



Research Paper

Computed Tomography-Based 3D Analysis of the Sternum for Forensic Age and Sex Estimation in the South Sulawesi Population

Zulfiyah Surdam^{1,2*}, Nesyana Nurmadilla², Berti Julian Nelwan¹, Rafikah Rauf^{1,3}, Rusdina Bte Ladju¹, Cahyono Kaelan¹, Muhammad Husni Cangara¹

1. Faculty of Medicine, Hasanuddin University, Makassar 90245, South Sulawesi, Indonesia.

2. Faculty of Medicine, Universitas Muslim Indonesia, Makassar 90231, South Sulawesi, Indonesia.

3. Dr. Wahidin Sudirohusodo General Hospital, Makassar 90245, South Sulawesi, Indonesia.

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ABSTRACT

Background: Forensic anthropology relies on skeletal analysis to establish a biological profile in medicolegal cases, including age and sex estimation. While the skull and pelvis are considered the most reliable indicators, they are not always available due to fragmentation or postmortem changes. The sternum, being centrally located and relatively resistant to damage, offers an alternative skeletal element for forensic identification.

Methods: A cross-sectional descriptive-analytical study was conducted using 200 thoracic CT scans from Dr. Wahidin Sudirohusodo General Hospital, Makassar, Indonesia. The samples consisted of 100 males and 100 females, distributed across four age categories. Morphometric parameters measured included Manubrium Length (ML), Manubrium Width (MW), Corpus Length (CL), Manubriocorpus Length (MCL), Corpus Width 1 (CW1), Corpus Width 2 (CW2), and the Sternal Index (SI). Statistical analyses were performed using the Kruskal-Wallis and Mann-Whitney U tests, followed by multivariate modeling to assess age- and sex-related differences.

Results: Significant sexual dimorphism was observed, with males showing larger sternum dimensions compared to females, except for SI, which was higher in females. Age-related changes were evident, with sternal dimensions increasing until early adulthood before plateauing. Minimal ethnic variation was found, with notable differences limited to CL among young adult Toraja males.

Conclusion: Three-dimensional CT-based sternal morphometry provides reliable markers for age and sex estimation, supporting its role as a complementary tool in forensic anthropology, particularly when traditional skeletal elements are unavailable.

* Corresponding Author:

Zulfiyah Surdam, MD

Faculty of Medicine, Hasanuddin University, Makassar 90245, South Sulawesi, Indonesia.

E-mail: zulfiyah.surdam@umi.ac.id



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Introduction

Forensic anthropology is the application of biological anthropology and its methods to identify living and deceased individuals, especially in legal investigations of human remains [1]. This process helps narrow down the possible matches for the victim in the inquiry. Metric methods for estimating age, sex, race/ethnicity, and height play an essential role in building biological profiles for unidentified human remains that are the first step towards identification [2]. Estimates of age, sex, race/ethnicity, and height depend on the methods derived from the most appropriate reference data for forensic practice [3]. For sex and height, the best estimate is usually given by a population-specific formula. Gender estimation helps narrow down search parameters by about 50% when searching through missing persons reports for identification hypotheses [4]. The primary measurement of the biological profile can be obtained by identifying the skeleton's structure [5]. Therefore, alternative framework elements are needed as potential indicators for determining biological profiles. The sternum can be found intact, given its relatively protected position in the body [6, 7].

Estimating an individual's biological age based on the length of the sternum is an interesting approach in forensic anthropology. The sternum bone has growth characteristics that can reflect a person's age [8]. Using these measurements, researchers can develop regression models that predict age from sternum length with greater accuracy. Further research is needed to develop a more comprehensive method for estimating age from sternum length [9]. The pelvis provides the best estimate of sexual dimorphism in size and shape between males and females [10].

A reasonable estimate of race/ethnicity can be achieved using cranial or postcranial metric data, provided appropriate reference data are available. Unlike the gender estimation method, which yields male or female results, race/ethnicity estimation requires a user's interpretation of statistical output to classify individuals into multiple groups [11, 12]. The anatomical method provides the best height estimate, is not specific to a population or time period, and should be used when a complete skeleton is available. Regression equations for height estimation from long bones have been used worldwide for a long time. Research in Indonesia has also found a correlation between sternum length and height [13, 14]. The sternum plays a crucial role in forensic anthropology due to its durability, central anatomical position, and significant variation in shape and size between sexes

and across age groups. With advances in medical imaging, computed tomography (CT)-based three-dimensional (3D) analysis offers a non-invasive, highly accurate method for evaluating sternal morphology, overcoming many limitations of traditional skeletal assessment. Since skeletal characteristics can vary among populations, developing population-specific reference data is essential. However, research on sternal-based age and sex estimation in Indonesian populations, particularly in South Sulawesi, remains scarce. This study aims to address this gap by analyzing sternal morphology using CT-based 3D techniques to enhance the reliability of forensic identification in this population.

Materials and Methods

This study employed a descriptive-analytical, cross-sectional observational design. The research was conducted in May 2025 at Dr. Wahidin Sudirohusodo Central General Hospital (RSUP) Makassar. The data used were secondary data obtained from the hospital system. Information on patient ethnicity and domicile was retrieved from the Hospital Information System (SIRS) and medical records. At the same time, data on age, sex, and sternum bone imaging were collected from the Picture Archiving and Communication System (PACS). The study population comprised patients who underwent thoracic CT scans in the Central Radiology Installation of Dr. Wahidin Sudirohusodo Hospital. The study was conducted from January 2023 to May 2025 in collaboration with the Department of Radiology at the Faculty of Medicine, Hasanuddin University. Eligible CT scan images were extracted from PACS, and measurements were performed on 3D reformatted sternum images. Parameters include ML, MW, CL, MCL, CW1, CW2, and SI. Participants included in this study were patients aged 17–45 years who underwent thoracic CT scans at the Central Radiology Department of Dr. Wahidin Sudirohusodo Hospital in Makassar. Only scans with a clearly visible and analyzable sternum were selected, and participants were required to have complete medical records, including age, sex, ethnicity, and domicile information. Furthermore, eligible participants were Bugis, Makassar, or Toraja, and had a registered residential address within South Sulawesi Province. Patients were excluded if their thoracic CT scans showed any abnormalities of the sternum, such as congenital malformations, fractures (pre- or post-operative), post-fracture changes, malignancies or tumors, infections, or other musculoskeletal disorders that could affect morphological assessment.

Results

Table 1 presents the frequency distributions of the variables studied, with N = 200 respondents. The age category was divided equally among the 50 respondents (25% per group). With a distribution of 100 males (50%) and 100 females (50%). The distribution of the tribes studied was 99 people (49.5%), Makassar 81 people (40.5%), and Toraja 20 people (10%). This table shows a balanced population across age, gender, and ethnicities.

Table 2 shows that Makassar males aged 18-30 have the highest average height (4,695 cm). At ages 31-45 years, Bugis males have the highest average (4.920

cm), and at age >45 years, Bugis females have a higher average than Makassar and Toraja. The length of the manubrium increases with age, especially from childhood to young adulthood.

Table 3 presents that Toraja men aged 18–30 years have the largest average (6.35 cm), Toraja men aged 31-45 years show the highest manubrium width (7.29 cm), larger than Bugis (6.54 cm) and Makassar (6.50 cm). Males aged >45 years are relatively uniform on average (about 6.2-6.3 cm). Women across all age groups have a smaller average manubrial width than men. The width of the manubrium increases with age and is generally larger in males than in females.

Table 1. Sample Characteristics by Age, Gender, and Ethnicity.

Variable		N (%)
Age Category	17 years old	50 (25)
	18–30 years old	50 (25)
	31–45 years old	50 (25)
	>45 years old	50 (25)
Gender	Man	100 (50)
	Woman	100 (50)
Tribe	Bugis	99 (49.5)
	Makassar	81 (40.5)
	Toraja	20 (10)

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Source: Primary Data

Table 2. Comparison of Manobrium Length (ML) Parameters by Age, Gender, and Ethnicity.

Age	Gender	Tribe	Mean	SD	Median	Min	Max	P* value
17 years old	Man	Bugis	3.29	1.04	3.23	0.85	4.62	0.798
		Makassar	3.39	1.00	3.52	0.92	4.82	
		Toraja	3.94	0.00	3.94	3.94	3.94	
	Woman	Bugis	3.02	1.21	3.53	1.24	4.41	
		Makassar	3.35	1.24	3.52	0.94	5.49	
		Toraja	4.27	0.15	4.27	4.16	4.37	
18-30 years old	Man	Bugis	4.68	.51	4.67	4.04	5.59	0.940
		Makassar	4.69	.35	4.75	4.13	5.09	
		Toraja	4.66	.50	4.66	4.30	5.01	
	Woman	Bugis	4.40	.51	4.33	3.77	5.44	
		Makassar	4.13	.39	4.12	3.77	4.90	
		Toraja	4.45	.53	4.45	4.07	4.82	
31-45 years old	Man	Bugis	4.92	.71	5.18	3.69	5.88	0.324
		Makassar	4.64	.39	4.54	4.21	5.41	
		Toraja	4.51	.39	4.64	3.96	4.80	
	Woman	Bugis	3.98	.43	3.89	3.51	5.00	
		Makassar	4.20	.46	4.08	3.48	4.96	
		Toraja	4.19	.49	3.98	3.84	4.76	
>45 years old	Man	Bugis	4.46	.40	4.48	3.46	5.01	0.643
		Makassar	4.62	.48	4.67	3.73	5.46	
		Toraja	4.52	.25	4.55	4.25	4.75	
	Woman	Bugis	4.24	.44	4.18	3.75	5.41	
		Makassar	4.15	.43	4.00	3.74	5.01	
		Toraja	4.13	.28	4.24	3.81	4.33	
	Toraja	4.13	.28	4.24	3.81	4.33		

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*Kruskal Wallis Test

Table 3. Comparison of Manubrium Width (MW) Parameters by Age, Gender, and Ethnicity.

Age	Gender	Tribe	Mean	SD	Median	Min	Max	P* value
17 years old	Man	Bugis	4.05	1.26	4.26	0.55	5.82	0.415
		Makassar	4.42	1.49	4.48	0.66	6.31	
		Toraja	4.15	0.00	4.15	4.15	4.15	
	Woman	Bugis	3.28	1.52	4.08	0.96	4.82	
		Makassar	3.93	1.18	4.34	1.04	5.02	
		Toraja	4.41	0.11	4.41	4.33	4.48	
18-30 years old	Man	Bugis	5.80	.58	5.73	4.97	6.83	0.370
		Makassar	5.98	.60	6.06	5.17	6.96	
		Toraja	6.35	.099	6.35	6.28	6.42	
	Woman	Bugis	5.39	.52	5.46	4.29	6.52	
		Makassar	5.27	.79	5.03	4.27	6.89	
		Toraja	5.84	.04	5.84	5.81	5.86	
31-45 years old	Man	Bugis	6.54	.68	6.41	5.59	8.08	0.156
		Makassar	6.50	.90	6.47	5.09	8.09	
		Toraja	7.29	.79	7.25	6.49	8.17	
	Woman	Bugis	5.14	.55	5.11	4.35	6.44	
		Makassar	5.28	.82	5.13	4.02	7.08	
		Toraja	5.54	.99	5.61	4.52	6.50	
>45 years old	Man	Bugis	6.25	.98	6.12	5.01	8.50	0.955
		Makassar	6.27	1.39	5.49	5.08	8.66	
		Toraja	6.15	1.11	6.08	5.07	7.29	
	Woman	Bugis	5.65	.85	5.52	4.58	7.29	
		Makassar	5.99	1.26	5.57	4.89	8.89	
		Toraja	5.99	.93	5.82	5.15	6.99	

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*Kruskal-Wallis Test

Table 4 presents a comparison of CL parameters by age, sex, and ethnicity, along with the results of the Kruskal-Wallis test to assess statistical significance.

The number of respondents between tribes is unbalanced, which can affect the strength of statistical tests. The p-value < 0.05 in males aged 18-30 years, which means that there is a significant difference in the

Table 4. Comparison of Corpus Length (CL) Parameters by Age, Gender, and Ethnicity.

Age	Gender	Tribe	Mean	SD	Median	Min	Max	P* value
17 years old	Man	Bugis	7.08	2.06	7.29	2.24	10.59	0.754
		Makassar	6.95	2.60	8.12	1.47	9.28	
		Toraja	7.39	0.00	7.39	7.39	7.39	
	Woman	Bugis	5.97	2.16	6.06	2.94	9.37	
		Makassar	6.21	1.73	6.61	1.90	8.49	
		Toraja	6.52	1.04	6.52	5.78	7.25	
18-30 years old	Man	Bugis	9.11	.95	9.02	7.50	11.05	0.041
		Makassar	9.88	.99	10.01	7.77	11.10	
		Toraja	11.58	2.31	11.58	9.94	13.21	
	Woman	Bugis	7.95	.69	7.98	6.56	9.24	
		Makassar	7.98	.89	7.58	6.75	9.42	
		Toraja	7.39	.33	7.39	7.16	7.62	
31-45 years old	Man	Bugis	9.59	1.19	9.25	8.14	11.96	0.629
		Makassar	9.51	.77	9.36	8.51	10.89	
		Toraja	10.04	.99	10.07	8.81	11.20	
	Woman	Bugis	8.04	.99	7.87	6.64	10.43	
		Makassar	8.02	.63	8.14	6.93	8.87	
		Toraja	9.55	1.28	9.13	8.54	10.99	
>45 years old	Man	Bugis	10.44	.86	10.55	9.17	12.22	0.648
		Makassar	10.50	.87	10.39	9.66	12.15	
		Toraja	10.80	.34	10.95	10.41	11.04	
	Woman	Bugis	8.27	.91	8.13	6.50	10.16	
		Makassar	8.69	.87	8.68	6.96	10.03	
		Toraja	8.71	.47	8.62	8.30	9.22	

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*Kruskal-Wallis Test

Table 5. Comparison of ManobrioCorpus Length (MCL) Parameters by Age, Gender, and Ethnicity.

Age	Gender	Tribe	Mean	SD	Median	Min	Max	P* value
17 years old	Man	Bugis	10.53	2.91	10.69	3.64	14.88	0.296
		Makassar	11.38	2.76	11.91	3.89	15.04	
		Toraja	11.46	0.00	11.46	11.46	11.46	
	Woman	Bugis	9.08	3.38	9.92	4.38	12.97	
		Makassar	9.59	2.78	10.89	2.83	12.29	
		Toraja	11.03	0.91	11.02	10.38	11.67	
18-30 years old	Man	Bugis	13.91	.84	13.85	12.67	16.17	0.055
		Makassar	14.70	1.06	14.85	12.72	15.87	
		Toraja	16.36	3.04	16.36	14.21	18.51	
	Woman	Bugis	12.39	.75	12.48	11.17	13.52	
		Makassar	12.16	.96	12.19	11.01	13.80	
		Toraja	11.91	.93	11.91	11.25	12.56	
31-45 years old	Man	Bugis	14.60	1.24	14.32	13.18	16.91	0.643
		Makassar	14.17	.82	14.02	12.77	15.43	
		Toraja	14.67	.81	14.96	13.50	15.25	
	Woman	Bugis	12.06	.98	12.15	10.94	14.42	
		Makassar	12.17	.88	12.23	10.98	13.87	
		Toraja	13.85	1.90	13.01	12.52	16.03	
>45 years old	Man	Bugis	15.10	1.03	15.15	13.49	17.40	0.833
		Makassar	15.13	1.26	14.93	13.68	17.53	
		Toraja	15.35	.37	15.17	15.10	15.78	
	Woman	Bugis	12.59	.84	12.46	11.36	14.14	
		Makassar	12.84	.59	12.63	12.06	13.96	
		Toraja	12.73	.25	12.83	12.44	12.91	

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*Kruskal-Wallis Test

length of the sternum corpus between tribes in this group, with the highest averages of Toraja (11,575 cm), Makassar (9.88 cm), and Bugis (9.11 cm). The p-value > 0.05 for other age groups, indicating no significant differences in ethnicity across age groups and genders.

Table 5 presents a comparison of MCL parameters by age, sex, and ethnicity, along with the results of the Kruskal-Wallis test to assess statistical significance. The number of respondents between tribes is

Table 6. Comparison of Corpus Width 1 (CW1) Parameters by Age, Gender, and Ethnicity.

Age	Gender	Tribe	Mean	SD	Median	Min	Max	P* value
17 years old	Man	Bugis	1.95	0.62	1.91	0.41	2.91	0.706
		Makassar	2.14	0.79	2.24	0.43	3.49	
		Toraja	2.12	0.00	2.12	2.12	2.12	
	Woman	Bugis	1.63	0.50	1.76	0.88	2.40	
		Makassar	1.79	0.46	1.73	0.86	2.61	
		Toraja	1.98	0.06	1.97	1.93	2.02	
18-30 years old	Man	Bugis	2.45	.24	2.45	2.11	3.09	0.131
		Makassar	2.53	.21	2.50	2.27	2.84	
		Toraja	2.86	.32	2.86	2.63	3.08	
	Woman	Bugis	2.25	.34	2.10	1.89	2.83	
		Makassar	2.20	.40	1.98	1.82	3.07	
		Toraja	2.02	.00	2.02	2.02	2.02	
31-45 years old	Man	Bugis	2.59	.27	2.44	2.27	3.02	0.734
		Makassar	2.76	.39	2.79	2.31	3.54	
		Toraja	2.66	.35	2.55	2.38	3.14	
	Woman	Bugis	2.28	.20	2.35	1.86	2.56	
		Makassar	2.26	.27	2.34	1.75	2.56	
		Toraja	2.42	.17	2.49	2.23	2.54	
>45 years old	Man	Bugis	2.69	.37	2.73	1.94	3.50	0.918
		Makassar	2.85	.64	2.71	2.20	4.32	
		Toraja	2.71	.18	2.80	2.51	2.83	
	Woman	Bugis	2.49	.20	2.54	2.12	2.72	
		Makassar	2.33	.22	2.26	2.10	2.75	
		Toraja	2.43	.27	2.40	2.17	2.71	

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*Kruskal-Wallis Test

unbalanced, which can affect the strength of statistical tests. The p-values > 0.05 for all groups indicated that no statistically significant differences in manubriocorpus length were found between tribes within each age group and sex.

Table 6 presents a comparison of CW1 parameters by age, sex, and ethnicity, along with the results of the Kruskal-Wallis test to assess statistical significance. The number of respondents between tribes is unbalanced, which can affect the strength of statistical tests. The p-values were > 0.05 for all groups, indicating no statistically significant differences in parameters between tribes within each age group and sex. In general, the width of the corpus one increases with age. The mean CW1 values increased in both male and female groups across age groups, especially in the young adult (18-30 years) and middle adult (31-45 years) age groups.

Table 7 presents a comparison of CW2 parameters by age, sex, and ethnicity, along with the results of the Kruskal-Wallis test to assess statistical significance. The number of respondents between tribes is unbalanced, which can affect the strength of statistical tests. The p-values > 0.05 across all groups indicated no statistically significant differences in CW2 parameters between tribes within each age group and sex. In general, the width of corpus 2 tends to increase with age. The young adult (18-30 years) and middle adult

(31-45 years) age groups had higher average scores than the younger age group (0-17 years).

Table 8 presents a comparison of SI parameters by age, sex, and ethnicity, along with the results of the Kruskal-Wallis test to assess whether differences are statistically significant. The number of respondents between tribes is unbalanced, which can affect the strength of statistical tests. The p-values > 0.05 across all groups indicated no statistically significant differences in SI parameters between tribes within each age group and sex. In general, the SI parameters tend to increase with age, especially among young adults (18-30 years) and middle-aged adults (31-45 years) of both males and females. Men have a higher Sternal Index than women across almost all age groups.

Discussion

The findings of this study demonstrate the potential of CT-based three-dimensional (3D) sternal morphology analysis as a valuable tool for forensic age and sex estimation. However, it is essential to acknowledge that the applicability and generalizability of these results may be limited to populations with similar ethnic and demographic backgrounds. Since this research was conducted exclusively among individuals from the Bugis, Makassar, and Toraja ethnic groups in South Sulawesi, the morphological patterns and distinguishing features identified may

Table 7. Comparison of Corpus Width 2 (CW2) Parameters by Age, Gender, and Ethnicity.

Age	Gender	Tribe	Mean	SD	Median	Min	Max	P* value
17 years old	Man	Bugis	2.21	0.88	2.09	0.21	3.85	0.219
		Makassar	2.59	0.79	2.67	0.75	3.67	
		Toraja	3.16	0.00	3.16	3.16	3.16	
	Woman	Bugis	1.89	0.70	1.95	0.67	2.68	
		Makassar	1.95	0.61	1.95	0.41	2.86	
		Toraja	2.16	0.42	2.16	1.86	2.46	
18-30 years old	Man	Bugis	2.96	.37	2.82	2.56	3.71	0.254
		Makassar	3.18	.63	3.20	2.15	3.92	
		Toraja	3.42	.06	3.41	3.37	3.46	
	Woman	Bugis	2.81	.48	2.78	2.01	3.61	
		Makassar	2.71	.34	2.66	2.24	3.31	
		Toraja	2.43	.33	2.43	2.20	2.66	
31-45 years old	Man	Bugis	2.94	.48	3.02	2.08	3.65	0.325
		Makassar	3.16	.62	2.98	2.58	4.29	
		Toraja	2.59	.39	2.54	2.23	3.05	
	Woman	Bugis	2.58	.50	2.62	1.34	3.20	
		Makassar	2.64	.42	2.57	2.04	3.26	
		Toraja	3.39	.25	3.38	3.14	3.64	
>45 years old	Man	Bugis	3.27	.49	3.20	2.34	4.13	0.730
		Makassar	3.46	.77	3.29	2.48	4.55	
		Toraja	3.28	.83	3.16	2.52	4.16	
	Woman	Bugis	2.93	.39	2.95	2.14	3.64	
		Makassar	2.72	.39	2.75	2.04	3.48	
		Toraja	3.09	.46	2.93	2.74	3.61	

*Kruskal-Wallis Test

Table 8. Comparison of Sternal Index (SI) Parameters by Age, Gender, and Ethnicity.

Age	Gender	Tribe	Mean	SD	Median	Min	Max	P* value
17 years old	Man	Bugis	30.74	3.63	30.47	23.35	36.43	0.264
		Makassar	29.42	4.47	29.56	23.07	39.97	
		Toraja	34.38	0.00	34.38	34.38	34.38	
	Woman	Bugis	32.80	5.00	34.19	24.75	37.85	
		Makassar	34.60	5.66	33.42	24.09	48.41	
		Toraja	38.87	4.56	38.87	35.65	42.10	
18-30 years old	Man	Bugis	33.72	4.14	33.56	27.08	42.17	0.123
		Makassar	32.01	2.34	31.22	29.78	36.56	
		Toraja	28.66	2.26	28.66	27.07	30.26	
	Woman	Bugis	35.56	3.55	35.11	29.30	40.78	
		Makassar	34.04	2.97	34.24	28.96	37.84	
		Toraja	37.28	1.55	37.28	36.18	38.38	
31-45 years old	Man	Bugis	33.81	4.88	34.92	24.24	39.98	0.379
		Makassar	32.79	2.80	32.14	29.62	37.67	
		Toraja	30.82	3.27	31.93	26.09	33.33	
	Woman	Bugis	33.17	3.98	32.47	27.12	40.65	
		Makassar	34.56	3.23	33.46	31.69	41.96	
		Toraja	30.33	1.26	29.69	29.52	31.79	
>45 years old	Man	Bugis	29.57	2.22	29.41	25.65	33.87	0.576
		Makassar	30.53	2.03	30.54	27.27	33.43	
		Toraja	29.44	1.79	28.83	28.02	31.46	
	Woman	Bugis	33.74	3.51	33.87	27.37	40.93	
		Makassar	32.48	4.41	31.69	26.79	41.54	
		Toraja	32.44	2.39	33.54	29.70	34.08	
		Toraja	32.44	2.39	33.54	29.70	34.08	

*Kruskal-Wallis Test

reflect specific genetic, environmental, and lifestyle factors inherent to these populations. Consequently, the results should be interpreted with caution when applied to populations with different biological or socio-environmental characteristics. Further studies involving more diverse and larger sample populations from various regions and ethnic groups are recommended to validate these findings and enhance the external validity of this forensic approach. Such research would not only strengthen the reliability of CT-based 3D sternal analysis but also broaden its applicability across diverse demographic settings in forensic investigations.

This study analyzed 200 CT scans of the sternum from individuals aged 0-88 years. The increase in CW1 and CW2 reflects transverse expansion of the corpus sterni, with CW2 showing greater changes, supporting earlier findings [15]. The reduction in SI at older ages suggests proportional widening of the sternum, likely influenced by aging-related trabecular changes and reduced bone density. Overall, sternum dimensions increase rapidly during childhood and adolescence, stabilize in early adulthood, and show subtle degenerative changes later in life [16].

Sexual dimorphism was evident across age groups. In children (0-17 years), CW1, CW2, and SI differed significantly between males and females, with males having wider corpus sterni and females showing higher

SI, consistent with early dimorphism reported in Croatian subadults [17]. These results align with CT-based studies in European and Turkish populations; most dimensions remained larger in males, except MW, which showed no significant differences [18, 19].

Similarly, reduced sexual dimorphism in manubrial width has been reported among elderly populations. These results suggest that ethnic variation plays a minimal role compared to biological factors in sternum morphometry [20]. Among the Bugis, Makassar, and Toraja populations, CL and MCL consistently demonstrated the strongest discriminatory power for sex estimation. The SI was also a significant parameter, with higher values in females, confirming a relatively longer manubrium than the corpus sterni. Width parameters (CW1, CW2) showed population-specific variability, as previously [21].

In the childhood group, the corpus sterni width and the sternal index already demonstrated clear sexual dimorphism. Males generally presented wider corpus sterni, while females showed a higher sternal index, reflecting a more slender and elongated sternum [22]. In young adults, sexual dimorphism became more pronounced, with males exhibiting larger dimensions of both the manubrium and corpus sterni. Females, on the other hand, retained a relatively higher sternal index, indicating proportional differences in sternum morphology [23, 24]. In middle adulthood, differences

remained evident in several parameters, including the length of the manubrium and the corpus sterni, as well as the width of the upper corpus. This pattern aligns with reports that morphological changes in the sternum become slower and more uniform after early adulthood [25].

In older age, most sternum parameters continued to reflect sexual dimorphism, with males maintaining larger dimensions. The exception was the manubrium width, which showed convergence between sexes, suggesting that some aspects of sternum morphology follow a similar trajectory in later life [26, 27]. Across age groups, sternum growth follows a steady trajectory, with increasing dimensions from childhood through young adulthood, followed by stabilization or slight reduction in later life [28-30].

Several parameters demonstrated extreme discriminatory power for sex estimation. The corpus sterni length and combined manubrio-corpus length were consistently reliable across different populations [31, 32]. The sternal index also showed significance in most groups, typically higher in females, indicating proportionally longer manubria relative to the corpus sterni [33, 34]. Width parameters showed greater variability across populations, with the upper and lower corpus widths exhibiting different discriminatory values, depending on local body-shape adaptations. Previous studies also confirm that width measures may be more population-dependent [35]. The manubrium width was found to significantly differentiate sex in some groups, further supporting its role as a robust indicator of sexual dimorphism [36, 37].

Limitation

We now acknowledge several potential sources of bias and imprecision. First, the relatively small sample size and the inclusion of participants from a single geographical area may limit the external validity of the results. Second, the broad age range used, although narrowed in the revised version, might still introduce age-related variability in sternal morphology. Third, the retrospective nature of the study and reliance on existing medical records may lead to incomplete or inconsistent data. Finally, inter-observer variability in 3D measurement analysis could contribute to minor measurement errors.

Conclusion

This study demonstrates that computed tomography (CT)-based three-dimensional (3D) analysis of the sternum provides valuable morphometric indicators for forensic age and sex estimation in the South Sulawesi

population. Several sternal parameters exhibited significant sexual dimorphism across different age groups and ethnicities. For example, males consistently showed larger manubrium length (ML) values, particularly between 4.68-4.92 cm in the 18-45 age group, compared to females who ranged between 3.98-4.45 cm. Similarly, manubrial width (MW) in males ranged from 5.80 to 7.29 cm, whereas in females it ranged from 5.14 to 5.84 cm. Corpus length (CL) was also greater in males (9.11-11.58 cm) than in females (7.39-9.55 cm), and the manubrio-corpus length (MCL) showed a distinct difference, with male averages between 13.91-16.36 cm compared to 11.91-13.85 cm in females.

Additionally, sternal index (SI) values were consistently lower in males (approximately 28.66-33.81) and higher in females (about 32.44-38.87), suggesting that this parameter is a useful numerical threshold for sex differentiation. These findings support the utility of 3D sternal morphometric analysis as a complementary tool in forensic identification. However, it is essential to note that these numerical values and cut-off points may be population-specific, as the current study focused exclusively on Bugis, Makassar, and Toraja ethnic groups.

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Ethical Approval

Compliance with ethical guidelines. This study was approved by the Ethics Committee of the Dr. Wahidin Sudirohusodo Hospital (Number: 168/UN4.6.4.5.31/PP36/2025).

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Conflicts of Interest

The authors report there are no competing interests to declare.

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