the marginal age-at-death distribution in the target case.

The aim of the present study is to test the Samworth and Gowland (1) "look-up" tables in three independent American contemporary "forensic" samples. The method is evaluated using (1) the average AME and bias of the age predictions and (2) the overall number of correctly classified individuals within the narrow (68%) and wide (90%) prediction intervals provided in the "look-up" tables.

The validation of new age-at-death methods must be conducted before they are applied in a forensic setting as mandated by the Daubert criteria (2). Further, without robust samples or error rate statistics for the population which the decedent derives from, age estimates could be skewed by unforeseen populational differences resulting in a misclassification. The necessity now is to test age-at-death estimation techniques on samples that are as contemporary as possible to the unknown individual. This allows for a better description of how the technique performs on an independent sample as well as possible refinement of previous age-at-death estimation criteria by including more variation. Without validation studies, age estimation techniques could result in very problematic age-at-death predictions.

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These new "look-up" procedures were developed with a focus on paleodemography, and Samworth and Gowland (1) warn about their heavy reliance on the aprioristic knowledge of the precise age-at-death distributions of the samples under study. These distribution dependencies may cause them to be highly population- or even sample-specific. If this hypothesis is true, the sensitivity of the method to deviations from the distribution of the original study samples would greatly limit their immediate utility in North American forensic contexts, as these are entirely different samples with entirely different distributions. This would require new estimates of all confidence intervals in order to adapt them to North American populations and would impede their application to individuals of uncertain ancestry/populational affinity.

Materials and Methods

This methodological evaluation is based on samples of North American males and females of multiple, but mainly European American ancestries. Skeletal (biological) age data were studied from the Hamann–Todd Collection (n = 66) located at the Cleveland Museum of Natural History, the William M. Bass Collection (n = 188) housed at the University of Tennessee, Knoxville, and the Forensic Data Bank (n = 100) (3) (Table 1). The Hamann–Todd Collection consists of modern human skeletons that were collected between the years of 1839 and 1938. The Bass skeletal collection began in 1981 and is still growing in size with contemporary individuals. The Forensic Data Bank consists of reported skeletal data from forensic cases and contemporary skeletal collections throughout the United States. From the Bass Collection, only positively identified individuals were chosen with ages ranging from 15 to 99 years and efforts were made to avoid pathological specimens. The Hamann–Todd sample (ages ranging from 18 to 81) was also collected with an effort to avoid pathological specimens; the ages of these skeletal elements are from positively identified individuals or at least soft tissue estimation (see [4] for further discussion). The Forensic Data Bank sample is unique because it is constructed from reported skeletal data from multiple observers at multiple institutions (see [5] for additional information). Because of possible interobserver or data entry error, any individuals that appeared to have erroneous scores (e.g., phase 1, aged 99 years) were not included.

All individuals were scored using the eight-phase system of Lovejoy et al. (6) and the six-phase system of Suchey and Katz (7), which is a revised system of Brooks and Suchey (8). The Suchey and Katz (7) phase descriptions are here considered identical to the Brooks and Suchey (8) phase criteria, which was employed in the Samworth and Gowland (1) study. Further, all data were collected by the author (excluding the Forensic Data Bank sample). See Table 2 for phase distribution by age-at-death within each sample.

To evaluate the performance of the methods in question, the data were analyzed in three ways. The three samples were first pooled and then divided into males and females to test for possible sex differences. Second, the data were assessed in terms of performance by collection. Finally, the entire dataset was pooled into a single sample (n = 337) and evaluated.

In an attempt to further appraise the performance of the Samworth and Gowland method, the "look-up" table statistics for males and females will be compared to the Osborne et al. (9) auricular surface method and Suchey and Katz (7) pubic symphysis method. The age-at-death estimates for the Lovejoy et al. method (6) will be from the revised data in Osborne et al. (9). The revised age estimation data of the alternative studies were chosen over the Lovejoy et al. (6) and Brooks and Suchey (8) methods because of their robust statistics and samples allowing for a more accurate comparison to the Samworth and Gowland methods.

Concerning accuracy, the validation statistics utilized were AME and bias. Statistics were calculated from mean (point) age estimates and compared to the recorded known ages-at-death. AME is a measure of the absolute difference between estimated and actual values. *Bias* is the determination of the average over- or under-aging of the individual by the age estimate (4,10,11). Percent correct was used to test method classification rates. Confidence intervals were evaluated in terms of *percent correct classification*. The percent correct merely reflects the number of individuals whose known age fell within the estimated 68%, 90%, or 95% prediction/confidence interval of the phase into which they classified. It should be noted that the revised age methods (7,9), report statistics in confidence intervals versus the Samworth and Gowland methods (1) which use prediction intervals. When comparing these performances, one should observe how close the percent correct is to the particular method's confidence/prediction interval, not necessarily the performance across methods; the method that performs more closely or above the prediction/confidence interval stated is actually performing better. To further evaluate method performance by age class, samples were broken up into three categories: ≤39, 40–59, and ≥60 years; roughly approximating young, middle, and old age adults; performance of individual method by phase is also presented.

TABLE 1—*Sample age distributions.*

	Hamann–Todd Collection		Bass Collection		Forensic Data Bank	
Age Range	Males (n)	Females (n)	Males (n)	Females (n)	Males (n)	Females (n)
≤39	19	7	9	4	30	26
40–59	20	8	42	22	20	8
≥60	10	2	56	55	10	6
Total	49	17	107	81	60	40
Mean age	45.2	42.6	61.5	64.9	42	40.1

TABLE 2—*Phase distributions by age.*

	Bass Collection (n)				Hamann–Todd Collection (n)				Forensic Data Bank (n)		
Phase	Lovejoy et al. Phase			Phase	Lovejoy et al. Phase			Phase	Lovejoy et al. Phase		
8	0	4	10	8	0	0	1	8	1	3	9
7	0	4	13	7	0	1	0	7	0	8	5
6	5	22	23	6	3	5	5	6	1	4	2
5	2	25	39	5	9	14	4	5	12	9	0
4	4	9	26	4	7	6	2	4	12	3	0
3	1	0	0	3	4	1	1	3	14	0	0
2	0	0	0	2	2	0	0	2	9	0	0
1	1	0	0	1	1	0	0	1	7	1	0
Age	≤39	40–59	≥60	Age	≤39	40–59	≥60	Age	≤39	40–59	≥60
Phase	Suchey and Katz Phase			Phase	Suchey and Katz Phase			Phase	Suchey and Katz Phase		
6	1	28	85	6	0	1	4	6	4	4	13
5	6	29	24	5	7	20	7	5	4	13	3
4	4	7	2	4	8	7	0	4	14	7	0
3	0	0	0	3	7	0	1	3	15	3	0
2	1	0	0	2	1	0	0	2	6	0	0
1	1	0	0	1	3	0	0	1	14	0	0
Age	≤39	40–59	≥60	Age	≤39	40–59	≥60	Age	≤39	40–59	≥60

TABLE 3—*Male and female performance by method.*

Age Range		Combined Method Males	Combined Method Females	Lovejoy et al. Auricular Surface Males	Lovejoy et al. Auricular Surface Females	Brooks and Suchey Pubic Symphysis Males	Brooks and Suchey Pubic Symphysis Females
≤39	90% PI	69%	84%	69%	81%	74%	81%
	68% PI	29%	46%	24%	41%	53%	38%
40–59	90% PI	100%	97%	99%	97%	100%	100%
	68% PI	89%	87%	93%	89%	91%	95%
≥60	90% PI	89%	76%	91%	67%	97%	97%
	68% PI	63%	43%	53%	27%	64%	60%
All ages	90% PI	88%	84%	88%	79%	92%	93%
	68% PI	64%	56%	60%	48%	72%	64%
≤39	Bias	11.0	7.7	13.8	9.2	10.5	8.7
	AME	11.1	8.3	13.8	9.8	10.8	9.5
40–59	Bias	4.0	3.1	4.3	−0.4	4.4	3.1
	AME	6.1	7.0	6.8	7.5	6.4	7.0
≥60	Bias	−12.3	−17.4	−16.9	−23.8	−13.0	−13.1
	AME	13.9	17.9	17.0	23.9	13.3	13.6
All ages	Bias	0.1	−5.0	−0.1	−8.5	−0.6	−2.1
	AME	10.2	12.3	10.0	15.6	12.3	10.6

AME, absolute mean error.

TABLE 4—*Combined method performance by collection.*

Age Range		Hamann–Todd Collection (*n* = 66)	Bass Collection (*n* = 188)	Forensic Data Bank (*n* = 100)
≤39	90% PI	65%	77%	79%
	68% PI	35%	31%	39%
40–59	90% PI	100%	100%	93%
	68% PI	93%	89%	86%
≥60	90% PI	75%	82%	94%
	68% PI	58%	50%	81%
All ages	90% PI	82%	88%	85%
	68% PI	64%	62%	59%
≤39	Bias	10.7	12.6	8.5
	AME	10.7	12.6	9.0
40–59	Bias	1.8	4.3	5.0
	AME	5.5	6.4	8.6
≥60	Bias	−14.8	−15.7	−8.4
	AME	14.8	16.6	11.2
All ages	Bias	2.3	−6.9	1.7
	AME	9.3	12.8	9.6

AME, absolute mean error.

TABLE 5—*Lovejoy et al. auricular surface performance by collection.*

Age Range		Hamann–Todd Collection (*n* = 66)	Bass Collection (*n* = 188)	Forensic Data Bank (*n* = 100)
≤39	90% PI	62%	85%	77%
	68% PI	31%	23%	32%
40–59	90% PI	96%	100%	96%
	68% PI	86%	95%	89%
≥60	90% PI	83%	77%	100%
	68% PI	50%	35%	75%
All ages	90% PI	80%	86%	86%
	68% PI	58%	55%	55%
≤39	Bias	13.6	14.0	10.7
	AME	13.6	14.0	11.0
40–59	Bias	2.2	2.1	4.8
	AME	7.9	6.2	9.8
≥60	Bias	−16.5	−21.3	−15.9
	AME	16.8	21.3	16.1
All ages	Bias	3.3	−10.9	−0.1
	AME	11.8	15.6	12.2

AME, absolute mean error.

TABLE 6—*Brooks and Suchey pubic symphysis performance by collection.*

Age Range		Hamann–Todd Collection (*n* = 66)	Bass Collection (*n* = 188)	Forensic Data Bank (*n* = 100)
≤39	90% PI	77%	69%	79%
	68% PI	46%	38%	50%
40–59	90% PI	100%	100%	100%
	68% PI	89%	92%	96%
≥60	90% PI	92%	98%	94%
	68% PI	75%	62%	63%
All ages	90% PI	89%	97%	87%
	68% PI	70%	71%	65%
≤39	Bias	10.7	14.0	8.2
	AME	11.0	14.0	9.0
40–59	Bias	4.3	6.0	3.3
	AME	5.7	7.3	6.0
≥60	Bias	−12.7	−12.9	−16.2
	AME	12.7	13.3	16.6
All ages	Bias	3.7	−4.6	−1.5
	AME	9.1	11.3	10.5

AME, absolute mean error.

Results

In attempts to find methodological performance differences based on sex, the three different collections were pooled, then divided into male and female samples. The precision of the methods and the classification accuracies are fairly similar in both the male and female test samples (Table 3); hence, there appears to be no significant differences between sexes. These findings are similar to those of Samworth and Gowland (1) who report no significant sexual differences in their own dataset.

The performance of the individual collections for the Samworth and Gowland combined method, Lovejoy et al. auricular surface, and Brooks and Suchey pubic symphysis methods are reported in Tables 4–6, respectively. There appears to be little differences in performance between collections for each of the methods.

To evaluate the performance of the Samworth and Gowland auricular surface and pubic symphysis estimates in comparison with other common age-at-death estimation techniques, datasets were also applied to the revised versions of the tested methods (Osborne et al.'s [9] age ranges to Lovejoy et al.'s method [6] and Suchey and Katz's [7] age ranges to the Brooks and Suchey method [8]). Data for the performances by sex and age class of the Osborne et al. (9) auricular surface method and the Suchey and Katz (7) method (Table 7) are similar to the results of the Samworth and Gowland methods for each respective area (note that the Suchey and Katz data must be presented by sex because there are different age ranges for men and women). In both cases, the pubic symphysis method out-performs the auricular surface method. However, the revised auricular surface method (Osborne et al. [9]) performs better than the Samworth and Gowland auricular surface method (1), but Samworth and Gowland pubic symphysis method performs better than the Suchey and Katz (7) method (see Tables 8–11).

Finally, the entire dataset was pooled into a single sample and applied to the Samworth and Gowland "look-up" tables. The performance of the pooled samples is presented in Table 12.

TABLE 7—*Male and female performances by revised method.*

Age Range		Osborne et al. Auricular Surface Males (*n* = 216)	Osborne et al. Auricular Surface Females (*n* = 138)	Suchey and Katz Pubic Symphysis Males (*n* = 216)	Suchey and Katz Pubic Symphysis Females (*n* = 138)
≤39	95% CI	98%	95%	93%	89%
	68% CI	57%	73%	67%	70%
40–59	95% CI	99%	95%	95%	100%
	68% CI	99%	95%	61%	92%
≥60	95% CI	75%	59%	68%	73%
	68% CI	21%	6%	39%	38%
All ages	95% CI	90%	78%	85%	85%
	68% CI	60%	49%	55%	62%
≤39	Bias	9.5	4.7	3.7	4.4
	AME	10.3	7.4	6.2	6.3
40–59	Bias	−0.6	−3.9	−2.6	1.0
	AME	4.6	7.1	7.2	5.9
≥60	Bias	−22.3	−26.8	−16.6	−16.6
	AME	22.3	26.8	−16.7	16.6
All ages	Bias	−5.5	−12.1	−5.8	−6.1
	AME	12.4	16.2	10.3	10.9

AME, absolute mean error.

Discussion

Results indicate that the performance of the revised methods (7,9) are similar to findings by Uhl (11). In the samples under study, the Samworth and Gowland estimates tend to have slightly larger prediction interval widths and lower error rates than the revised methods (see Tables 8–11).

The combined method performs similar in these samples to most attempts at multifactorial age-at-death estimation (11–14). Interestingly, unlike most attempts at combining age-at-death indicators, the presented combined method does not appear to further enhance the bias/AME or the percent correct classification of the single pubic symphysis age-at-death estimate. On the contrary, the addition of the auricular surface data to the pubic symphysis estimate actually decreases the utility of the age-at-death prediction. The Samworth and Gowland pubic symphysis method is the only method that performed above the overall stated prediction/confidence intervals.

The precision of all the methods seems to be lower than what could be considered ideal, but at this time, little data exist on the calculation of satisfactory percent correct classification, AME and bias estimates in age-at-death estimation, and the current

TABLE 8—*Osborne et al. auricular surface performance by phase.*

Phase	1	2	3	4	5	6	7	8
n	10	11	21	69	114	70	31	28
% Correct-95% CI	90%	73%	90%	74%	88%	89%	87%	100%
CI Age Range	10.0–26.4	14.3–26.7	13.4–45	15.0–69.8	18.9–75.7	21.3–76.1	24.9–81.3	28.5–89.3
CI Width	16.4	12.4	31.6	54.8	56.8	54.8	56.4	60.8
% Correct-68% CI	80%	64%	76%	46%	54%	57%	52%	57%
CI Age Range	14.1–22.3	17.4–23.6	21.3–37.1	28.7–56.1	33.1–61.5	35.0–62.4	3.9–67.2	43.7–74.1
CI Width	8.2	6.2	15.8	27.4	28.4	27.4	28.2	30.4
Bias	−1.9	−2.9	−1.9	−11.0	−6.9	−8.2	−12.4	−9.2
AME	6.2	4.4	7.0	18.4	13.9	13.9	14.6	13.2

AME, absolute mean error.

TABLE 9—*Lovejoy et al. auricular surface performance by phase.*

Phase	1	2	3	4	5	6	7	8
n	10	11	21	69	114	70	31	28
% Correct-90% PI	80%	82%	81%	65%	88%	91%	90%	96%
PI Age Range	14.0–30.7	18.3–45	22.9–56.4	27.6–68.1	32.1–79.1	35.9–88.4	38.6–95.1	39.9–98.9
PI Width	16.7	26.7	33.5	40.5	47.0	52.5	56.5	59.0
% Correct-68% PI	30%	55%	38%	39%	54%	64%	81%	75%
PI Age Range	16.7–29	21.8–37.7	27.4–47.2	33.0–56.9	38.4–66.1	42.9–73.9	46.1–79.6	47.7–82.6
PI Width	12.3	15.9	19.8	23.9	27.7	31.0	33.5	34.9
Bias	1.9	5.3	4.8	−10.1	−3.9	−0.6	−4.9	−5.3
AME	8.5	6.7	9.7	18.1	13.6	13.1	12.5	11.9

AME, absolute mean error.

TABLE 10—*Brooks and Suchey pubic symphysis performance by phase.*

Phase	1	2	3	4	5	6
n	18	8	26	49	113	140
% Correct-90% PI	94%	100%	92%	82%	92%	96%
PI Age Range	16.1–27.2	21.4–36.0	27.6–46.4	34.4–57.8	41.5–69.7	48.5–81.6
PI Width	11.1	14.6	18.8	23.4	28.2	33.1
% Correct-68% PI	67%	63%	73%	67%	63%	74%
PI Age Range	13.6–32.2	18.1–42.7	23.2–55.0	29.0–68.5	34.5–82.7	40.9–96.8
PI Width	18.6	24.6	31.8	39.5	48.2	55.9
Bias	2.2	2.2	3.0	5.0	−0.3	−4.6
AME	3.6	4.5	7.1	8.3	11.5	11.7

AME, absolute mean error.

TABLE 11—*Suchey and Katz pubic symphysis performance by phase.*

Phase	1	2	3	4	5	6
Males						
n	8	5	17	32	80	74
% Correct-95% CI	75%	100%	82%	94%	80%	88%
CI Age Range	14.1–22.9	16.2–30.6	15.7–41.7	16.4–54.0	24.8–66.4	36.8–85.6
CI Width	8.8	14.4	26	37.6	41.6	48.8
% Correct-68% CI	63%	60%	76%	59%	49%	54%
CI Age Range	16.3–20.7	19.8–27.0	22.2–35.2	25.8–44.6	35.2–56.0	49–73.4
CI Width	4.4	7.2	13	18.8	20.8	24.4
Bias	−1.4	−1.4	−3.7	−4.6	−7.3	−6.0
AME	2.5	2.9	5.1	7.6	11.5	12.6
Females						
n	10	3	9	17	33	66
% Correct-95% CI	80%	67%	89%	94%	85%	83%
CI Age Range	14.2–24.6	15.2–34.8	14.5–46.9	16.4–60.0	18.9–77.3	35.2–84.8
CI Width	10.4	19.6	32.4	43.6	58.4	49.6
% Correct-68% CI	30%	67%	89%	76%	67%	56%
CI Age Range	16.8–22	20.1–29.9	22.6–38.8	27.3–49.1	33.5–62.7	47.6–72.4
CI Width	5.2	9.8	16.2	21.8	29.2	24.8
Bias	1.7	−2.0	−2.7	−0.7	−9.1	−7.8
AME	3.5	5.3	7.5	7.2	14.1	12.1

AME, absolute mean error.

TABLE 12—*Pooled dataset performance by Samworth and Gowland method.*

Age Range		Combined Method	Lovejoy et al. Auricular Surface	Brooks and Suchey Pubic Symphysis
≤39	90% PI	75%	74%	77%
(*n* = 95)	68% PI	36%	31%	47%
40–59	90% PI	99%	98%	100%
(*n* = 120)	68% PI	88%	92%	93%
≥60	90% PI	83%	80%	97%
(*n* = 139)	68% PI	54%	41%	63%
All ages	90% PI	86%	84%	93%
(*n* = 354)	68% PI	61%	55%	69%
≤39	Bias	9.7	12.0	9.8
(*n* = 95)	AME	10.0	12.2	10.3
40–59	Bias	3.7	2.8	4.8
(*n* = 120)	AME	6.4	7.0	6.5
≥60	Bias	−14.6	−20.0	−13.0
(*n* = 139)	AME	15.7	20.1	13.4
All ages	Bias	−1.9	−3.7	−0.9
(*n* = 354)	AME	11.0	13.6	10.2

AME, absolute mean error.

performance is congruent with previous research [11,14,15] and references therein. Error rates are obviously tied to correct phase classifications, and interobserver and intraobserver error always play a significant role in nonmetric assessments. All phases appear to have similar accuracy rates by method which suggests that the reason older individuals are being aged less accurately is a function of their retention of a younger phase state. However, all methods, including the Samworth and Gowland "look-up" tables, overage younger individuals and underage older individuals, as is a common trend in age-at-death estimation.

Based on these performances, the new methods seem to be more robust to possible age-at-death distribution deviations than originally proposed by Samworth and Gowland (1). From this enhanced performance compared to the revised methods, the lack of sexual preferences and the methodological precision and accuracy on these tested North American samples, the Samworth and Gowland "look-up" tables are recommended for usage on North American skeletal data for forensic anthropology. Caution should be used as no method appears to perform at levels that would be ideal for all phases; however, the Samworth and Gowland pubic symphysis estimate is the most accurate predictor of age overall.

Conclusions

Results indicate that the "look-up" tables presented by Samworth and Gowland (1) perform adequately when applied to the independent North American samples. They are therefore suitable for forensic usage in North American contexts, similar to the current age-at-death estimation methods being used. No differences between sexes were identified, and the single Samworth and Gowland pubic symphysis method performed better when combined with the auricular surface method. The Samworth and Gowland pubic symphysis and auricular surface methods performed similar to if not slightly better than the revised methods (7,9). It would also appear from these results that the statistical methods utilized by Samworth and Gowland (1) to create their age-at-death tables should be further explored.

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