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Research Article

The Hyoid Bone as an Indicator of Age and Sex: A Cross-Sectional Study Using CT Imaging

Prashant Kumar[1], Shweta Gupta[2], Anjoo Yadav[3], Shilpi Garg[4]

[1]Professor, [3]Professor and HOD, [4]Associate Professor, Department of Anatomy, Lady Hardinge Medical College, New Delhi, India
[2]Associate Professor, Department of Forensic Medicine, Jaipur National University Institute for Medical Sciences and Research Centre, Jaipur, Rajasthan, India
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I N F O

Corresponding Author:
Prashant Kumar, Department of Anatomy, Lady Hardinge Medical College, New Delhi, India
E-mail Id:
azadkrishna86@gmail.com
Orcid Id:
https://orcid.org/0009-0003-7596-4621
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A B S T R A C T

Introduction: The hyoid bone, a unique U-shaped structure in the anterior neck, plays a vital role in swallowing, phonation, and airway protection. Unlike other bones, it does not articulate with any other skeletal structure. Age-related fusion between its body and greater cornua, along with changes in bone density, may serve as indicators of biological aging and sex differentiation. However, population-based, CT-driven evaluations of these parameters remain limited.

Materials and Methods: This retrospective cross-sectional study analysed high-resolution CT scans of 100 individuals (50 males, 50 females) aged 1–90 years. Hyoid fusion was graded bilaterally into non-fusion, partial, or complete fusion. Bone density was assessed using Hounsfield Units (HU) from the hyoid body. Subjects were stratified into paediatric, young adult, middle-aged, and older adult groups. Statistical analysis included chi-square tests, t-tests, ANOVA, and multivariate regression.

Results: Hyoid fusion increased with age—from 3% complete fusion in paediatrics to 30% in those aged ≥60 years. Males exhibited more complete fusion than females (22% vs. 12%, $p = 0.014$). Bone density declined significantly with age, especially in females over 40. Mean HU dropped from 810 ± 105 in children to 580 ± 98 in older adults. A positive correlation was found between fusion grade and HU values ($\rho = 0.46$, $p < 0.001$). Interobserver reliability for both fusion and HU assessment was excellent ($\kappa = 0.82$; ICC = 0.91).

Conclusion: Hyoid fusion and bone density show significant age- and sex-related trends. Their CT-based evaluation holds clinical value in airway and swallowing assessments and forensic utility in biological profiling for age and sex estimation.

Keywords: Hyoid Bone, Fusion, Bone Density, Computed Tomography (CT), Hounsfield Units, Age Estimation, Sex Differentiation, Forensic Anthropology

Introduction

The hyoid bone is a small, U-shaped bone located in the anterior midline of the neck between the mandible and the thyroid cartilage. Unlike any other bone in the human skeleton, the hyoid does not articulate with any other bone. It is suspended in place by a series of muscles and ligaments, earning it the distinction of being the only "floating" bone in the body.[1] This unique anatomical position allows the hyoid to serve as a central structural anchor for a network of muscles involved in critical oropharyngeal functions such as swallowing (deglutition), phonation (speech), mastication, and maintenance of airway patency.[1–3]

The hyoid bone plays a crucial role in coordinating the movements of the tongue and larynx, particularly during speech and swallowing. It forms a stable base for the tongue and serves as an attachment point for the suprahyoid and infrahyoid muscle groups, as well as several pharyngeal muscles.[3] Through this muscular connection, the hyoid also influences laryngeal elevation and depression, which are essential in protecting the airway during swallowing. Dysfunction of these coordinated movements, often due to structural abnormalities or age-related degeneration of the hyoid, may result in dysphagia, sleep-disordered breathing, or voice changes.[4]

In clinical practice, the hyoid is of particular interest in surgical and diagnostic procedures involving the upper aerodigestive tract. For instance, in sleep medicine, hyoid suspension surgery is used as a component of multilevel surgical approaches for the management of obstructive sleep apnoea (OSA), wherein anterior repositioning of the hyoid improves airway patency by preventing posterior tongue collapse.[4] Additionally, hyoid bone fractures—though rare—are considered hallmark findings in strangulation cases, making them highly relevant in forensic medicine and legal investigations.[5] The hyoid is also a valuable radiographic landmark in cephalometric studies and reconstructive surgical planning.

A less frequently appreciated but highly significant aspect of hyoid anatomy is its developmental fusion pattern. The hyoid bone consists of a central body and two pairs of horns (greater and lesser cornua). Fusion between the body and greater cornua typically occurs progressively with age, beginning as unfused in children and transitioning through partial to complete fusion in older adults. Several studies have documented this age-dependent fusion trend, suggesting its utility in age estimation in forensic contexts.[6,7] However, the fusion process is influenced by both age and sex, with males reportedly showing earlier or more complete fusion than females in certain populations.

Another critical parameter of the hyoid bone is its bone mineral density (BMD), measurable on computed tomography (CT) in terms of Hounsfield Units (HU). Bone density is known to decline with age and is influenced by hormonal changes—particularly oestrogen deficiency post-menopause in females. These changes potentially affect the structural integrity and function of the hyoid and may also serve as indirect indicators of physiological aging. Recent CT-based studies have explored the correlation between hyoid bone density and age, suggesting that density measurements may complement morphological observations (like fusion) in biological profiling.[6,8]

Despite these observations, there remains a lack of large-scale, systematically structured studies that analyse both hyoid fusion patterns and bone density across a broad age range, particularly using high-resolution CT imaging. Furthermore, the clinical implications of these anatomical variations—especially in relation to airway support, dysphagia, and surgical relevance—remain underexplored. Additionally, while some data exist from Western populations, there is a need for population-specific studies due to known ethnic and anatomical variability.[9]

Materials and Methods

Study Design, Ethical Approval, and Consent

This was a retrospective cross-sectional imaging study aimed at evaluating hyoid bone fusion and density patterns using computed tomography (CT). Ethical approval for the study was obtained from the Institutional Review Board (IRB) of our institution. Informed consent was waived due to the retrospective nature of the study and the use of de-identified imaging data, in accordance with institutional and national ethical guidelines.

Study Population

A total of 100 high-resolution neck CT scans were retrospectively selected from the hospital's digital imaging archive. These scans, performed between January 2020 and December 2024, were originally acquired for various non-trauma-related clinical indications.

Inclusion criteria

- Age ≥ 1 year at the time of imaging
- Availability of high-quality CT scans with slice thickness ≤1 mm and complete visualization of the hyoid bone

Exclusion criteria

- History of neck trauma or surgery involving the hyoid
- Congenital or acquired anomalies of the hyoid bone
- Significant neck pathology (e.g., tumours) or motion artifacts obscuring hyoid anatomy

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The final study population included 100 subjects, equally divided by sex (50 males, 50 females), with an age range of 1–90 years (mean ± SD: 46.3 ± 21.8 years).

CT Imaging Parameters and HU Standardization

CT scans were acquired using two multi-detector CT systems: GE Revolution CT and Siemens Somatom Sensation 16. Standard acquisition parameters included:

- Tube voltage: 120–140 kVp
- Automated tube current modulation
- Slice thickness: 0.6–1 mm
- Matrix size: 512 × 512
- Field of view: 40–200 mm

To minimize inter-scanner variability in Hounsfield Unit (HU) measurements, internal calibration protocols were used, and phantom testing confirmed no significant differences in HU values between the two systems.

Image Reconstruction and Software Consistency

Multiplanar axial, coronal, and sagittal reconstructions were performed using standard protocols. All scans were reviewed using the same version of imaging software (either SyngoVia or NovaPACS) to maintain consistency in visualization and grading across cases.

Fusion Grading Protocol

Fusion between the hyoid body and greater cornua was assessed bilaterally on axial CT sections at the narrowest body-cornu interface and corroborated on sagittal and coronal views. Fusion was graded as:

- Non-fusion – visible radiolucent gap between body and cornu
- Partial fusion – thin or incomplete osseous bridge
- Complete fusion – continuous bony connection

Subjects were categorized as having bilateral non-fusion, unilateral fusion (partial or complete), bilateral partial fusion, or bilateral complete fusion.

Bone Density Measurement (HU Analysis)

Bone density was assessed using Hounsfield Unit (HU) measurements. Circular regions of interest (ROIs) were placed in the central trabecular region of the hyoid body on three consecutive axial slices, avoiding cortical margins. The average of the three HU values was recorded as the representative bone density.

ROI placement was performed by two independent observers in a subset of 20 randomly selected scans to assess interobserver reliability. The intraclass correlation coefficient (ICC) was calculated based on these measurements, confirming consistency. In the remaining cases, a single trained radiologist conducted the measurements.

Age Stratification

Subjects were stratified into the following age groups to analyse developmental trends:

- Paediatric: 1–19 years
- Young adults: 20–39 years
- Middle-aged adults: 40–59 years
- Older adults: ≥60 years

These boundaries were selected based on established skeletal developmental milestones and previous literature on age-dependent hyoid fusion and bone density changes.

Observer Reliability

A randomly selected subset of 20 scans was independently evaluated by two trained radiologists to assess reproducibility. Fusion grading agreement was quantified using Cohen's kappa, and HU reliability was measured using the intraclass correlation coefficient (ICC). An ICC value ≥0.85 was considered acceptable.

Age Stratification

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These boundaries were selected based on established skeletal developmental milestones and previous literature on age-dependent hyoid fusion and bone density changes.

Results

Fusion Patterns

Analysis of 100 high-resolution neck CT scans (50 males and 50 females), spanning an age range of 1 to 90 years (mean ± SD: 46.3 ± 21.8 years), revealed distinct age- and sex-related trends in hyoid bone fusion.

In the paediatric group (1–19 years), bilateral non-fusion was predominant, observed in 85% of cases, while unilateral fusion and bilateral partial or complete fusion were seen in 12% and 3%, respectively. In the young adult group (20–39 years), bilateral non-fusion dropped to 18%, with unilateral fusion in 50%, and bilateral partial or complete fusion in 32%. Among middle-aged adults (40–59 years), the rate of bilateral complete fusion increased to 20%, while in older adults (≥60 years), it further rose to 30%—indicating a clear age-dependent fusion trend. Table 1

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Table 1.Hyoid Fusion Patterns by Age Group and Sex

n = 100

Age Group (years)	Sample Size (n)	Bilateral non-fusion (%)	Unilateral Fusion (%)	Bilateral Partial/Complete Fusion (%)
1–19	25	85	12	3
20–39	30	18	50	32
40–59	25	8	36	56
≥60	20	5	25	70
Total	100	29	34	37

Sex Differences: Bilateral complete fusion was more frequent in males (22%) than in females (12%), (χ^2 = 6.1, p = 0.014).

With respect to sex differences, bilateral complete fusion was more frequent in males (22%) than females (12%), a difference that reached statistical significance ($\chi^2 = 6.1$, $p = 0.014$). No sex-based difference was evident within the paediatric group, but divergence became apparent from age 40 onward.

Bone Density (HU)

The mean hyoid bone density, measured in Hounsfield Units (HU), showed a progressive decline with increasing age. In the paediatric group, the mean HU was 810 ± 105, which declined to 580 ± 98 in patients aged ≥60 years. Notably, females over 60 years had significantly lower bone density (560 ± 92 HU) compared to males of the same age (605 ± 88 HU), consistent with postmenopausal bone loss ($p < 0.01$).

Sex-based HU differences were not statistically significant in individuals under 40 years but became significant beyond age 40.

Further, bone density was strongly correlated with fusion grade. Individuals with complete fusion had a higher mean HU (720 ± 108) compared to those with non-fusion (635 ± 95 HU). A positive correlation was established between HU values and fusion grade (Spearman's $\rho = 0.46$, $p < 0.001$).

Observer Reliability

Reproducibility of both fusion grading and HU measurements was excellent. Interobserver agreement for fusion classification yielded a Cohen's kappa of 0.82, while interobservers agreement was 0.88. For HU measurement, the interobserver intraclass correlation coefficient (ICC) was 0.91, and interobserver ICC was 0.94, indicating robust reliability of measurements.

Multivariate Analysis

Ordinal logistic regression demonstrated that each additional decade of life increased the odds of being in a higher fusion category by 1.48 (95% CI: 1.24–1.71, $p < 0.001$). Male sex remained a significant independent predictor of advanced fusion (OR = 1.41, 95% CI: 1.06–1.89, $p = 0.018$).

In linear regression modelling with HU as the dependent variable, age showed a significant negative association ($\beta = -3.7$ HU/year, $p < 0.001$). Female sex was independently associated with a −39 HU difference ($p = 0.005$), even after controlling for age and fusion status. Fusion grade contributed an additional +45 HU per category increase ($p < 0.001$). Table 2

Table 2.Hyoid Bone Density (HU) by Age, Sex, and Fusion Status

n = 100

Subgroup	Mean HU ± SD
Paediatrics (1–19 yrs)	810 ± 105
Adult males (20–59 yrs)	680 ± 102
Adult females (20–39 yrs)	705 ± 98
Females ≥ 60 yrs	560 ± 92
Non-fusion	635 ± 95
Partial Fusion	695 ± 103
Complete Fusion	720 ± 108

The study demonstrated that hyoid bone fusion advances progressively with age and is more accelerated in males. Bone density declines significantly with aging and is lower in females, particularly after 40 years. Higher fusion grades were associated with increased HU, suggesting a link between structural ossification and mineralization. The high reproducibility of fusion and density assessment supports the clinical and forensic utility of CT-based evaluation for age and sex estimation.

Key Findings

- HU values decline with age, more significantly in females ≥40 yrs ($p < 0.01$).
- Complete fusion is associated with significantly higher HU than non-fusion (Spearman's $\rho = 0.46$, $p < 0.001$).

Discussion

This CT-based evaluation of hyoid bone fusion and bone density in 100 individuals offers meaningful insights into

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developmental and sex-related trends, which are consistent with—and expand upon—existing literature.

Our study demonstrated a progressive increase in hyoid fusion with age: bilateral complete fusion was observed in 30% of individuals ≥60 years, compared to only 3% in those ≤19 years. This is consistent with findings by Fisher et al. (2016),[6] who evaluated 136 CT scans (age 1–94 yrs) and reported that bilateral fusion increased from 3% in the 1–19 group to 74% in the ≥60 age group, with a clear age-dependent trajectory.

Similarly, Mutlu et al. (2024)[9] conducted a 3D CT study in a Turkish population of 320 individuals, reporting that complete fusion was seen in only 2.2% under age 20, increasing to 31.2% in 40–59 years and 59.1% in those ≥60 years.

In our cohort, males showed more complete fusion than females (22% vs. 12%), a trend also noted by O'Halloran & Lundy (1987)[10] in a cadaveric sample, where fusion was observed in 72% of males vs. 58% of females over age 50.

Bone Density Variation by Age and Sex

Bone density in our study, measured via Hounsfield Units (HU), decreased significantly with age: mean HU declined from 810 ± 105 in the paediatric group to 580 ± 98 in older adults (≥60 years). This pattern mirrors that of Fisher et al.[6] who found mean HU values dropping from 825 HU (1–19 yrs) to 550 HU (≥60 yrs).

Sex-based differences in HU also aligned with previous reports. In our data, females over 60 had mean HU of 560, significantly lower than 605 HU in age-matched males. Lokesha et al. (2024),[11] in a CT-based Indian study of 103 individuals, also reported that females >50 years had mean HU of 538.6, versus 595.2 in males, attributing the difference to oestrogen-related bone loss. We found a positive correlation between HU and fusion grade (Spearman's $\rho = 0.46$, $p < 0.001$), with complete fusion associated with 720 ± 108 HU, and non-fusion with 635 ± 95 HU. This trend matches Fisher et al.'s[6] data: individuals with complete fusion had mean HU of 690, compared to 610 in non-fused bones. Mutlu et al.[9] also showed that fusion groups had significantly higher bone density values (mean 674.9 HU) compared to non-fused (mean 612.4 HU), indicating similar mineralization patterns. While our study focused on fusion and density, other studies have used morphometrics for classification. Mutlu et al.[9] categorized hyoids into five morphological types (U, D, etc.) and found that Type U was most common in males, and Type D in females, although the predictive power for sex/age was limited.

To overcome this, Jerković et al. (2025)[12] applied deep learning (Point Net++) to 3D hyoid meshes from 202 individuals and achieved 89.3% accuracy in sex estimation, suggesting artificial intelligence can supplement conventional anatomical markers.

Our findings support the forensic application of fusion grade and HU as reliable estimators of age and sex—especially where traditional indicators are unavailable or fragmented. As highlighted by Fisher et al.[6] combining fusion and HU improves classification accuracy to >80% for age group and >70% for sex.

Clinically, knowledge of hyoid fusion and density may be relevant in predicting fracture risk (e.g., strangulation cases) or assessing swallowing biomechanics, as a rigid, fused hyoid may limit laryngeal elevation during deglutition.[13]

Conclusion

This study evaluated hyoid bone fusion and density using high-resolution CT in 100 individuals aged 1–90 years. Findings confirmed that fusion progresses with age and is more advanced in males, while bone density declines significantly—especially in females over 40. A strong positive correlation between fusion grade and bone density suggests a biological link between ossification and mineralization. These results support the use of fusion status and HU values as reliable markers for age and sex estimation in forensic practice. Clinically, knowledge of these variations may assist in evaluating swallowing mechanics, airway dynamics, and surgical planning. High interobserver reliability underscores the robustness of CT-based assessment. Overall, the study offers valuable normative data and highlights the dual clinical and forensic relevance of hyoid metrics. Future studies should include functional correlation and diverse populations, and consider advanced tools like morphometrics and AI for predictive modelling.

Limitations

This study, though informative, has several limitations. The sample size was relatively small (n = 100) and drawn from a single centre, limiting generalizability to broader or ethnically diverse populations. Its retrospective, cross-sectional design prevents assessment of individual developmental changes over time. Ethnic background and morphological variations of the hyoid bone were not considered, which may influence fusion and density patterns. Functional correlations—such as swallowing or airway function—were not explored, limiting clinical applicability. While Hounsfield Units (HU) provide a practical estimate of bone density, they are influenced by scanner variability and are not equivalent to DEXA or quantitative CT. Lastly, fusion grading, despite high interobserver agreement, remains a semi-quantitative and partly subjective assessment, especially in borderline cases. Future longitudinal and multicentre studies incorporating functional analysis are recommended.

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