Int J Legal Med (2001) 114 : 215–223

ORIGINAL ARTICLE

Joachim Wahl · Matthias Graw

Metric sex differentiation of the pars petrosa ossis temporalis

Received: 6 March 2000 / Accepted: 3 May 2000

Abstract The importance of the petrous portion for metric sex determination is a controversial subject in the archaeological and anthropological literature. To achieve a forensically suitable method for sex differentiation, 10 measuring distances were determined on recent forensic material in the form of 410 petrous portions, which had proved to be reliable in the preliminary examinations. The most important findings can be summarized as follows: the petrous portion revealed significant metric sex differences, in particular the width:height index ($P < 0.001$); the sex differences are age-dependent; differences in the measuring distances on the petrous portion can be observed with regard to their lateral location on either side of the skull; the discrimination analysis allows a correct classification of two-thirds of all petrous portions studied. To some extent, these findings contrast with those already published, but the discrepancies can be attributed primarily to the different composition of the samples used in the respective studies.

Keywords Sex determination · Temporal bone · Petrous portion · Pars petrosa ossis temporalis · Skull base

Introduction

Bone measurements (morphometric variables) have always been part of the anthropological spectrum of methods used for sex differentiation. In the assessment of cremated skeletal remains in particular, these data, which naturally only relate to small dimensions, provide important factors in determining the sex of an individual. These examinations still play a significant part in the forensic practice. It is therefore in the interest of both disciplines that the published measuring schemes are verified using new samples of both prehistoric and recent material and that new methods are established, examined and optimised (van Vark and Amesz-Voorhoeve 1996; Wahl 1996).

The pars petrosa ossis temporalis (petrous portion of the temporal bone) is located on both sides of the skull between the middle cranial and posterior fossae, and its pronounced shape determines the relief of the cranial base. The observation that the metrical features of the cranial base are markedly different in males and females (Graw 1999a; Holland 1986, 1989; Teixeria 1982) suggests that the petrous portion could be used for a differential sex diagnosis. Few papers have been published so far on this subject and in those that have, the composition and low number of samples included in the investigations must be viewed critically (Wahl and Henke 1980; Wahl 1981; Schutkowski 1983, 1990; Kalmey and Rathbun 1996). In addition, the anatomical landmarks on the petrous portion have not yet been defined unambiguously (Schaefer 1961; Kloiber 1965). By examining a larger number of petrous portions it should therefore be possible to assess the suitability for application to sex differentiation.

Material and methods

Recent forensic material in the form of 410 isolated and macerated petrous portions were used for the investigations (Table 1). The landmarks (MP) were selected to meet the requirement that re-

Table 1 Material used for the investigations

Sex	Left petrous portions (n)	Symmetrical right petrous portions	Age distribution and range (years)
Male	170	78	47.7 ± 19.6 (19–94)
Female	104	58	54.5 ± 20.7 (21–95)

J. Wahl
Landesdenkmalamt Baden-Württemberg, Archäologische Denkmalpflege, Osteologie, Stromeyersdorfstrasse 3, 78467 Konstanz, Germany

M. Graw (✉)
Institut für Gerichtliche Medizin, Universität Tübingen, Nägelestrasse 5, 72074 Tübingen, Germany
e-mail: matthias.graw@gmx.de,
Tel.: +49-7071-2976820, Fax: +49-7071-252456

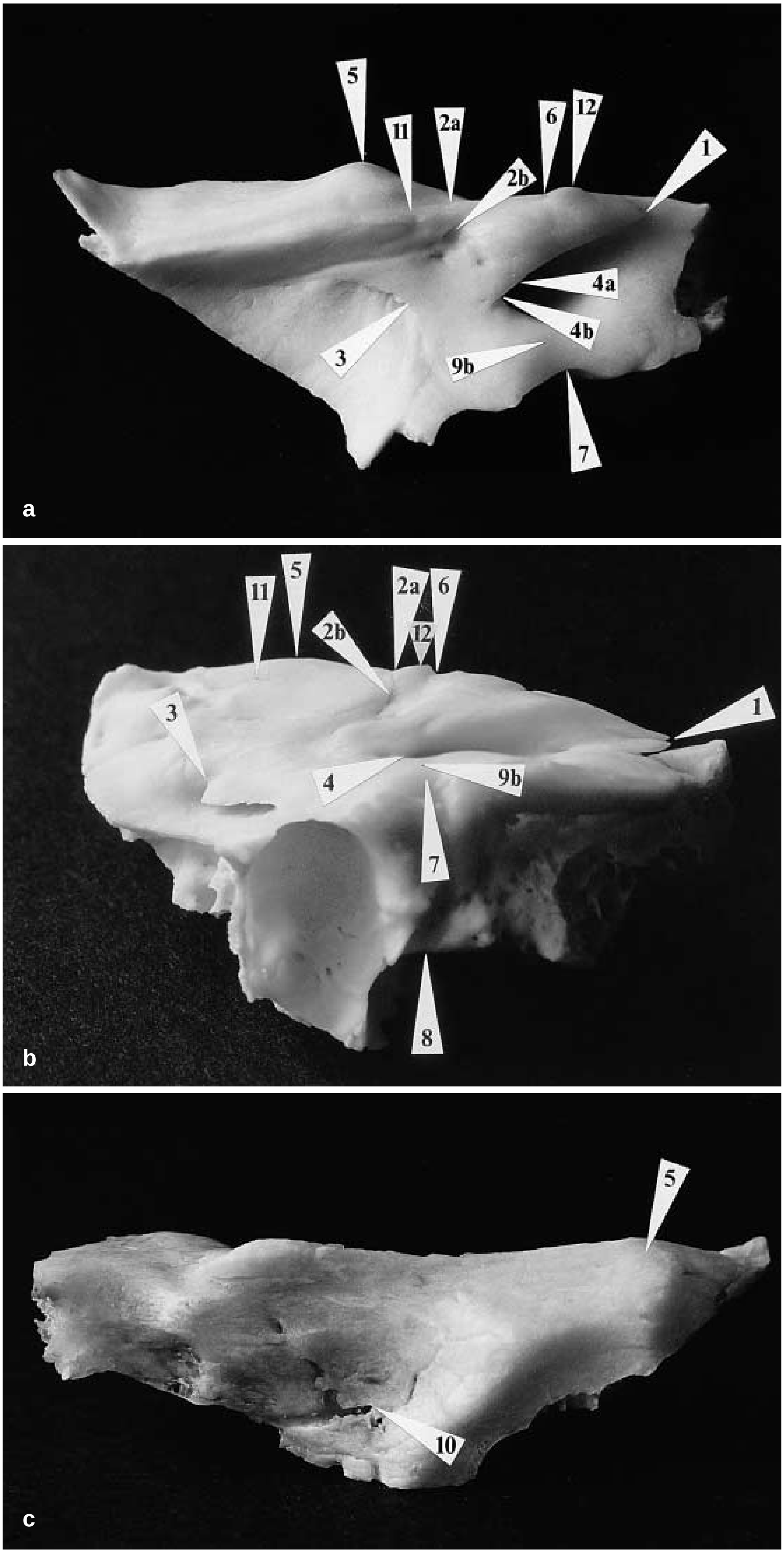

Fig. 1 a–c Landmarks on the petrous portion of the temporal bone for measurements. **a** Posterior surface; **b** posterior surface and basilar part; **c** anterior surface (definitions are given in the text; measuring point 9a is located in close vicinity to MP7) spective measurements can still be taken even in the case of fractured or damaged skulls. Longitudinal measurements were therefore only considered to a limited extent. The following 15 landmarks (Figs. 1a–c) were initially defined:

1. MP 1: Superior margin (margo superior): medial end of the exostosis suprameatum, medial from the porus acusticus internus (P.a.i.; opening of internal acoustic meatus) the “end of the torus” is occasionally only recognisable by a fine suture, but is sometimes marked by an overhanging exostosis
2. MP 2a: Superior margin: lowest point in the area of the fossa subarcuata (subarcuate fossa)
3. MP 2b: Posterior surface: largest foramen in the area of the fossa subarcuata (1–3 are shown here; sometimes there are additional minute apertures); if an exostosis forms a roof over the foramen, then the lowest point has to be located
4. MP 3: Posterior surface: cranial angle of the free (i.e. protruding) medial border of the apertura externa canaliculi aquaeductus vestibuli (external opening of the vestibular aqueduct)
5. MP 4a: Posterior surface, P.a.i.: landmark on the dorsal border above the centre of the porus canal
6. MP 4b: Posterior surface, P.a.i.: lateral landmark on the dorsal border at the porus, occasionally descending to MP 4a
7. MP 5: Anterior surface: punctum maximum of the highest elevation (eminentia arcuata), located more or less cranially from MP 3
8. MP 6: Superior margin: landmark selected cranially from the P.a.i. and with the smallest distance to MP 7; if the margin has a double contour where the sulcus sinus petrosi superioris (groove for superior petrosal sinus) tapers out, the MP is located on the dorsal (usually lower) border
9. MP 7: Posterior surface/base: landmark on the apertura externa canaliculi cochleae (external opening for the cochlear canaliculus) that is most strikingly directed towards the P.a.i.: if it runs in a curve it can easily “wander”, depending on the measuring distance
10. MP 8: Base (ventral): top-most landmark on the upper edge of the canalis caroticus (carotid canal)

Table 2 Metric lateral differences of the petrous portion (The measuring distances are explained in the text and in Figs. 1, 2, 3, *variable, petrous portions of both hemispheres; measurements given in mm)

Measuring distance, side	*n*	Mean	SD	SE	Difference	Significance	SE_{diff}
*1→2b							
Left	122	15.7574	2.960	0.268			
Right	122	15.4344	2.508	0.227	0.3230	$P = 0.359$	0.351
*1→3							
Left	123	24.4894	3.074	0.277			
Right	123	24.0672	3.080	0.279	0.4220	$P = 0.284$	0.393
*3→4b							
Left	132	11.5614	2.185	0.190			
Right	131	11.4489	2.087	0.182	0.1125	$P = 0.670$	0.264
*3→11							
Left	130	9.3077	2.123	0.186			
Right	130	9.4738	2.030	0.178	0.1662	$P = 0.519$	0.258
3→2b							
Left*	130	9.6100	2.103	0.184			
Right	129	9.3605	2.036	0.179	0.2495	$P = 0.333$	0.257
*2b→4b							
Left	131	5.3107	1.183	0.103			
Right	131	5.1893	1.273	0.111	0.1214	$P = 0.425$	0.152
*7→4b							
Left	131	6.8282	1.069	0.093			
Right	129	7.3062	1.188	0.105	0.4780	$P = 0.001$	0.140
*7→4b (♂♂)							
Left	73	7.0945	1.034	0.121			
Right	73	7.5370	1.086	0.127	0.4425	$P = 0.013$	0.175
*7→4b (♀♀)							
Left	58	6.4931	1.026	0.135			
Right	56	7.0054	1.257	0.168	0.5123	$P = 0.019$	0.215
*7→6							
Left	130	13.6977	1.756	0.154			
Right	129	13.9202	1.757	0.155	0.2225	$P = 0.309$	0.218
*8→9b							
Left	126	10.1929	1.672	0.149			
Right	124	10.0258	1.423	0.128	0.1671	$P = 0.396$	0.197
*7→12							
Left	131	15.6588	1.821	0.159			
Right	128	15.7430	1.830	0.162	0.0842	$P = 0.711$	0.187

Table 3 Metric sex differences of the petrous portion (the measuring distances are explained in the text and in Figs. 1, 2, 3, *variable, left petrous portions; measurements given in mm)

Measuring distance, sex	*n*	Mean	SD	SE	Difference	Significance	SE_{diff}
*1→2b							
♂	156	16.1327	3.090	0.247			
♀	98	15.4459	2.802	0.283	0.6868	$P = 0.075$	0.384
*1→3							
♂	157	24.7567	3.314	0.264			
♀	100	24.6000	3.047	0.305	0.1567	$P = 0.703$	0.411
*3→4b							
♂	168	11.4226	2.058	0.159			
♀	104	12.0125	2.231	0.219	0.5899	$P = 0.027$	0.265
*3→11							
♂	166	9.3946	2.051	0.159			
♀	103	9.1126	1.882	0.185	0.2820	$P = 0.259$	0.249
*3→2b							
♂	166	9.7639	2.171	0.168			
♀	102	9.8294	2.205	0.218	0.0656	$P = 0.812$	0.275
*2b→4b							
♂	167	5.4719	1.310	0.101			
♀	102	4.9735	1.107	0.110	0.4983	$P = 0.002$	0.156
*7→4b							
♂	167	7.0826	1.052	0.081			
♀	103	6.6327	0.986	0.097	0.4499	$P = 0.001$	0.128
*7→6							
♂	167	14.0838	1.771	0.137			
♀	103	13.3447	1.530	0.151	0.7391	$P = 0.001$	0.211
*8→9b							
♂	163	10.1337	1.503	0.118			
♀	100	10.3850	1.809	0.181	0.2513	$P = 0.225$	0.206
*7→12							
♂	167	15.9701	1.974	0.153			
♀	104	15.4269	1.651	0.162	0.5431	$P = 0.020$	0.232
*Width:height index (8→9b/7→4b)							
♂	163	1.4609	0.284	0.022			
♀	100	1.6154	0.421	0.042	0.1545	$P < 0.001$	0.044
*Surface index I (3→4b/2b→4b)							
♂	166	2.2112	0.761	0.059			
♀	102	2.5094	0.646	0.064	0.2982	$P = 0.001$	0.090
*Surface index II (3→4b/7→6)							
♂	167	0.8187	0.153	0.012			
♀	103	0.9068	0.163	0.016	0.0881	$P < 0.001$	0.020

11. MP 9a: Base (dorsal): landmark on the upper edge of the apertura externa canaliculi cochlea (external opening for the cochlear canaliculus) with the smallest distance to MP 8
12. MP 9b: Posterior surface: highest point on the area covered by MP 7 and P.a.i.
13. MP 10: Anterior surface: opening of the hiatus canalis facialis (hiatus of facial canal)
14. MP 11: Superior margin: landmark on the margin with the shortest distance to MP 3 [in the case of a double ridge of the sulcus sinus petrosi superioris dorsalis, (groove for superior petrosal sinus)]
15. MP 12: Anterior surface/superior margin: highest point above the porus opening with maximal distance to MP 7

Nineteen distances determined by MP 1–12 were selected; the measurements taken by Wahl (1981) (W1–3) and Schutkowski (1983) (BM, HM, LM) are given in parentheses:

Measurements on the longitudinal axis (medial-lateral): 1→2a; 1→2b (LM5); 1→3 (LM4); 2b→4b; 3→4a; 3→4b (LM6); 3→2b; 5→10 (LM3)

Measurements on the normal axis: 5→7 (HM3); 3→5 (HM4); 3→11; 7→4a (W2); 7→4b (HM1); 7→6 (W1; HM2); 7→12

Measurements in the sagittal direction: 3→10 (BM3); 7→10 (BM2); 8→9a (W3; BM1); 8→9b

To check that the landmarks were unequivocal and the measurements reliable, a test run was carried out involving 50 petrous portions from males and females, which were measured by two independent researchers using calibrated calipers (with a measuring accuracy of 0.1 mm) and 20 petrous portions were measured 5 times each. The data were compared, and intra-individual variations of 0.2 mm, and inter-individual variations of 0.3 mm were defined as the limits of tolerance. The measurements for MP 5 and MP 10 in particular, varied by up to 6 mm and were thus unacceptable as landmarks. MP 5 is referred to as the punctum maximum of the eminentia arcuata and cannot be precisely determined: this region is often raised to form a plateau or rises constantly over a longer stretch so that it is difficult to define an exact punctum maximum. MP 10 is problematic for two reasons. Firstly, several anatomical variants of the canal end exist: it can consist of several openings or can be incompletely covered, with the result that no single definitive opening can be made out. Secondly, because the hiatus is located close to the border of the petrous portion, in some cases the natural opening is not present at all. In the case of the alternative landmarks MP 2a/b, 4a/b and 9a/b, those which allowed handling with "clamp measures" led to better results.

Following these initial examinations, it was possible to define 10 of the original 15 landmarks accurately and well, and the following 10 out of the 19 distances could be reliably determined (Graw 1999b):

1→2b, 1→3, 2b→4b, 3→2b, 3→4b, 3→11, 7→4b, 7→6, 7→12, 8→9b

The 410 isolated temporal bones were measured, but due to fractures and maceration artefacts not all distances could be measured on all of the petrosa. Statistical calculations were carried out with the computer programme SPSS (SPSS, version 9.0.1.).

Results

Lateral differences

In both sexes the variable 7→4b is larger in the right hemisphere and for this reason, the width:height index (WH index) is smaller in the right hemisphere than in the left; otherwise no marked side (lateral) differences were observed (Table 2).

Sex dimorphism

The male petrous portions generally gave larger values than the female petrous portions; only the distances 3→4b (significant) and 8→9b (broadly similar) are longer in females (Table 3). The median differences of the longitudinal distances 1→2b, 1→3 and 3→2b and the height 3→11 were not significant and three quotients were determined from the individual distances to characterise the width:height ratio and the relative size differences on the posterior surface. The width:height index (WH-index: 8→9b/7→4b) and the surface indexes I (3→4b/2b→4b) and II (3→4b/7→6) are highly significant in their capacity to differentiate the gender due to the contrasting size ratios of the individual components; because of the distance 7→4b the WH-index also differs between the right and left hemispheres (left > right, P = 0.002).

In total, the measurements were extremely variable in both sexes, thus making it rather difficult to predict the sex of an individual with one single measurement. In some cases, the distribution frequencies were so different, however, that values needed to be estimated to serve as a threshold from which point onwards the sex of an individual can be predicted with high probability and which can, in certain cases, be used for assessment, at least as a means of orientation (Table 4).

Table 4 Uni- and bivariate threshold values for the diagnosis of gender using petrous portion; median values and variation for females and males; threshold values relating to the relative frequency of prevalence in either sex (*WHI* width-height index of the left side)

Measure	♂			♀			Threshold value		
	n	Mean	Min–Max	*n*	Mean	Min–Max	Value	% ♂	% ♀
WHI_l	163	1.46 ± 0.28	0.95–2.28	100	1.62 ± 0.42	1.01–3.69	> 2.1	3.0	11.0
3–4b/7–6	167	0.82 ± 0.15	0.35–1.31	103	0.91 ± 0.16	0.53–1.31	> 1.1	3.6	12.0
7→6	167	14.08 ± 1.77	10.4–20.6	103	13.34 ± 1.53	8.9–16.7	> 17.0	6.0	0.0
7→4b	167	7.08 ± 1.05	4.9–9.8	104	6.63 ± 0.99	3.7–8.8	> 8.5	9.6	2.9
2b→4b	167	5.47 ± 1.31	1.8–12.0	102	4.97 ± 1.11	2.7–8.3	> 7.0	10.2	4.9

Table 5 Age-dependent size differences in males division into a group with younger (<50 years) and a group with older individuals (>50 years) (*Variable, measurements given in mm)

Measuring distance, age (♂♂, years)	n	Mean	SD	SE	Difference	Significance	SE_{diff}
*1→3							
<50	87	25.2460	2.927	0.314			
>49	70	24.1486	3.671	0.439	1.0974	P = 0.039	0.526
*3→4b							
<50	91	11.7176	1.914	0.201			
>49	77	11.0740	2.178	0.248	0.6436	P = 0.043	0.316
*7→12							
<50	91	16.2989	1.993	0.209			
>49	76	15.5763	1.890	0.217	0.7226	P = 0.018	0.302
*7→6							
<50	91	14.3495	1.737	0.182			
>49	76	13.7658	1.771	0.203	0.5837	P = 0.034	0.272

Table 6 Age-dependent size differences in females; division into a group with younger (<50 years) and a group with older individuals (>50 years) (*Variable, measurements given in mm)

Measuring distance, age (♀♀, years)	*n*	Mean	SD	SE	Difference	Significance	SE_{diff}
*1→2b							
<50	48	16.1729	3.098	0.447			
>49	50	14.7480	2.306	0.326	1.4249	$P = 0.011$	0.550
*1→3							
<50	48	25.3938	3.127	0.451			
>49	52	23.8673	2.806	0.389	1.5264	$P = 0.012$	0.593
*7→12							
<50	50	15.8080	1.688	0.239			
>49	54	15.0741	1.548	0.211	0.7339	$P = 0.023$	0.317

All distances were checked for correlation with age. In total, a tendency to smaller measurements in more advanced age was registered, however, significant differences were only observed for the "outer measurements", i.e., the shape-giving outer dimensions. The age-dependent differences were more pronounced in females than in males (Table 5, 6).

In view of the significant sex differences of some measurements it was important to elucidate whether a multivariate analysis allowed a sufficiently reliable prediction of sex. For this, the petrous portions of the two hemispheres were divided according to their location on either side of the skull and a step-wise linear discriminant analysis was carried out (Table 7), in which the age-dependent variables, in males at least, proved to be essential for the division.

Correct identification ranged between 63% and 71% in this sample, and approximately two-thirds of all individuals could thus be classified correctly. In view of the greatly differing coefficients, the ability to transfer the functions to the contralateral side, and thus arrive at a generalisation, was very difficult to achieve, even if the side-different variable 7→4b was excluded from the analysis. Reconfirmation of the discriminant functions with the petrous portions, which were not available in pairs, resulted as expected in worse results (by 5–10%).

The ability to differentiate between the hemispheres improved if the age-dependent variability could be adequately accounted for by determining separate discriminant functions on the left petrous portions for partial samples that consisted only of individuals above and below 50 years of age.

Younger individuals could be classified correctly in 68.15% of all cases studied using the discriminant function:

$$y = -0.5256202 \times 2b{\rightarrow}4b + 2.1205574 \times \text{WH-index}_{left} - 0.4466887 \quad (1)$$

(males 66.3%, females 71.4%, intersection point 0.104425, females >males; WH - index = 8→9b/7→4b).

For older individuals, positive results based on the discriminant function

$$y = 0.4109333 \times 3{\rightarrow}4b - 0.5063140 \times 7{\rightarrow}5 + 2.1826772 \quad (2)$$

amounted to 74.19% (males 72.7%, females 75.9%, intersection point 0.05318, females > males).

Discussion

With regard to its suitability for sex differentiation, the human petrous bone has until now been examined mainly from a prehistoric, anthropological point of view. In journals that appear in English, only very few papers have

Table 7 Discriminant functions of the petrous portion; three each are given for the left side (left I-III) and the right side (right I-III)

Measuring distance	Left I	Right I	Left II	Right II	Left III	Right III
2b→4b	0.2762061	0.4077059	–	–	0.2261543	–0.2240305
3→4b	–0.3408813	–0.2852090	–0.3216359	–0.2445353	–	–
7→6	0.4476418	0.4392061	0.3155736	0.3753353	0.4069368	–0.2618918
7→4b	–	–	0.5430454	0.4199971	–	–
WH-ind	–	–	–	–	–1.2698041	2.5035955
Constant	–3.6666203	–4.9797823	–4.2812041	–5.4908212	–4.7895543	1.2885634
♂ Mean	0.37489	0.255554	0.39826	0.26197	0.27522	–0.33094
♀ Mean	–0.48200	–0.33916	–0.51627	–0.34150	–0.35676	0.43709
Intersection point	–0.053555	0.04181	–0.059005	–0.07953	–0.04077	0.053075
Correct % ♂	70.8%	64.4	65.8	64.4	77.1	71.4
Correct % ♀	71.4%	65.5	68.4	62.5	48.1	64.2
Correct % ♂ + ♀	71.1%	64.8	66.9	63.6	64.5	68.3
n ♂	72	73	73	73	70	70
n ♀	56	55	57	56	54	53

been published on this topic so far. Due to its protected location at the cranial base it is frequently found intact after cremation and can thus still be used in anthropological investigations (Wahl and Henke 1980; Wahl 1981; Schutkowski 1983). As far as recent forensic material is concerned, only investigations carried out on fetuses (Kósa and Fazekas 1973), as well as recent investigations carried out on skulls from the American Terry-Collection (Kalmey and Rathbun 1996) are available. Schutkowski (1983, 1990) carried out investigations with material obtained from a German neuropathology collection, where the average age of the donors (approximately 70 years) was disproportionately high. The results of these investigations, as far as general applicability is concerned, must be viewed critically. Other findings obtained from studies using recent petrous portions from Germany or Europe have not yet been published, so that the value of this bony structure with regards to its use in the assessment of forensically relevant bone finds still remains unclear.

Of the ten distances which could be reliably determined, five revealed significant sex differences. Wahl (1981; 85 males, 69 females) found significant differences in two of the three variables used to assess the temporal surface; Schutkowski (1983; 47 males and 47 females) found significant differences in 6 out of 13 variables; Kalmey and Rathbun (1996; 66 females, 72 males, Europeans and Africans) found two significant left-sided and three significant right-sided sex-differentiating measurements on the petrous portion. Papangelou (1975) found that the meatus acusticus internus was larger in females. Schaefer's claim (1961) that the petrous bone is unsuitable for sex differentiation does not therefore hold true. However, the absolute differences of the median values as regards interindividual variations are sometimes so large that a univariate sex differentiation is only possible in a few cases. Of particular importance here are the quotients and distances on the longitudinal axis (Table 4). Wahl (1981) chose slightly different measuring distances but also emphasised the significant sex differences of the width:height ratio (e.g. 8→9b, 7→6), as well as the width of the petrous portion (which can be compared to 7→6) and the width of the porus (similar to 7→4b).

When the data are compared directly (Table 8) it becomes obvious that Wahl's distances (1981) were smaller despite a relatively larger difference between the sexes (15–20% of the absolute values). This finding can certainly be attributed to the historical samples, which were morphologically different, and the relatively small sample size used in this investigation. On the other hand, Wahl investigated skulls of individuals whose sex had already been determined beforehand, i.e. skulls where the morphology was definitely sex-specific; so-called indifference types therefore remained unconsidered. In the present sample, material of known sex was used which had not, however, undergone preselection and exclusion of indifference types, so that the whole spectrum of variability of petrous portions could be taken into account.

Schutkowski (1983) found values that corresponded to the distances 7→6 and 7→4b used in this study. The tendency to lower values might be attributed to the high average age of that sample. A marked discrepancy was apparent, however, for the distance 8→9b (BM1), where although the landmarks differed only slightly, the distances measured differed by a factor of almost 2. Wahl (1981), whose measuring distance was referred to by Schutkowski (1983) expressis verbis, found values similar to those determined in the present investigation. In addition, in most cases the female values were nearly always higher in both this study and the study by Wahl, whereas Schutkowski registered significantly higher values for the male specimens. However, he selected a distance that cannot be reproduced anatomically with any precision and that is not compatible with the distance 8→9a/b.

In the initial investigations carried out to ensure an accurate allocation of the measuring distances, the landmarks MP 5 and MP 10, which are included in three of the nine distances used by Schutkowski (1983) for the differentiation of males and females, were excluded from the study because they were not entirely unequivocal. Kalmey and Rathbun (1996) also excluded all distances that involved MP 5 (*EA* eminentia arcuata), with the exception of one distance on the right hemisphere (with a surprisingly high standard deviation), from their further investigations. The difficulties experienced by these authors with MP 5 can be deduced from the extremely complex description "take measurement on *EA* at the highest point; if *EA* is plateau or if it has two peaks at either end then take the measurement in the center" (Table 9). In view of the problems arising with definition and reliability, it is doubtful whether the general transfer of these data for use in the classification of other petrous portions is justified. In addition, measurements that involved the apex partis petrosae, as carried out by Schutkowski (1990), who found good results when determining the sex of children (aged 0–3 years old) using a rather small eighteenth/nineteenth century sample, were not taken into consideration in the

Table 8 Data of different authors comparing three sizes of the petrous portion, the terms allocated to comparable measurements of other authors cited in the text are given in parentheses

Wahl 1981			Schutkowski 1983			Our data		
7→6 (Var1)	7→4a (Var2)	8→9a (Var3)	7→6 (HM2)	7→4b (HM1)	8→9a (BM1)	7→6	7→4a	8→9b
13.02 ± 1.09	7.12 ± 0.83	8.40 ± 1.31	13.79 ± 1.72	7.31 ± 1.23	17.88 ± 1.77	14.08 ± 1.77	7.08 ± 1.05	10.13 ± 1.50
11.49 ± 0.78	6.08 ± 0.67	8.75 ± 1.22	13.12 ± 1.49	6.50 ± 0.94	17.01 ± 1.65	13.34 ± 1.53	6.63 ± 0.99	10.39 ± 1.81

present investigation: experience has shown that it is usually difficult to unambiguously identify this anatomical structure on fragmented skulls.

When left and right distances were compared, only a single significant difference between the hemispheres (7→4b) was observed: the left petrous portions revealed on average much lower values in both males and females. This finding could be associated with the accentuation of the left carotid bulbus in the majority of right-handed subjects. Schmidt and Dahn (1977), as well as Naga (1965/6), described corresponding hemisphere differences (up to 10%). Wahl (1981) found no hemisphere differences and thus combined the measurements obtained for the left and right petrous portions, which is not unproblematic in view of the most important measuring distance 7→4b of this method, especially when considering the significant lateral differences revealed by the investigation. Schutkowski (1983) examined only petrous portions of the right hemisphere and did not comment on possible side differences. Kalmey and Rathbun (1996) also included right and left petrous portions in their sex assessment but as separate measurements, and they did not elaborate on any possible lateral differences. From the small amount of published data (only 5 out of 18 variables are definitively mentioned) differences of up to 5% from the median values of the right and left measurements can be deduced.

All measuring distances revealed lower values in individuals over 50 years of age in contrast to younger individuals and a significant age-dependency could be confirmed for the "outer measures", i.e. those distances that determine the dimension of the petrous portions. Apparently, the involutive changes in the skull during the late adult/senile phase also involve the cranial base and the petrous portion.

Atrophical and modification processes (Henschen 1949; Angel 1971, 1984; Susanne et al. 1985) might possibly explain reduced width and height in advanced age. The smaller longitudinal dimensions of the petrous portions of older individuals can hardly be attributed to these atrophic alterations, however, due to their medial and lateral fixation. In combination with the significantly smaller distances between glabella and P.a.i./P.a.e., which can be observed in older females in particular, influences caused by accelerated degeneration must also be considered.

The age-dependent changes (along with a reduction of the variance) can explain why Schutkowski (1983) also found distinctly lower values for recent petrous portions in nearly all the distances that were comparable: this sample included individuals with an average age of nearly 70 years (31–94 years), the data therefore corresponded to the subgroup ">49 years" in this study. Wahl did not comment on the age-dependency of the values determined on adult petrous portions, but found a clear correlation between the height:width index and age in children and young adults while examining specimens obtained from fire graves of the imperial and migration years (Wahl 1988). According to his findings, this quotient continually decreased between 1 and 11 years of age from over 70 to below 55 and reaches a value of nearly 65 up to 18 years of age. Kalmey and Rathbun (1996) provided no data on the age structure of their samples. Papangelou (1975) negated a correlation between age and size of the meatus acusticus internus.

Taking all investigations into consideration, univariate sex differentiation seems only possible to a limited degree but a bivariate analysis would be possible using the width:height index, as confirmed by Wahl (1981, 1988). The best procedure, however, is provided by discriminant analysis. Wahl (1981) was able to classify more than 80% of the individuals correctly using the discriminant function:

$$y = 8.5686 \times 7\rightarrow6 + 4.8618 \times 7\rightarrow4b - 1.7151 \times 8\rightarrow9a \quad (3)$$

where the ratio of false predictions was significantly higher in male petrous portions (28.7%) than in females (7.6%).

Table 9 Measuring distances of the petrous portion according to Kalmey and Rathbun 1996

Term	Landmark
L	Sigmoid sulcus-petrous apex intersection (*SS*) to most medial point on petrous (*med. pt.*) (sliding caliper)
C	SS to posterior (lateral) margin of internal acustic meatus (*IAM*) (sliding caliper)
E	Posterior margin of *IAM* to eminentia arcuata (*EA*). Take measurement on *EA* at highest point; if *EA* is plateau or if it has two peaks at either end then take measurement in centre (sliding caliper)
HI	Height of *IAM* (taken at centre of meatus) (vernier dial caliper)
B	Cochlear aqueduct (*CA*) to *EA* (sliding caliper)
D	*CA* to superior margin at *IAM* (centre of superior *IAM*) (vernier dial caliper)
F	*CA* to posterior (lateral) margin of *IAM* (from Wahl) (vernier dial caliper)
G	*EA* to *med. pt.* (sliding caliper)
W	*CA* to hiatus of facial canal (sliding caliper)

Table 10 Discriminant functions of a petrous portion that was not destroyed by fire (Schutkowski 1983)

Measurement	Function No.		
	1	3	6
LM 2	0.25274	–	0.23639
LM 4	–	–	–
LM 5	0.14320	0.14594	–
LM 6	–0.17627	–	–
HM 1	0.58435	0.73064	0.71015
HM 2	0.33077	0.20329	–
BM 1	0.34230	0.42790	–
BM 2	–0.49327	–0.39867	–
BM 3	–	–0.19460	–
Constant	–9.61037	–7.59385	–7.60248
♂ Mean	0.66391	0.54903	0.45406
Section point	0	0	0
♀ Mean	–0.66391	–0.54903	–0.45406
False diagnosis ♀	29.8%	23.4%	29.8%
False diagnosis ♂	17.0%	27.7%	29.8%
False diagnosis ♀+♂	23.4%	25.5%	29.8%

Schutkowski (1983) described three discrimination functions (DF) for petrous portions not affected by fire (Table 10) which were able to classify 75% of the petrous portions correctly (false diagnoses: 23.4–29.8%) when males and females were examined alternatively. The problematic definition of the variable BM1 (= 8→9a), which is included in two DFs, has already been mentioned.

Kalmey and Rathbun (1996) achieved an accuracy of 66–74% (7 DFs, 5 variables). The DF calculated in the present study, which includes all petrous portions, can only differentiate the genders to a far lesser degree than in Wahl's findings (1981); our results are less favourable than the data provided by Schutkowski (1983) and are in the same order of magnitude as the data published by Kalmey and Rathbun (1996). The greater accuracy achieved by Wahl (1981) can be explained by the selection of specimens that were restricted to morphologically sex-typed skulls and thus eliminated indifference types. The material used by Schutkowski (1983) was "artificially homogenised": the restriction to largely senile petrous portions minimises the age-dependent variance of the variables employed.

The comparable differentiation abilities of the DF as far as ethnically mixed American samples are concerned, support the assumption that population-dependent influences of the pars petrosa are of minor importance for sex differentiation (Schutkowski 1983; Kalmey and Rathbun 1996).

If age and the application of a specific DF is incorporated into the investigations, the ability to differentiate the genders improves and corresponds with Schutkowski's findings (1983) to a greater extent. The presumption that a homogenised sample was used in Schutkowski's studies is therefore also confirmed.

As a control, discrimination values were calculated for the isolated petrous portions that were not available pairwise; here the accuracy was reduced to 4–12%. Taking all findings into consideration, the realistically expected maximum accuracy of the sex determination based on measurements of the pars petrosa allows a correct classification in two-thirds of all adult individuals. Thus the reliability of the differentiation reaches an order of magnitude that is satisfactory for archaeological examinations, but is still of marginal importance in forensic sex assessment. Only in the case of severe fragmentation or cremation, i.e. in the case of defensive maceration of the corpse when no other features can be assessed, is it possible to use these criteria; in this case, however, formulae which reflect the absolute longitudinal distances, including the fragile medial and lateral tips (Schutkowski 1983; Kalmey and Rathbun 1996), cannot be applied.

References

Angel JL (1971) Skull vault thickness. Am J Phys Anthropol 35: 272

Angel JL (1984) Variation in estimation age at death of skeletons. Collegium Anthropol 8: 163–168

Graw M (1999a) Metric sex determination of the skull base. Homo 50/2: 101–106

Graw M (1999b) Metrische Geschlechtsbestimmung am Felsenbein. Rechtsmedizin 9 [Suppl)]: A67

Henschen F (1949) Morgagnis Syndrome; Hyperostosis frontalis interna; Virilismus; Obesitas. Oliver and Boyd, Edinburgh

Holland TD (1986) Sex determination of fragmentary crania by analysis of the cranial base. Am J Phys Anthropol 70: 203–208

Holland TD (1989) Use of the cranial base in the identification of fire victims. J Forensic Sci 34: 458–460

Kalmey JK, Rathbun TA (1996) Sex determination by discriminant function analysis of the petrous portion of the temporal bone. J Forensic Sci 41: 865–867

Kloiber Ä (1965) Das Knochenklein aus den norisch-pannonischen Hügelgräbern von Kapfenstein, pB Feldbach Oststeiermark. Arch Austriaca 7: 85–92

Kósa F, Fazekas IG (1973) Regressions- und Korrelationsuntersuchungen fetaler Schädelbasisknochen mit Hinsicht auf die Geschlechtsunterschiede. Gegenbaurs Morphol Jahrb 119: 336–345

Naga HA (1965/6) Transbasale Venenableitungen im und am Foramen jugulare. Gegenbaurs Morphol Jahrb 108: 363–390

Papangelou L (1975) Study of the human internal auditory canal in relation to age and sex. J Laryngol Otol 89: 79–89

Schaefer U (1961) Grenzen und Möglichkeiten der anthropologischen Untersuchung von Leichenbränden. Proceedings of the 5th International Congress of Prehistoric and Protohistoric Sciences, Hamburg, 1958, pp 717–724

Schmidt HM, Dahn P (1977) Die postnatale Entwicklung des menschlichen Os temporale I. Gegenbaurs Morphol Jahrb 123: 484–513

Schutkowski H (1983) Über den diagnostischen Wert der Pars petrosa ossis temporalis für die Geschlechtsbestimmung. Z Morphol Anthropol 74: 129–144

Schutkowski H (1990) Zur Geschlechtsdiagnose von Kinderskeletten – Morphognostische, metrische und diskriminanzanalytische Untersuchungen. Doctoral thesis, Göttingen

Susanne C, Guidotti A, Hauspie R (1985) Age changes of skull dimensions. Anthropol Anz 43: 31–36

Teixeria WRG (1982) Sex identification utilizing the size of the foramen magnum. Am J Forensic Med Pathol 3: 203–206

Vark GN van, Amesz-Voorhoeve WHM (1996) Sex diagnosis of human cremated skeletal material by means of mathematical-statistical and data-analytical methods. Homo 47: 305–338

Wahl J (1981) Ein Beitrag zur metrischen Geschlechtsdiagnose verbrannter und unverbrannter menschlicher Knochenreste – ausgearbeitet an der Pars petrosa ossis temporalis. Z Rechtsmed 86: 79–101

Wahl J (1988) Süderbrarup. Ein Gräberfeld der römischen Kaiserzeit und Völkerwanderungszeit in Angeln. II. Anthropologische Untersuchungen. Offa Bücher 64, Neumünster

Wahl J (1996) Erfahrungen zur metrischen Geschlechtsdiagnose bei Leichenbränden. Homo 47: 339–359

Wahl J, Henke W (1980) Die Pars petrosa als Diagnostikum für die multivariat-biometrische Geschlechtsbestimmung von Leichenbrandmaterial. Z Morphol Anthropol 70:258–268