J Forensic Sci, March 2007, Vol. 52, No. 2
doi:10.1111/j.1556-4029.2006.00367.x
Available online at: www.blackwell-synergy.com

TECHNICAL NOTE

Laurent Martrille,[1] M.D.; Douglas H. Ubelaker,[2] Ph.D.; Cristina Cattaneo,[1,3] M.D. Ph.D.; Fabienne Seguret,[4] M.D. Ph.D.; Marie Tremblay,[4] Ph.D.; and Eric Baccino,[1] M.D.

Comparison of Four Skeletal Methods for the Estimation of Age at Death on White and Black Adults*

ABSTRACT: When analyzing human adult skeletal remains, it is often difficult to decide whether a single aging method will give a more reliable age estimation than a combination of methods. This study evaluates four macroscopic indicators for age estimation on 218 American White and Black individuals, ranging in age from 25 to 90 years of age, from the Terry collection. Individuals in the sample were selected to have a balanced race, sex, and age distribution. The following aging methods were applied to each skeleton by one experienced observer: the Suchey–Brooks (SB) pubic symphysis method, the Lovejoy auricular surface method, the monoradicular teeth Lamendin (LM) method, and the Işcan (IC) method for fourth ribs. The statistical study involved the evaluation of inaccuracy and bias (based on median age) for each age indicator and the combination of methods using Principal component analysis (PCA). Analysis was performed on the entire sample, then by race, then sex, and then age group (25–40 years, 41–60 years, and >60 years). PCA was the most accurate method for both racial groups when all age groups are analyzed together. When the sample was divided into age groups, SB was the most accurate for young adults (25–40 years) and LM was the most accurate for middle adults (41–60 years). After the age of 60, all methods are highly inaccurate, although IC gives the lowest inaccuracy. As regards bias, the study highlights the tendency of all methods to overestimate the age of young individuals and to underestimate in the older age group. No single skeletal indicator of age at death is ever likely to reflect accurately the many factors that accumulate with chronological age. In fact, one must use as many dental and skeletal indicators as possible. However, in order to maximize the potential of each method, in the final evaluation one should consider mainly the method or methods that have a higher accuracy for a particular age range.

KEYWORDS: forensic science, aging, ribs, pubic symphysis, teeth, auricular surface

Age estimation of adult human remains continues to be a complicated task. Researchers have raised various methodological problems such as the applicability of various methods on different populations (1–3) and on subjects of various age ranges (4,5), the effect of inter- and intraobserver error (6), and the use of different statistical approaches (4,5). However, because these studies use different samples, methods, and statistical procedures, comparison between results is difficult to evaluate.

A survey of the existing literature, however, seems to indicate a general trend. The more user-friendly macroscopic methods are valid for young adults but less accurate for older age groups and more complex dental and osseous microscopic methods yield slightly better results for all age groups, although it is questionable whether the effort is worth the gain (7).

Another complex issue concerns the applicability of several methods, e.g., the multifactorial approach or principal component analysis (PCA) to single cases (4,5). When dealing with a real case, investigators must decide whether a single selected method will likely produce a better result or whether a combination of methods is preferable. If the latter is selected, what methods should be combined and in what manner? The answers to such questions provided in the literature are variable.

In addition to the issues stated above and the related statistical problems, there are relatively few studies addressing the applicability of macroscopic methods to large samples comprised of individuals of varied ancestries. This is surprising as considerable research has documented population differences in adult sexual dimorphism (8,9)

In contrast, very few studies have evaluated population differences in the accuracy of aging methods. Lovejoy et al. (4) evaluated 130 subjects but their sample was unequally divided among different population groups. Furthermore, the study was conducted on the Todd sample, in which uncertainties exist regarding the age at death of some individuals. Katz and Suchey (10) studied racial differences in pubic symphyseal aging patterns, but only for males and using a modified Todd six-stage system. Işcan et al. (2) and Oettle and Steyn (3) studied racial variation and aging also, but only in regard to sternal rib ends.

To supplement the literature cited above, this study evaluates four macroscopic age estimation methods that focus on the pubic symphysis, the sternal end of the fourth rib, the auricular surface (AS), and anterior teeth within a large sample of Whites and Blacks.

Materials and Methods

Two hundred and eighteen skeletons from the Terry collection housed at the Smithsonian Institution's National Museum of

[1]Service de Médecine Légale, Centre Hospitalier Universitaire, Montpellier, France.
[2]Department of Anthropology, Smithsonian Institution, NMNH, MRC 112, Washington, DC 20560-0112.
[3]Istituto di Medicina Legale, Università Degli Studi, via Mangiagalli 37, 20133, Milano, Italy.
[4]DIM, Centre Hospitalier Universitaire, Montpellier, France.

*Presented at the 57th meeting of the American Association of Forensic Sciences. New Orleans, February 2005.

Received 24 Aug. 2006; and in revised form 14 Feb. 2006, 18 Sept. 2006; accepted 7 Oct. 2006; published 30 Jan. 2007.

Natural History in Washington, DC, were studied, ranging in age from 25 to 90 years. The lower limit of the age range was set at 25 years to accommodate the Lamendin (LM) method (11). Its correction factor of 25.53 years implicitly requires it to be tested on individuals over this age. The White sample consisted of 98 skeletons (55 males and 43 females), and the Black sample of 120 skeletons (60 males and 60 females). The sample was selected to demonstrate a balance of race, sex, and age groups. Skeletons were included that had the appropriate anatomical components for the application of all four methods. Because of local damage, all four methods could not be applied to a few skeletons. The median, mean, and range of ages for each age group are presented in Table 1. The following methods were applied to each skeleton by one single experienced observer: the Suchey–Brooks (SB) method for the pubic symphysis (12–13), the Lovejoy method for the AS (14,15), the LM method on monoradicular teeth (11), and the Işcan (IC) method for fourth ribs (16–19). For the IC method, when the fourth rib was not available, the third or fifth ribs were used (20,21). Furthermore, the fourth rib method for Whites was applied to both the White and Black samples, as previous test on the sample indicates an overall greater accuracy for this method. In assessing the pubic symphysis and the fourth rib, appropriate sex-specific methods were used. For the auricular area and teeth, sex-specific methods are not available.

Each of the indicators was applied independently from all others. For this reason, only the anatomical area being evaluated was viewed at any one time (the others being covered at the time of data collection).

Statistical Analysis

The statistical study involved the evaluation of inaccuracy and bias and was performed using SAS software (version 8.2). Inaccuracy represents the average absolute error of the age estimation for each individual without reference to overaging or underaging. Bias is defined as follows: (estimated age − chronological age)/(number of individuals) and therefore indicates overprediction or underprediction.

The median as opposed to the mean was used in the evaluation of the inaccuracy because of the non-gaussian distribution of the data.

Statistical analysis was performed on the entire sample, and then by racial, sex, and age groups. Age groups were defined as young (25–40 years), middle (41–60 years), and old (>60 years). These large age groups reflect practicality in forensic practice, where the anthropologist or pathologist should avoid the risks of very narrow age ranges (22).

PCA was performed to evaluate the effectiveness of the combination of the different methods, and relates to the multifactorial method applied by Lovejoy et al. (4). However, unlike that study, individual ages were not seriated. PCA was performed on the whole sample (203 individuals). Weights were calculated as the correlation between the first principal component and the age indicators, as suggested by Lovejoy et al. (4). For SB and IC, the mean ages were utilized in the original articles as point estimates, but for AS, a 5-year age range for each stage was utilized. Thus, for statistical purposes in the application of AS, the mid-point of each age range was arbitrarily used as the age estimate. As the range of the last phase in the AS method is infinite (over 60 years), we decided to use 65 years as the mean age, again to facilitate statistical analysis. Linear combination weights were then calculated as in the original article.

TABLE 1—*Median, mean, and range of ages for each age group.*

	N* Min–Max† Median (Mean)‡	
Age (Years)	White	Black
25–40		
Female	9	25
	29–40	26–39
	35 (35.6)	33.0 (33.4)
Male	15	17
	27–39	26–38
	33.0 (33.7)	32.0 (32.0)
41–60		
Female	20	20
	41–60	41–60
	52.0 (52.4)	48.5 (49.5)
Male	19	18
	41–59	42–60
	53 (51.9)	51.5 (51.8)
>60		
Female	14	15
	61–80	61–83
	71.5 (70.7)	70.0 (69.7)
Male	21	25
	61–85	61–91
	72.0 (73.0)	70.0 (73.7)
All Ages		
Female	43	60
	29–80	26–83
	54.0 (54.8)	46.0 (47.8)
Male	55	60
	27–85	26–91
	57.0 (55.0)	58.0 (55.3)

*Sample size.
†Minimum and maximum ages.
‡Median age (mean age).

Results

The results of the described study are shown in Tables 1–6 and in Figs. 1 and 2, which, in general, reveal the relative accuracy of the different methods in different instances. The correlation between the first principal component and age indicators and correlations between real age and age indicators are presented in Table 2. The PCA equation is as follows, with the weights representing the correlations from Table 2:

$$\begin{aligned}\text{Estimated age} \;=\; & 0.76{\times}\text{AgeIC} + 0.83{\times}\text{AgeAS} + 0.86{\times}\text{AgeSB} \\ & + 0.69{\times}\text{AgeLM}/(0.76 + 0.83 + 0.86 + 0.69)\end{aligned}$$

These results show the considerable proportion of total variation explained by the first principal component, which is 62.5%. In the discussion, we only take into account the median but we also present the mean to allow comparison with other studies. If we consider

TABLE 2—*Correlations of age indicators with first principal component and with real age.*

	Correlation* With	
Age Indicator	First Component†	Real Age
Işcan (IC)	0.76	0.66
Lovejoy (AS)	0.83	0.57
Suchey–Brooks (SB)	0.86	0.67
Lamendin (LM)	0.69	0.58

*Pearson's correlation coefficients.
†Proportion of total variation explained by the first principal component is 62.5%.

TABLE 3—*Median [P5-P95] and mean ± SD values of inaccuracy in the combined White and Black samples.*

Age Group (Years)	IC		SB		AS		LM		PCA	
	Median	Mean	Median	Mean	Median	Mean	Median	Mean	Median	Mean
25–40	6.3 [0.7–21.2]	8.1 ± 7.8	4.3 [0.7–15.6]	6.2 ± 5.4	6 [0–20]	8.2 ± 6.7	10.7 [1.4–21.5]	11.3 ± 6.2	5.5 [0.4–18.4]	6.4 ± 5.2
n	65	65	62	62	64	64	66	66	59	59
41–60	8.2 [0.8–22.3]	9 ± 6.1	8.2 [0.4–23.3]	9 ± 7.1	7 [1–20]	8.8 ± 6.1	5.1 [0.5–15.5]	6.1 ± 4.7	5.1 [0.4–12.9]	5.8 ± 4.2
n	76	76	75	75	77	77	77	77	74	74
>60	10.8 [1.2–33]	13.4 ± 10.3	15.1 [1.8–36.8]	16 ± 10.6	16.5 [1–36]	17.4 ± 10.4	16.1 [2.4–32.5]	16.6 ± 9.3	14.1 [3.2–28.3]	14.7 ± 8.2
n	75	75	70	70	74	74	75	75	70	70
All ages	8.8 [0.8–27.8]	10.3 ± 8.6	8.6 [0.8–27]	10.5 ± 9	10 [1–29]	11.6 ± 9	9.7 [0.7–27.7]	11.3 ± 8.2	6.7 [0.5–23]	9.1 ± 7.3
N	216	216	207	207	215	215	218	218	218	218

IC, Işcan; SB, Suchey–Brooks; AS, auricular surface; LM, Lamendin method; PCA, principal component analysis.

the entire population (Table 3), IC and SB performed better than LM and AS. Multiple indicators (PCA), however, yielded the lowest inaccuracy, with a median of 6.7. On the other hand, if the population is broken down by age groups ([i.e., young [25–40], middle [41–60], old [>60]), the order changes. In the young adult range, the more accurate methods, in decreasing order, are SB; PCA; AS; IC; and LM. In the middle adult age range, the situation is drastically different: LM and PCA rate as the best methods and are equally accurate (median 5.1), followed by AS, SB, and IC. In the old age range, medians increase greatly but the most accurate method is IC, followed by PCA, SB, LM, and AS.

If we subdivide the population by race (i.e., Blacks and Whites), patterns are similar, with only slight differences (Tables 4 and 5).

For Whites, if we consider all ages, again, the best method is PCA (median 6.6), followed by LM; IC; SB; and AS. For Blacks, PCA (median 6.7) is the most accurate method, followed by SB, IC, LM, and AS.

If we consider the young adult age range, SB (median 3.25) is the most accurate method for both races. The IC method seemed to be the most accurate method for Blacks but the least accurate method for Whites (Tables 4 and 5).

When looking at the middle age range, for Whites, LM (median 3.9) is the most accurate, followed by PCA; AS; IC; and SB, while for Blacks PCA (median 4.8) is the most accurate. Finally, if we consider the old age range, IC (median 10.4 for the Blacks and 10.3 for the Whites) is the most accurate for both groups.

If we subdivide the study sample by sex, the results show, once again, a similar pattern. If all ages are included, regardless of the sex, PCA gives the lowest inaccuracy. If the different age groups are considered within each population or sex group, results are compatible to those obtained with the combined sample (Table 6).

As regards bias (Figs. 1 and 2), the study highlights the tendency of all methods to overestimate the age of young individuals, and to underestimate age in older individuals. For the middle adult age group, the bias is the smallest and the LM method is the most accurate, especially for Black individuals.

Thus, if we consider the three age groups separately, from 25 to 40 years of age, the most accurate method, on the whole, is SB, from 41 to 60 years of age, the best method is LM, and after the age of 60 years, all methods are highly inaccurate although IC gives the lowest inaccuracy. For combined age groups, PCA is the most accurate.

Discussion

Our results agree in part with those of Saunders et al. (5), as the multifactorial method does not seem to perform largely better than single methods.

On the other hand, they differ from Baccino et al. (23), who compared seven methods of estimating age on 19 White individuals, and showed that combined approaches offer superior results to single ones. These differences may stem from different sample numbers and age ranges observed.

TABLE 4—*Median [P5-P95] and mean ± SD values of inaccuracy in the Black sample.*

Age group (years)	IC		SB		AS		LM		PCA	
	Median	Mean	Median	Mean	Median	Mean	Median	Mean	Median	Mean
25–40	5.8 [0.7–27.2]	8.6 ± 8.8	4.7 [0.5–19.6]	6.6 ± 5.6	6 [1–18]	8.1 ± 6.5	13.6 [5–22.6]	13 ± 6	6.6 [0.4–19.7]	7.1 ± 5.2
n	42	42	40	40	41	41	42	42	39	39
41–60	9.1 [0.3–24.3]	9.5 ± 6.8	6.4 [0.4–27]	8.4 ± 7.7	6.5 [1–20]	8.5 ± 5.8	5.6 [0.5–13.2]	6.2 ± 4	4.8 [0.3–16]	6 ± 4.4
n	38	38	37	37	38	38	38	38	37	37
>60	11.4 [1.5–34.5]	14.4 ± 10.4	15.8 [1.8–30]	15.2 ± 9.4	15 [1–36]	15.8 ± 10.1	16.8 [2.1–32]	16.2 ± 9.6	12.5 [0.8–28.2]	14 ± 8.3
n	35	35	35	35	35	35	35	35	35	35
All ages	8.8 [0.7–30.1]	10.8 ± 9.1	8.6 [0.8–25.8]	9.9 ± 8.4	10 [1–27]	10.8 ± 8.4	9.7 [1.1–27.4]	11.9 ± 8	6.7 [0.4–22.8]	8.9 ± 7
N	120	120	112	112	118	118	120	120	111	111

IC, Işcan; SB, Suchey–Brooks; AS, auricular surface; LM, Lamendin method; PCA, principal component analysis.

TABLE 5—*Median [P5-P95] and mean ± SD values of inaccuracy in the White sample.*

Age Group (Years)	IC		SB		AS		LM		PCA	
	Median	Mean	Median	Mean	Median	Mean	Median	Mean	Median	Mean
25–40	6.8 [0.8–15.7]	7.1 ± 5.3	3.25 [0.8–14.6]	5.6 ± 4.9	5 [0–24]	8.3 ± 7.4	6.7 [1.4–20]	8.5 ± 5.4	6.6 [0.37–17]	5.1 ± 5.1
n	230	23	22	22	23	23	24	24	20	20
41–60	8.1 [1.2–19]	8.5 ± 5.4	9.3 [0–23.3]	9.7 ± 6.6	7 [1–21]	9.1 ± 6.4	3.9 [0.14–17]	6 ± 5.3	5.1 [0.45–13]	5.7 ± 4.1
n	38	38	38	38	39	39	39	39	37	37
> 60	10.3 [0.8–32]	12.2 ± 10.1	14.8 [1–42]	16.7 ± 11.8	21 [0–37]	19.1 ± 10.6	16.1 [2.4–37]	16.9 ± 9.1	14.4 [5–33]	15.3 ± 8.2
n	35	35	35	35	35	35	35	35	35	35
All ages	8.2 [0.8–22.3]	9.5 ± 7.7	9.8 [0.4–31.3]	11.3 ± 9.6	11 [0–30]	12.5 ± 9.7	8 [0.6–27.7]	10.5 ± 8.4	6.6 [0.6–24.5]	9.3 ± 7.8
N	96	96	95	95	97	97	98	98	92	92

IC, Işcan; SB, Suchey–Brooks; AS, auricular surface; LM, Lamendin method; PCA, principal component analysis.

In our study, PCA analysis gave better results for inaccuracy regardless of population ancestry and sex if one does not consider the age range. If we take into account the three age ranges proposed, PCA gives lower inaccuracies only in one single group: 40–60-year-old Blacks.

As regards the validity of single methods tested on samples of varied ancestries, we did not find significant differences. Schmitt (1) applied the SB and AS methods to an Asian population and found a greater error with respect to what was reported in the literature. In 2002, Prince and Ubelaker (24) studied the applicability of the LM method to the Terry collection and created new equations for both males and females of Blacks and Whites. Nevertheless, their results with initial formulae were better than those reported in the initial publication of Lamendin et al. (11). Katz and Suchey (10) showed that the SB methods overestimated age in Blacks, whereas Işcan et al. (2) tested the fourth rib method on the Terry collection and found that it gave different results for Blacks compared with Whites. The study reported here, however, does not reveal such significant differences in the application of the four methods to Blacks and Whites.

The above-mentioned observations concerning PCA analysis and ancestry differences appear to be reliable. This study in fact has the strength of sample size, as it includes 218 subjects with an almost equal number of Blacks and Whites, of both sexes. All methods were tested on all subjects. The presence of only three large age ranges enabled a sufficient number of individuals per age group. The minimal samples presented in other studies complicate interpretation. For example, Bedford et al. (6) studied between 48 and 54 individuals, Saunders et al. (5) 27–49 individuals, Baccino et al. (23) 19 individuals, and Schmitt (1) 66, with some age groups represented by only two individuals.

Although the Lovejoy method (14) is utilized most frequently in paleodemography, it retains a valid place in forensic anthropology, as Osborne et al. (22) have suggested. It is more accurate than the IC method in the White sample, and is more accurate than IC and SB for the 41–60-year age group. However, if we pool all ages, AS is the least precise method, regardless of specimen ancestry. This suggests that one should take into account, if possible, the presumed age range in the final evaluation.

As concerns the performance of each single method, this study suggests that for White and Black young adults, the pubic symphysis and AS methods, followed by fourth rib evaluation, are the most reliable; in older adults (> 40), the LM method seems to be the most reliable.

More importantly, this study supports the results obtained by Baccino et al. (25) and Martrille and colleagues (26,27) with their "two-step procedure" (TSP), which has recently been tested on a large population, with greater accuracy than that found using single methods individually (28). TSP consists of first observing the pubic symphysis. If the symphysis corresponds to phases I, II, or III of the SB method, age estimation should be performed with this method for more accurate results. From phase IV onwards, estimation should be made by the LM method. Similarly, in the absence of the pubis or AS, when sex is known, if ribs are in

TABLE 6—*Comparison of male and female median [P5-P95] values of inaccuracy in combined White and Black samples.*

Age Group (Years)	IC		SB		AS		LM		PCA	
	Female	Male	Female	Male	Female	Male	Female	Male	Female	Male
25–40	6.6 [0.7–34.2]	5.8 [0.2–21]	4.7 [0.8–17]	3 [0.3–15]	6 [0–20]	5 [0–24]	12.7 [1.6–23]	8.6 [1.3–19]	5 [0.2–19.7]	6.3 [1.1–18]
n	42	42	40	40	41	41	42	42	39	39
41–60	9.3 [0.7–23.3]	8 [0.8–18]	9.8 [0–27]	7 [0.4–23]	9 [2–22.5]	6 [1–20]	3.8 [0.2–16]	6.5 [0.8–13]	5 [0.2–17.7]	5.2 [0.4–12]
n	38	38	37	37	38	38	38	38	37	37
> 60	14.3 [1.2–36]	10.3 [2.5–28]	17.9 [4–31]	14.8 [1.8–41]	20 [1–37]	15 [1–32]	15.4 [1.8–28]	17.4 [4–32]	17.2 [2–27]	13.9 [5–28.3]
n	35	35	35	35	35	35	35	35	35	35
All ages	9.5 [0.7–30]	8 [0.8–26]	9.8 [0.8–27]	7.8 [0.7–26]	9 [1–29]	11 [1–27]	8.2 [0.5–24.6]	10.2 [1.2–30]	6.4 [0.4–22.8]	6.9 [0.6–27]
N	120	120	112	112	118	118	120	120	111	111

IC, Işcan; SB, Suchey–Brooks; AS, auricular surface; LM, Lamendin method; PCA, principal component analysis.

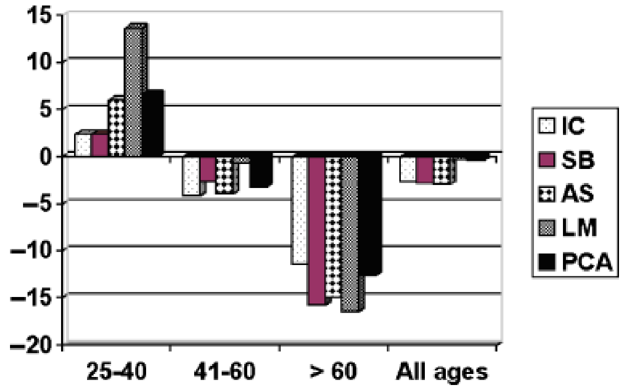

FIG. 1—*Age distribution of bias of the different methods in the Black sample.*

phases 1–5 of the IC method, this should be the selected method for age determination. For older phases, the LM method should be used.

The study reported here goes one step further to show that in individuals over 60 years of age, inaccuracy is lower with IC and SB than with LM. Thus, in the examination of an unknown case, the investigator can first apply TSP and then knowing the approximate age at death can select the appropriate method to produce the most accurate result.

Concerning the underestimation of age for old individuals, the extreme underaging in the >60 category is partly an artifact of the aging criteria of arbitrarily setting the maximum age of 65 years, although some individuals in the sample greatly exceed that maximum. The overestimation of age for young individuals could be an artifact of the regression equations used in the original studies.

As noted by Saunders et al. (5), no single skeletal indicator of age at death is ever likely to reflect accurately the many factors that accumulate with chronological age. In fact, one must use as many dental and skeletal indicators as possible. However, in order to maximize the potential of each method, in the final evaluation one should consider mainly the method or methods that have a lower inaccuracy for a particular age range, once one has, as mentioned above, placed the individual in a general young/old age group by preliminary selection with the pubic symphysis or the ribs.

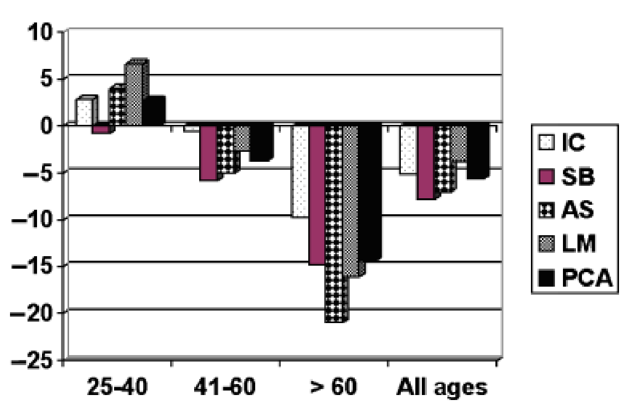

FIG. 2—*Age distribution of bias of the different methods in the White sample.*

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Additional information and reprint requests:
Laurent Martrille, M.D.
Service de Médecine Légale
Centre Hospitalier Universitaire
Hopital Lapeyronie
191 Avenue du Doyen Gaston Giraud
34295 Montpellier, Cedex 5
France
E-mail: l-martrille@chu-montpellier.fr