Section: Orthopaedic Surgery

Original Research Article

AN ANALYSIS OF ANTHROPOMETRIC DATA OF THE CERVICAL VERTEBRAE USING MRI IN SOUTH INDIAN POPULATION

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Received : 10/05/2026
Received in revised form : 03/07/2026
Accepted : 18/07/2026

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DOI: 10.70034/ijmedph.2026.3.166

Source of Support: Nil,
Conflict of Interest: None declared

Int J Med Pub Health
2026; 16 (3); 1035-1040

ABSTRACT

Background: Comprehensive morphometric knowledge of the sub-axial cervical spine is essential for safe surgery and implant selection, as vertebral dimensions vary with sex, race, and geographic origin. **Objective:** To evaluate magnetic resonance imaging (MRI)-based morphometric parameters of sub-axial cervical vertebrae (C3-C7) in a South Indian population and assess sex-wise and level-wise variations.

Materials and Methods: This retrospective observational study was conducted at Dr. Pinnamaneni Siddhartha Institute of Medical Sciences and Research Foundation, Vijayawada, from January 2023 to May 2026, using MRI scans of 100 individuals (49 males, 51 females; aged 16-83 years). Superior and inferior end plate breadth, length, and surface area (elliptical approximation), vertebral body height and diameter, disc height, spinal canal diameter, and Torg-Pavlov ratio were measured at C3-C7. Data were analysed using descriptive statistics, independent t-tests, Spearman's correlation, and one-way ANOVA.

Results: Males showed significantly larger superior and inferior end plate widths, lengths, surface areas, and vertebral body heights and diameters than females. End plate widths and surface areas rose gradually from C3 to C7, but end plate lengths and spinal canal diameter showed no significant upward trend. Vertebral body height followed a non-monotonic U-shaped pattern. Disc height differed significantly between sexes at upper cervical levels, but spinal canal diameter showed no sexual dimorphism. Torg-Pavlov ratios were significantly higher in females than males at all levels.

Conclusion: This study revealed considerable sexual dimorphism and level-wise variation in sub-axial cervical spine morphometry. These MRI-derived reference data may assist preoperative planning and design of population-specific cervical spine implants.

Keywords: Cervical vertebrae; Magnetic resonance imaging; Morphometry; Sexual dimorphism; Torg-Pavlov ratio.

INTRODUCTION

The cervical spine is a multifaceted anatomical area that facilitates movement, maintains the cranium, safeguards the spinal cord, and aids in total spinal alignment. Precise knowledge of cervical vertebral measurements is crucial for comprehending normal anatomy, identifying spinal canal stenosis, planning surgical interventions, and choosing suitably sized implants. Anthropometric metrics, including vertebral body dimensions, spinal canal diameter, pedicle measures, end plate width, and end plate length, exhibit variation based on age, sex, ethnicity, and body habitus. Consequently, population-specific morphometric data are crucial for enhancing diagnostic precision and clinical decision-making in cervical spine illnesses.[1,2]

Magnetic resonance imaging (MRI) is a dependable, non-invasive technique for evaluating cervical vertebrae morphology, spinal canal dimensions, intervertebral discs, spinal cord, and adjacent soft tissues without radiation exposure. MRI-based morphometric evaluation aids in detecting small anatomical variances and degenerative alterations that may not be clinically apparent. Prior research indicates that cervical spinal dimensions vary throughout populations and between genders, underscoring the inadequacy of utilising Western or generalised reference values for Indian patients. Due to the unique anthropometric traits of South Indian people, region-specific MRI reference data are necessary.[3,4]

The literature on MRI-based anthropometric examination of cervical vertebrae in the South Indian population is scarce. Defining normative cervical vertebral measures in this group can assist radiologists, orthopaedic surgeons, neurosurgeons, and spine surgeons in enhancing the interpretation of imaging data, preoperative planning, implant design, and the avoidance of instrumentation-related problems. This study aims to analyse cervical vertebral anthropometric characteristics using MRI in the South Indian population and to produce clinically relevant reference data that may enhance diagnosis, treatment planning, and surgical safety.

Aims and Objectives

1. To evaluate cervical vertebral morphometry from C3 to C7 using MRI in a South Indian population.
2. To compare cervical spine dimensions between males and females and assess level-wise variations.
3. To generate baseline morphometric data useful for preoperative planning and designing population-specific cervical spine implants.

MATERIALS AND METHODS

Study Design and Setting

This retrospective observational study was conducted at Dr. Pinnamaneni Siddhartha Institute of Medical Sciences and Research Foundation, Vijayawada, from January 2023 to May 2026.

Participants

The study comprised 100 participants, consisting of 49 males and 51 females, aged between 16 and 83 years. MRI scans of the cervical spine from healthy people without limitations in daily activities owing to neck or back discomfort were examined.

A morphometric evaluation of the sub-axial cervical vertebrae from C3 to C7 was conducted with digitised MRI data. The assessed criteria comprised superior and inferior end plate widths and lengths, vertebral body height, vertebral body diameter, spinal canal diameter, disc height, and Torg-Pavlov ratio. Measurements were acquired in the mid-coronal and mid-sagittal planes when necessary.

The surface areas of the superior and inferior end plates were computed using an elliptical approximation method derived from the observed width and length parameters. All data were analysed hierarchically from C3 to C7 and compared between males and females to evaluate sexual dimorphism and anatomical variance.

Statistical Analysis

Data were inputted and analysed using Python version 3.10.16. Descriptive statistics were employed to encapsulate the morphometric characteristics. Gender-based differences were analysed using independent t-tests, whereas level-specific trends were examined by Spearman's correlation and one-way analysis of variance (ANOVA) if appropriate.

RESULTS

Table 1: Superior and inferior end plate widths by vertebral level and sex (mm)

Level	Parameter	Male (mean ± SD)	Female (mean ± SD)	P value
C3	Superior end plate	22.76 ± 1.92	20.22 ± 1.60	<0.0001
C3	Inferior end plate	21.61 ± 2.46	19.33 ± 2.29	<0.0001
C4	Superior end plate	22.92 ± 1.61	20.16 ± 1.55	<0.0001
C4	Inferior end plate	21.67 ± 2.25	19.73 ± 2.38	<0.0001
C5	Superior end plate	23.59 ± 1.75	21.12 ± 1.63	<0.0001
C5	Inferior end plate	22.84 ± 1.87	20.51 ± 2.21	<0.0001
C6	Superior end plate	24.49 ± 1.66	21.91 ± 3.40	<0.0001
C6	Inferior end plate	24.49 ± 1.87	21.67 ± 1.77	<0.0001
C7	Superior end plate	26.63 ± 2.11	24.16 ± 1.97	<0.0001
C7	Inferior end plate	26.27 ± 1.86	23.37 ± 2.20	<0.0001

Trend: Superior and inferior end plate widths increased from C3 to C7 ($p<0.0001$).

Table 2: Superior and inferior end plate lengths by vertebral level and sex (mm)

Level	Parameter	Male (mean ± SD)	Female (mean ± SD)	P value
C3	Superior end plate	15.63 ± 1.44	13.49 ± 1.41	<0.0001
C3	Inferior end plate	16.47 ± 1.63	13.86 ± 1.40	<0.0001
C4	Superior end plate	16.08 ± 1.72	13.65 ± 1.51	<0.0001
C4	Inferior end plate	16.69 ± 1.92	14.02 ± 1.29	<0.0001
C5	Superior end plate	15.96 ± 1.54	13.12 ± 2.17	<0.0001
C5	Inferior end plate	16.67 ± 1.43	14.06 ± 1.59	<0.0001
C6	Superior end plate	16.16 ± 1.96	13.76 ± 1.24	<0.0001
C6	Inferior end plate	16.86 ± 1.34	14.29 ± 1.35	<0.0001
C7	Superior end plate	16.37 ± 1.60	13.71 ± 1.20	<0.0001
C7	Inferior end plate	16.10 ± 1.60	13.61 ± 1.42	<0.0001

Trend: no significant increasing trend from C3 to C7 for superior end plate length (p=0.14) or inferior end plate length (p=0.77).

Table 3: Superior and inferior end plate surface areas by vertebral level and sex (cm^2)

Level	Parameter	Male (mean ± SD)	Female (mean ± SD)	P value
C3	Superior end plate	2.68 ± 0.41	2.07 ± 0.33	<0.0001
C3	Inferior end plate	2.86 ± 0.43	2.23 ± 0.35	<0.0001
C4	Superior end plate	2.78 ± 0.33	2.14 ± 0.32	<0.0001
C4	Inferior end plate	2.92 ± 0.42	2.30 ± 0.38	<0.0001
C5	Superior end plate	2.86 ± 0.41	2.18 ± 0.30	<0.0001
C5	Inferior end plate	3.03 ± 0.42	2.37 ± 0.44	<0.0001
C6	Superior end plate	3.02 ± 0.40	2.40 ± 0.36	<0.0001
C6	Inferior end plate	3.24 ± 0.42	2.52 ± 0.36	<0.0001
C7	Superior end plate	3.33 ± 0.47	2.61 ± 0.43	<0.0001
C7	Inferior end plate	3.38 ± 0.44	2.68 ± 0.38	<0.0001

Trend: superior and inferior end plate surface areas increased from C3 to C7 (p<0.0001).

Table 4: Vertebral body height by vertebral level and sex (mm)

Level	Male (mean ± SD)	Female (mean ± SD)	P value
C3	9.18 ± 1.33	8.26 ± 1.03	0.0002
C4	8.46 ± 1.28	7.83 ± 0.99	0.0071
C5	8.19 ± 1.30	7.68 ± 1.10	0.0370
C6	8.35 ± 1.08	7.87 ± 1.15	0.0350
C7	10.18 ± 1.32	9.25 ± 1.21	0.0004

U-shaped pattern with lowest values around C5 and highest values at C7; Spearman overall relationship p=0.00009.

Table 5: Disc height by cervical disc level and sex (mm)

Level	Male (mean ± SD)	Female (mean ± SD)	P value
C3-C4	5.94 ± 1.16	5.36 ± 1.02	0.0093
C4-C5	5.79 ± 0.98	5.18 ± 1.13	0.0050
C5-C6	5.58 ± 1.09	5.16 ± 1.05	0.0532
C6-C7	6.02 ± 1.59	5.76 ± 0.85	0.2970

Sex difference was significant at C3-C4 and C4-C5, borderline at C5-C6, and not significant at C6-C7.

Table 6: Vertebral body diameter by vertebral level and sex (mm)

Level	Male (mean ± SD)	Female (mean ± SD)	P value
C3	14.63 ± 1.63	12.60 ± 1.57	<0.0001
C4	14.91 ± 1.63	12.33 ± 1.42	<0.0001
C5	15.29 ± 1.62	12.47 ± 1.64	<0.0001
C6	15.66 ± 1.57	12.81 ± 1.54	<0.0001
C7	14.73 ± 1.33	12.25 ± 1.41	<0.0001

Male vertebral body diameters were significantly greater than female values at every level; maximum average was observed at C6.

Table 7: Spinal canal diameter by vertebral level and sex (mm)

Level	Male (mean ± SD)	Female (mean ± SD)	P value
C3	10.62 ± 2.30	10.67 ± 1.27	0.8967
C4	10.13 ± 2.28	10.26 ± 1.35	0.7357
C5	9.93 ± 2.25	10.28 ± 1.53	0.3721
C6	9.87 ± 1.82	10.31 ± 1.32	0.1641
C7	10.99 ± 1.42	11.08 ± 1.16	0.7152

No statistically significant sexual dimorphism was observed at any level; overall increasing trend from C3 to C7 was not significant (p=0.08).

Table 8: Torg-Pavlov ratio by vertebral level and sex

Level	Male (mean ± SD)	Female (mean ± SD)	P value
C3	0.74 ± 0.18	0.87 ± 0.18	0.0005
C4	0.69 ± 0.16	0.85 ± 0.18	<0.0001
C5	0.66 ± 0.15	0.84 ± 0.20	<0.0001
C6	0.64 ± 0.14	0.82 ± 0.17	<0.0001
C7	0.75 ± 0.13	0.92 ± 0.16	<0.0001

Females had higher Torg-Pavlov ratio values than males at all levels; no significant increasing trend from C3 to C7 was observed (p=0.47).

DISCUSSION

This MRI-based investigation revealed strong sexual dimorphism in sub-axial cervical vertebral morphometry, with men exhibiting considerably larger superior and inferior end plate widths, end plate lengths, surface areas, vertebral body heights, and vertebral body diameters than females. The findings align with the comparative anatomical investigation by Yao et al., which indicated substantial differences in cervical end plate diameters between sexes and ethnic groups, with males typically exhibiting greater measures than females. Their research highlighted that cervical end plate shape differs among populations, underscoring the necessity for region-specific implant design.[5]

The current study indicates that end plate widths and surface areas steadily grew from C3 to C7, although end plate lengths did not exhibit a significant upward trend, indicating that transverse expansion may be more pronounced than anteroposterior growth in the lower cervical spine. This aligns with the systematic analysis by Liu et al., which determined that most of the research indicated an increase in cervical end plate diameters and surface area with declining vertebral levels, and that females often exhibited smaller cervical end plate diameters.[6]

The vertebral body height in this research was larger in men than in females, exhibiting a non-linear U-shaped pattern, falling until C5 and thereafter rising until C7. Ezra et al. revealed analogous sex-related disparities in cervical vertebral body dimensions, noting that cervical vertebral bodies were broader, longer, and taller in males than in females, while also emphasising racial and population-based variances in vertebral size. The increased vertebral body diameter noted in men in this study aligns with the findings of the Indian MRI study by Kar et al., which demonstrated considerable sexual dimorphism in sagittal vertebral body diameter, being greater in males. The observed commonalities reinforce the conclusion that male cervical vertebrae possess greater bony dimensions, perhaps indicative of variations in total skeletal structure and body composition.[1,7]

The current study observed no statistically significant sexual dimorphism in spinal canal diameter, despite notable sex differences in vertebral body dimensions; nonetheless, females exhibited somewhat bigger and less variable channel sizes. This finding aligns with Kar et al., who indicated that although vertebral body diameter was significantly greater in males, spinal canal diameter, spinal cord diameter, Torg ratio, and space available for the cord exhibited no significant gender differences; nevertheless, the Torg ratio was generally higher in females owing to their smaller vertebral body size. Nell et al. similarly showed that reference ranges for spinal canal characteristics were mostly comparable across males and females, whereas vertebral body width was greater in males. The current study's observation that the spinal canal diameter did not exhibit a substantial rise from C3 to C7 aligns with the notion that canal dimensions are comparatively constant in relation to vertebral body dimensions.[1,3]

The Torg-Pavlov ratio in this study was markedly elevated in females compared to men across all levels, mostly due to females possessing lower vertebral body diameters despite having equivalent or slightly larger canal diameters. This trend resembles the findings of Kar et al., who identified elevated mean Torg ratio values in females attributable to reduced vertebral body size. The clinical significance of this ratio has been emphasised in Korean population data by Moon et al., who investigated Pavlov's ratio as an indicator for assessing cervical canal stenosis in asymptomatic persons. The current study indicates that the average male Torg-Pavlov ratio below 0.80 at C4–C6 implies a greater anatomical susceptibility to cervical canal stenosis in males, while females, on average, exceeded this threshold.[1,8]

The current investigation revealed notable sex variations in disc height at the upper levels, namely C3–C4 and C4–C5, although such differences were non-significant at the lower levels. The C6–C7 intervertebral disc had the greatest height on average in both genders. The computed tomography-based work by Shin et al. partially corroborates this trend, establishing normative measures for cervical disc space height and highlighting that disc height fluctuates according to spinal level and demographic variables, including sex and race. The relative augmentation of lower cervical dimensions, particularly at C7, is physically significant as implants at the cervicothoracic junction may necessitate bigger footprints than those employed in the mid-cervical spine.[9]

The results of this study underscore that sub-axial cervical spine morphometry cannot be generalised across sexes or demographic groupings. The consistently greater end plate widths, lengths, surface areas, vertebral body heights, and diameters observed in males in this study align with the findings of Stemper et al., who showed that most geometric measurements of the cervical vertebrae were larger in men, even after adjusting for sitting height and head circumference. Their data substantiate the perspective that male cervical vertebrae are not only proportionally bigger but may also possess structurally distinct load bearing and support qualities in comparison to females. Miller et al. similarly observed that sexual dimorphism in cervical vertebral body size becomes more pronounced post-puberty, with men exhibiting increased anteroposterior growth and bigger total cervical vertebral bodies. This developmental disparity may partially elucidate why the current adult MRI-based investigation revealed considerably larger vertebral body and end plate dimensions in males.[10,11]

The incremental growth in transverse dimensions and surface area from C3 to C7 in our study holds significant biomechanical and surgical ramifications. The lower cervical spine, particularly C6–C7 and C7, endures increased mechanical stress and serves as a transition to the cervicothoracic junction. Consequently, the increased dimensions seen at lower levels may signify adaptation to enhanced axial load transfer and mobility requirements. Kulkarni et al. emphasised in their study on cervical footprint anthropometry within the Indian population that the dimensions of cervical end plates are crucial for selecting suitably sized cages or artificial discs, as a discrepancy between the implant footprint and the native end plate may elevate the risk of subsidence, migration, or insufficient coverage. This is especially pertinent to the current investigation, since the significant increase in dimensions at C7 indicates that implants intended for mid-cervical levels may not consistently be appropriate for the cervicothoracic junction.[12]

The current discovery that spinal canal diameter exhibited no significant sexual dimorphism, despite males possessing higher vertebral body size, is clinically noteworthy. It indicates that the relative connection between the vertebral body and canal, rather than canal diameter alone, may be more effective in identifying persons at risk for stenosis. Kar et al. conducted a MRI-based spinal canal morphometry research in India, revealing that the vertebral body diameter was greater in males, but the Torg-Pavlov ratio was often elevated in females due to their reduced vertebral body dimensions. The current investigation demonstrated a comparable trend, with females exhibiting elevated Torg-Pavlov ratios across all levels. This corroborates the conclusion that males may possess somewhat narrower canals proportional to vertebral body size, despite the absolute spinal canal diameter not being considerably smaller.[1]

The clinical significance of the Torg-Pavlov ratio has been extensively examined in the literature. Nell et al. indicated that conventional Torg ratio cut-offs could exaggerate stenosis in certain groups and proposed the need for population-specific reference values. Aebli et al. discovered that a diminished Torg-Pavlov ratio effectively identifies patients at risk for acute spinal cord damage following mild trauma, with a suggested threshold of 0.7. The current study's result that typical male values went below 0.80 at C4–C6 should be regarded with caution; it may suggest a considerably diminished canal reserve in men, but the diagnosis of stenosis should not depend solely on this ratio. The MRI evaluation of the spinal cord, cerebrospinal fluid space, degenerative alterations, and clinical manifestations is crucial.[3,13]

The findings regarding disc height in this study also provide practical significance. The pronounced sexual disparity at higher levels, with reduced differences at lower levels, indicates that sex-specific implant height selection may be more critical in upper sub-axial cervical surgeries than at C6–C7. Shin et al. have demonstrated that cervical disc space height considerably changes based on vertebral level and demographic characteristics, including sex, race, and ethnicity. This corroborates the current study's finding that a singular, consistent disc height criterion is improbable to accommodate all patients or cervical levels. Furthermore, Kolstad et al. indicated that increasing cervical disc degeneration correlates with a decrease in disc height, suggesting that age and degenerative condition must be taken into account when analysing disc height data.[9,14]

This work corroborates existing literature indicating that cervical vertebral body and end plate diameters are greater in males, exhibit a caudal rise in some metrics, and demonstrate population-specific variability. The diameter of the spinal canal exhibits reduced sexual dimorphism compared to vertebral body size, leading to elevated Torg-Pavlov ratios in females. These findings underscore the necessity of utilising population-specific morphometric databases for preoperative planning, anterior cervical discectomy and fusion, cervical arthroplasty, and the creation of suitably sized cervical implants for the South Indian demographic. The current findings derive from MRI evaluations of 100 subjects and encompass C3–C7 end plate, vertebral body, disc, canal, and Torg-Pavlov measures.

This study provides valuable MRI-based reference data for the South Indian population. The findings corroborate previous research indicating that cervical vertebral bony dimensions exhibit pronounced sexual dimorphism, but spinal canal dimensions are comparatively less influenced by sex. The findings further underscore the necessity for population-specific and level-specific implant design in anterior cervical discectomy and fusion, cervical arthroplasty, and other reconstructive cervical spine interventions. The noted variations in end plate footprint, vertebral body dimensions, disc height, spinal canal diameter, and Torg-Pavlov ratio suggest that preoperative planning must be tailored to the person rather than relying on generalised Western or non-Indian morphometric criteria.

This study has some drawbacks. The study was conducted at a single centre with a small sample size of 100 individuals, thus constraining the generalisability of the findings to the broader South Indian community. Measurements were derived from MRI images; hence, slight discrepancies attributable to imaging techniques, slice selection, or observer-related measurement bias could not be entirely eliminated. The study just encompassed morphometric examination and did not associate the findings with clinical complaints, degenerative alterations, functional outcomes, or surgical implant compatibility. The age-wise subgroup analysis was constrained, despite the potential variability in cervical spine diameters due to age, degeneration, and body habitus. Consequently, extensive multicentric investigations with clinical and surgical correlation are necessary to authenticate these reference values.

This study has several strengths. The study conducted an MRI-based morphometric evaluation of several sub-axial cervical spine parameters from C3 to C7, encompassing end plate dimensions, surface area, vertebral body height and diameter, disc height, spinal canal diameter, and Torg-Pavlov ratio. Comparisons were conducted both by sex and by cervical level, facilitating the assessment of sexual dimorphism and anatomical diversity across cervical levels. The study produced population-specific reference data for the South Indian demographic, which may aid in preoperative planning, implant selection, and the design of cervical spine apparatus according to regional anatomical characteristics.

CONCLUSION

The current investigation revealed notable sexual dimorphism in sub-axial cervical spine morphometry, with males exhibiting larger end plate dimensions, surface areas, vertebral body height, and vertebral body width than females. A progressive rise in end plate widths and surface areas was noted from C3 to C7, although end plate lengths and spinal canal diameters exhibited very less change between levels.

The results offer valuable MRI-derived baseline reference data for cervical vertebral morphometry in the South Indian demographic. This data may assist in preoperative planning, suitable implant selection, and the design of population-specific cervical spine apparatus, especially for operations like anterior cervical discectomy and fusion and cervical arthroplasty.

Conflict of Interest

The authors declare that there is no conflict of interest.

Financial Disclosure

The authors declare that there was no financial support for this study.

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