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Sex Determination of the Sternum in Koreans

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Abstract : Identification of an individual is the mainstay of forensic investigation. In the present study, criteria for sex determination were established using 111 adult Korean sternums (63 males and 48 females). They were analyzed using identification points (IPs) and limit points (LPs), as reported previously. Only three of the ten parameters measured-sternal body length, sternal length (i.e., manubrium+body), and sternal area-were useful for sex determination, with sternal length being the most useful. The IP of sternal length was 147 and 130 mm for males and females, respectively. Using this parameter, 53.9% of males and 37.5% of females could be sexed with 100% accuracy. The LP was 141 mm for both males and females; sex could be discriminated accurately using this parameter in 85.7% of males and 85.4% of females.
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Key words : Sternum, Sex determination, Morphometry, Korean

Introduction

Identification of sex from human skeletal remains is an indispensable element of medicolegal investigation, forensic science, and physical anthropology (Park et al. 2003, Hu et al. 2006, Kim et al. 2006, Yu et al. 2008). Advancements in science and technology have resulted in many studies on sex determination using the human skeleton. This can be achieved with almost 100% accuracy if the entire skeleton is presented for examination. The presence of the skull or pelvis enables sex to be determined in up to 90% of cases, but if either of these elements is missing it becomes fairly difficult to judge either the age or the sex accurately (Gautam et al. 2003).

The sternum occupies the middle portion of the anterior thoracic wall in humans. It consists of three parts: the manubrium, the body, and the xiphoid process. It would be rare to find the sternum in isolation from the rest of the skeleton, and so it would be particularly helpful if this bone could be used for the determination of sex. Indeed, the sternum has been studied extensively for its sexual dimorphism, which was first reported by Wenzel (cited from Ashley 1956b), and has been since supported by others (Hyrtl 1853, Dwight 1881, 1889, Narayan and Verma 1958, Jit et al. 1980).

According to the so-called Hyrtl's law, the ratio between the length of the manubrium and that of the body is more than 1 : 2 in females, and less in males (Hyrtl 1853). The '149 rule', which states that a male sternum exceeds 149 mm in length whereas the female sternum is less than 149 mm, was formulated in another study in Europe (Ashley 1956b). Hunnargi et al. (2007) measured the length of the manubrium, the body, and both in combination in skeletons from the Maharashtrian region of India. Based on overlapping values, they

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defined the identification point (IP) and the limiting point (LP) for sex determination.

Because the size and shape of the sternum vary with race and topographic region, the rules used to discriminate sex have differed between studies. The purpose of present study was therefore to apply data from Korean sternums to previously reported formulae for sex determination and to establish a new rule for this process for the Korean population.

Materials and Methods

One hundred and eleven sternums obtained from routine anatomy class were used. These comprised 63 males and 48 females; the average age was 69.6 years. The dry sternums were prepared via routine procedures. The length of the xiphoid process was not considered in this study because it is highly variable.

The parameters of the sternum that were measured morphometrically were as follows (Fig. 1):

1. Length of the manubrium: M
2. Sternal body length: B
3. Sternal length: M+B
4. Maximum width of the manubrium: MW
5. Maximum width of the sternal body: BW
6. Minimum width of the manubrium: mw
7. Body width between the incisurae costales II-III: S_1
8. Body width between the incisurae costales IV-V: S_2
9. Thickness of the manubrium (TM): at the level of the number six measurement
10. Sternal area: MW × (M+B)

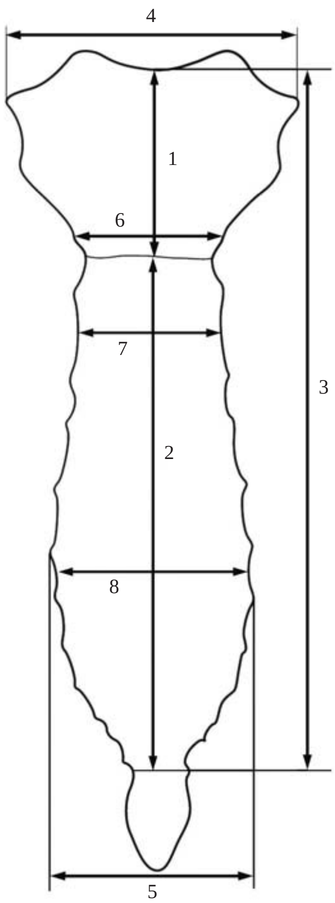

Fig. 1. Parameters measured (each measurement point is explained in detail in the text).

Each parameter of the sternum was measured using vernier calipers (CD-15CP, Mitutoyo, Japan). The consistency of measurements was maximized by having only one person (first author) measured all parameters on all bones. The computer programs SPSS for Windows (version 12.0, SPSS, Chicago, IL, USA) and Microsoft Office Excel 2007 (Microsoft, Redmond, WA, USA) were used for analysis. An independent-sample *t*-test was performed to analyze the difference between sexes. The IP is defined as the critical point at which measurement values do not overlap between males and females. The LP is derived from the average of the male and female IP (Hunnargi et al. 2007). A dividing line between the sexes was extracted by trial and error for each parameter based on the LP.

Sternal area is introduced here for the first time as a

Table 1. Morphometric measurement of various parts of the sternum. Data are presented in mm or cm^2 (sternal area only). SD: standard deviation

Measurements	Sex	Range	Mean	SD
Length of the manubrium (M)	M	41.2～59.6	49.9	4.3
	F	35.8～57.0	45.4	4.3
Sternal body length (B)	M	84.1～130.5	101.4	10.3
	F	74.8～104.0	86.9	8.0
Sternal length (M+B)	M	130.2～187.5	151.3	11.5
	F	111.9～147.4	132.4	8.5
Maximum width of the manubrium (MW)	M	47.3～73.4	57.9	5.8
	F	38.3～60.7	51.1	4.8
Maximum width of the body (BW)	M	29.0～51.2	37.4	4.6
	F	25.5～45.1	32.7	4.0
Minimum width of the manubrium (mw)	M	24.4～50.8	34.5	5.0
	F	19.2～43.1	29.7	4.4
Body width between the incisurae costales II-III	M	19.5～39.4	26.9	3.6
	F	17.0～32.3	23.9	3.3
Body width between the incisurae costales IV-V	M	24.2～41.3	30.5	3.8
	F	18.9～36.8	27.1	4.3
Thickness of the manubrium (TM)	M	8.8～17.5	12.5	2.0
	F	8.4～14.4	11.2	1.3
Sternal area: MW × (M+B)	M	61.5～119.2	85.8	12.8
	F	46.6～86.7	67.4	9.2

M: male, F: female

possible parameter for sex determination. The value of sternal area is defined as: MW × (M+B). We also adapted Hyrtl's law [(M/B) × 100, where male < 50 and female > 50] to our samples to verify its suitability for the Korean population.

Results

The various sternal measurements are listed in (Table 1). There are statistically significant differences between both sexes in all measurements ($p < 0.001$). However, the IPs and LPs of only sternal body length, sternal length, and sternal area were suitable for sex determination (Figs. 2-4).

1. Sternal body length (B)

Sternal body length in males and females ranged from 84.1 to 130.5 mm (mean 101.4 mm) and from 74.8 to 104.0 mm (mean 87.0 mm), respectively. The difference in the mean sternal body length between males and females (14.4 mm) was highly significant ($p < 0.001$). The IP was 104 and 84 for males and females, respectively, based on the overlapping range (84.0～104.0 mm). Sex could be discriminated accurately using IP analysis in 30.2% and 41.7% of male and female cases, respectively. The LP was 92; 87.3% of male and 72.9% of female cases could be determined by LP (Fig. 2).

2. Sternal length (M+B)

Sternal length in males and females ranged from 130.2 to 187.5 mm (mean 151.4 mm) and from 111.9 to 147.4 mm (mean 132.4 mm), respectively, and the IP was 147 and 130, respectively. Sex could be discriminated accurately using IP analysis in 53.9% and 37.5% of males and females, respectively. The LP was 141;

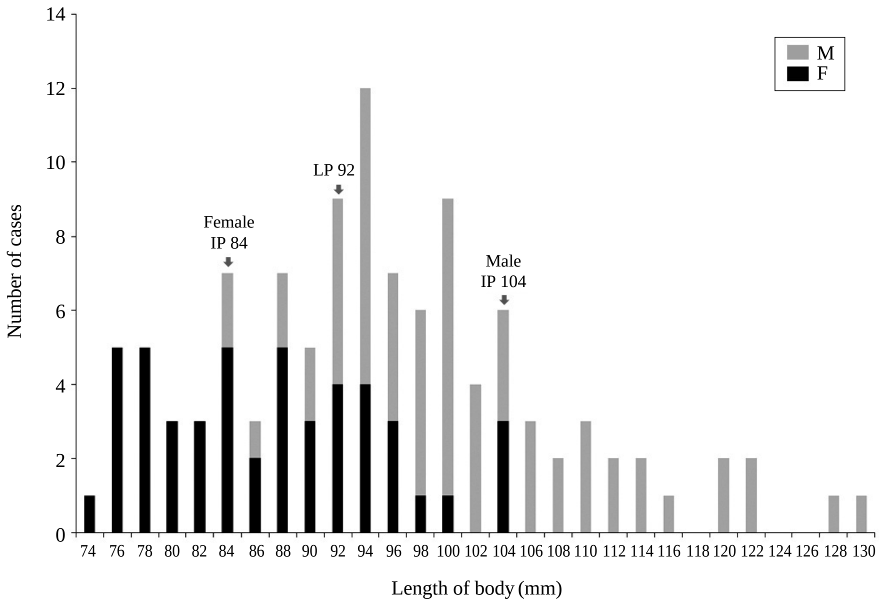

Fig. 2. Distribution patterns of sternal body length according to sex. The identification point (IP) was 104 and 84 for males and females, respectively. Based on the average IP value, the limiting point (LP) was calculated as 92.

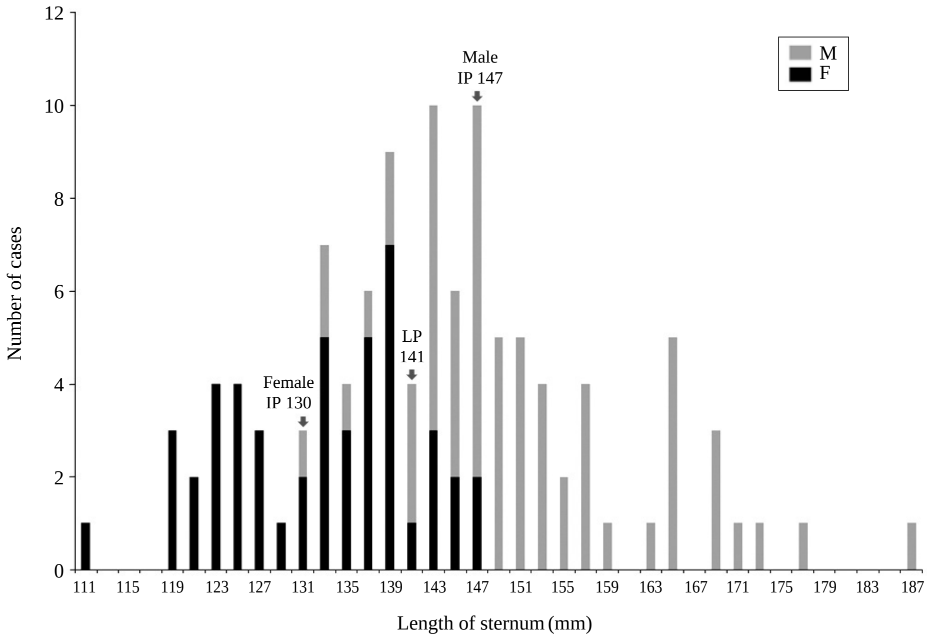

Fig. 3. Cumulative distribution of sternum lengths. The IP was 147 and 130 for males and females, respectively; the LP was 141.

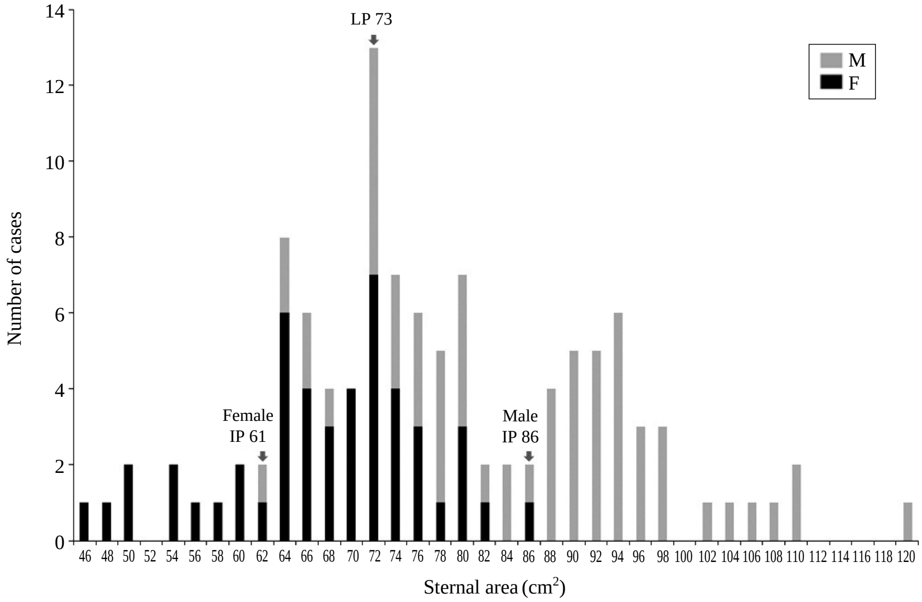

Fig. 4. Cumulative distribution of sternal area. The IP was 86 and 61 for males and females, respectively; the LP was 73.

85.7% of male and 85.4% of female cases could be determined by LP (Fig. 3).

3. Sternal area

Sternal area in males and females ranged from 61.5 to 119.2 cm^2 (mean 85.8 cm^2) and from 46.6 to 86.7 cm^2 (mean 67.4 cm^2), respectively, and the IP was 86 and 61, respectively. Data for 52.4% of males and 20.8 % of females were located outside of the overlapping range. The LP was 73; sternal areas of 73 cm^2 and above were suggestive of male gender, and those less than 73 cm^2 were suggestive of the female gender. LP accurately determined sex in 81% of male and 72.9% of female cases (Fig. 4).

Discussion

Recent studies regarding sexual dimorphism of the sternum (Dahiphale et al. 2002, Gautam et al. 2003, Hunnargi et al. 2007) suggest that there are sex-specific morphometric differences in this bone. Of the ten parameters measured in the present study, only three have been identified as being useful for sex determination in the Korean skeleton: sternal body length, sternal length, and sternal area. The overlapping ranges of the remaining seven parameters were either too wide or narrow to use as criteria.

Wenzel demonstrated that the manubrium is of almost equal length in both sexes (Ashley 1956a), a finding that was supported by Dwight (1881). However, Ashley (1956b) suggested that the manubrium in the European female was definitely shorter than in the male. Paterson (1904) reported that mesosternum (sternal body) was longer and narrower in males than in females. In the present study, the mean length of the manubrium was 50.0 mm and 45.4 mm in males and females, respectively; the difference is 4.6 mm. The determination accuracy was 55.6% for males and 77.3 % for females based on an LP of 48. Hunnargi et al.

(2007) reported an accuracy of 77.1% for males and 77.5% for females based on an LP of 50. In present study, 81 of the samples (72.9%) overlapped, the length of the manubrium is not a good criterion for sex determination.

In the report of Hunnargi et al. (2007), the concept of IP was derived from the overlapping range between the sexes, and that of LP was calculated based on the mean value of the distribution. Although LP analysis was less reliable than IP analysis in this study, we adopted both as criteria for sex determination. Sternal length was calculated as the sum of the length of the manubrium and the sternal body length because of individual variations in sternal angle. In European people, the combined lengths (M+B) were measured as 156.9 mm in males and 138.7 mm in females, and 149 mm was considered the dividing point between both the sexes. The '149 rule' was accurate in determining sex in 76.7% of male and 80.4% of female European cases. The '136 rule' was similarly applied to East Africans, with an accuracy of 77.6% and 84.6% for males and females, respectively (Ashley 1956b). Jit et al. (1980) found sternal length to be an extremely useful criterion for discriminating sex in North Indians. By applying the '136 rule', they could clarify the sex with an accuracy of about 80%. In the present study, we derived the '141 rule' for Koreans, which has an accuracy of 85.7% and 85.4% for discriminating males and female, respectively. This could be considered a very good criterion for sex determination in this population. Therefore, it appears that sternal length is so far the best parameter for sex determination, regardless of race.

It has been reported that LP varies with geographical location (Hunnargi et al. 2007). However, other studies have demonstrated that no difference between race and geographical location can be shown because of the large individual variation, and as such no predictive parameter could be defined (Stieve and Hintzsche 1923, McCormick et al. 1985). The '141 rule' of the present study was somewhat higher than the 'rules' determined in other studies for other races, suggesting that the sternal length varies not only according to geographical location, but also to race. We speculate that this is due to cultural differences. It is thought that food culture in particular affects the physical growth and development of the population, possibly contributing to differences in bone growth and development between races.

Table 2. Applicability of Hyrtl's law

Studies	N	Sex	Percentage obeying law (%)
Dwight (1890)	142 86	M F	59.1 60.4
Patermoller (1890) - cited by Jit et al.	55 33	M F	65.0
Ashley (1956)			
Africans	85 13	M F	64.7 69.2
Europeans	378 171	M F	52.9 69.3
Narayan and Verma (1958)	126 27	M F	34.1 81.5
Jit et al. (1980)	312 88	M F	31.1 88.6
Dahiphale et al. (2002)	96 47	M F	52.2 100
Present study (2008)	63 48	M F	49.2 60.4

M: male, F: female

Hyrtl's law, the so-called sternal index, is a well-known parameter that uses the length of the manubrium and sternal body length to predict sex. However, many studies raised doubts as to the suitability of Hyrtl's law and tested its reliability (Table 2). According to Hyrtl's law, the manubrium-body index [(M/B) × 100] exceeds 50 in females but is less than 50 in males (Hyrtl 1853). We also applied Hyrtl's law to our samples and found it to determine sex correctly with an accuracy of 49.2% in males and 60.4% in females. However, we also found that the law was not useful for sex prediction in the Korean skeleton, in agreement with previous reports

Table 3. Sex differences recorded by previous studies in sternal body length and sternal length. Sternal areas have been excluded

Studies	Sex	N	Sternal body length (mm)		Sternal length (mm)	
			Mean	Difference in means	Mean	Difference in means
Dwight (1890)	M F	142 86	110.4 91.9	18.5	164.1 141.3	22.8
Ashley (1956b)						
African	M F	85 13	96.5 82.9	13.6	142.6 127.1	15.5
European	M F	378 168	104.7 90.8	13.9	156.9 138.7	18.2
Jit et al. (1980)	M F	312 88	95.3 78.6	16.7	147.1 127.0	20.1
Dahiphale et al. (2002)	M F	96 47	94.4 70.1	24.2	142.1 113.8	29.3
Hunnargi et al. (2007)	M F	75 40	89.2 72.4	16.8	141.2 117.3	23.9
Present study (2008)	M F	63 48	101.4 87.0	14.4	151.4 132.4	19.0

M: male, F: female

that established this law to be unreliable (Ashley 1956b, Jit et al. 1980).

In the study of McCormick et al. (1985), the manubrio-body area index was suggested as a criterion. They obtained a mean area of 6,380 mm^2 for males and 4,752 mm^2 for females, a difference that was significant. However, they measured samples using radiological images and performed overly complicated calculations to obtain the sternal area. This method is less reliable than measurements taken from actual dried bone samples. In the present study, we defined the sternal area as a simple rectangular area [MW × (M+B)]. The LP of sternal area was 73. We discriminated male skeletons with an accuracy of 81.0% and female skeletons with an accuracy of 72.9%. This is not hugely different to the accuracies reported in the previous study, when compared with other useful parameters of samples. A comparison of the sternal body length and sternal length (M+B) data from the present study with those of other published studies revealed only a small difference in the mean value (Table 3). However, it is possible that the minor differences between measurements can be explained by differences in stature between skeletons.

In conclusion, the IP and LP values for sternal body length, sternal length, and sternal area can be used with reliable accuracy for sex determination in Korean skeletons, with sternal length being the most useful. The reliability and accuracy might be further improved if these three parameters are used in combination.

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한국인 복장뼈를 이용한 성판별

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간추림 : 법의학연구에서 개개인의 신원확인은 중요한 요소이다. 몸전체의 뼈대가 발견되는 경우 성별확인은 어렵지 않으며, 전체가 아니라 머리뼈나 골반만 있는 경우에서도 성별확인은 매우 쉽게 이루어질 수 있다. 한국인의 머리뼈나 골반 등을 이용하여 성판별을 이용한 연구는 많았으나 독립적으로 발견되기 어려운 복장뼈의 성판별에 대한 연구는 없었다. 이번 연구에서 한국인 성인의 복장뼈 111개를 이용하여 성판별을 위한 기준을 설정하고자 하였다(남자 63명, 여자 48명). 이전에 보고되었던 인식점(IPs)과 제한점(LPs)을 이용하여 분석하였고, 10가지 매개변수 중 단지 3가지 - 복장뼈몸통길이, 복장뼈길이(즉, 복장뼈자루+몸통), 그리고 복장뼈넓이 - 가 성판별에 유용했고 그 중 복장뼈길이가 가장 유용했다. 복장뼈길이의 인식점은 남자에서 147 mm, 여자에서 130 mm이었다. 이를 기준으로 남자의 53.9%와 여자의 37.5%는 100% 정확도로 성판별이 되었다. 남녀 모두에서 제한점은 141 mm이었고, 남자의 85.7%와 여자의 85.4%에서 성을 판별할 수 있었다. 또한 오랫동안 복장뼈의 성판별의 기준으로 사용되었던 Hyrtl의 법칙(Hyrtl's law: 몸통길이가 자루길이보다 2배 이상이면 여자)은 판별도가 낮아 한국인에서는 사용할 수 없는 기준이었다. 결론적으로 제한점을 이용한 복장뼈의 성판별이 한국인 복장뼈의 성판별에 유용함을 알 수 있었다.

찾아보기 낱말 : 복장뼈, 성판별, 형태계측, 한국인

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