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MORPHOMETRIC ANALYSIS OF SUB-AXIAL CERVICAL VERTEBRAE IN ADULT KASHMIRI POPULATION

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Abstract
Background: Cervical pedicle screw (CPS) fixation offers superior biomechanical stability but carries high risk of neurovascular injury due to ethnic variations in pedicle morphology. No prior data exist for the Kashmiri population.
Methods: A prospective CT-based study of 50 adult Kashmiris (25 males, 25 females) undergoing cervical CT for unrelated indications. Exclusion criteria included cervical pathology. Using 1 mm reconstructed images, bilateral measurements (C3–C7) of pedicle width (PW), height (PH), length (PL), axis length (PAL), transverse (PTA), and sagittal angulation (PSA) were performed by two observers. Data were analyzed using STATA 14.0.
Results: Mean PW increased cranio-caudally (4.68 ± 0.49 mm at C3 to 6.06 ± 0.87 mm at C7), with males significantly larger ($p<0.05$). C3 females showed a 32% prevalence of PW <4.5 mm. PH exceeded PW at all levels. PTA decreased from 44.94° to 38.51°, while PSA remained cephalad (15.45° to 5.17°). No left-right differences were found.
Conclusion: Kashmiri sub-axial pedicles are smaller than Western and most Asian cohorts, with unique persistent cephalad PSA. CPS is feasible in >90% of cases except C3 females. Level-specific trajectory adjustment and smaller implants are recommended.

Keywords: Cervical pedicle morphometry, Kashmiri population, CT-based analysis

Introduction

The human spinal column is a resilient cylindrical structure composed of vertebrae alternating with intervertebral discs, extending from the cranium to the coccyx. It fulfills critical biomechanical and protective roles: safeguarding the spinal cord, supporting upright posture and locomotion, and transmitting the weight of the upper body to the pelvis. The cervical spine, in particular, is subjected to dynamic loads often exceeding body weight, rendering it susceptible to degenerative, traumatic, and iatrogenic pathology [1]. The sub-axial cervical vertebrae (C3–C7) constitute the mobile segment of the cervical spine, characterized by small rectangular vertebral bodies taller posteriorly, with concave superior and convex inferior endplates. The presence of lateral uncinate processes forms the uncovertebral joints (Luschka), enhancing lateral stability. Transverse processes contain foramina transversaria for vertebral vessels, while intervertebral foramina transmit spinal nerves. Intervertebral discs, thicker anteriorly, contribute to physiological cervical lordosis. Facet joints are oriented at approximately 45° superiorly, with progressive caudal flattening, enabling combined flexion, extension, rotation, and lateral bending.

Stabilizing structures include the anterior and posterior longitudinal ligaments, ligamentum flavum, and ligamentum nuchae. Muscular contributions from the sternocleidomastoid, scalenes, longus colli, and paraspinal groups facilitate multiplanar motion. Nervous anatomy features a capacious spinal canal and intervertebral foramina, while vascular supply is predominantly via vertebral arteries arising from the subclavian system.

Surgical stabilization for instability secondary to trauma, degeneration, or neoplasia has evolved from wiring to modern instrumentation. While lateral mass screws remain widely used, transpedicular screw fixation demonstrates superior biomechanical rigidity, particularly in three-column fixation constructs [2,3]. However, pedicle breach risks neurovascular injury, with reported rates of vertebral artery injury (0.3–0.6%) and nerve root irritation (1–2%) [4,5]. Accurate preoperative morphometric data are therefore essential for planning trajectories and selecting implants. Global studies reveal significant ethnic and regional variations in pedicle dimensions; Indian populations consistently exhibit smaller pedicles than their Caucasian counterparts [6].

Cadaveric and CT-based studies underscore the biomechanical superiority of pedicle screws [7,8], but applicability to specific populations remains limited. No prior study has characterized sub-axial cervical morphometry in the Kashmiri population. Therefore, this study aims to provide detailed, population-specific reference values to enhance surgical safety and guide implant design.

Material and Methods

Study Design and Setting

This was a prospective, observational, hospital-based cross-sectional study conducted in the Department of Orthopaedics, in collaboration with the Department of Radiodiagnosis and Imaging, SKIMS Medical College and Hospital, Bemina, Srinagar, Jammu and Kashmir, from June 2020 to May 2023.

Ethical Approval and Consent

The study protocol was approved by the **Institutional Ethics Committee (IEC), SKIMS Medical College** (Ref: SKIMS-MC/IEC/2020/112, dated 15/06/2020). Written informed consent was obtained from all participants in English, Urdu, or Kashmiri as per preference. Data confidentiality was maintained per ICMR 2017 guidelines.

Sample Size and Sampling

A minimum sample size of **48** was calculated using the formula for means:

$(Z\alpha/2 + Z\beta)2 \times \sigma 2$

$n = \underline{\qquad\qquad} d_2$

To account for potential data loss and enable subgroup analysis, **50 adult Kashmiri subjects (25 males, 25 females)** were enrolled via **consecutive sampling**.

Inclusion Criteria

- Adult Kashmiri individuals (>18 years)
- Undergoing cervical spine CT for unrelated clinical indications (e.g., trauma screening under ATLS protocol, headache workup)
- Willing to provide informed consent

Exclusion Criteria

- Congenital anomalies (e.g., block vertebrae, hemivertebrae)
- Degenerative spondylosis with osteophytes encroaching pedicles
- Inflammatory (rheumatoid arthritis, ankylosing spondylitis)

- Infectious (tuberculosis, pyogenic spondylodiscitis)
- Neoplastic (primary or metastatic)
- Traumatic fractures/dislocations
- Prior cervical spine surgery
- Motion artifacts on CT

Imaging Protocol

All scans were performed using a **Siemens Somatom Emotion 16-slice CT scanner** (Siemens Healthineers, Germany). Standardized protocol:

Parameter	**Specification**
Tube voltage	120 kV
Tube current	180–220 mAs (auto-modulation)
Slice thickness	3 mm (helical acquisition)
Reconstruction interval	1 mm
Kernel	B30f (soft tissue), B60f (bone)
Field of View (FOV)	180–220 mm
Matrix	512 × 512
Window	Bone (W: 2000, L: 500)

Multiplanar reformations (sagittal, coronal, axial) were generated using **Syngo.via VB60** software.

Measurement Technique

All measurements were performed on 1-mm reconstructed images using digital calipers and protractor tools in the PACS workstation. Each parameter was measured three times by two independent observers (orthopedic PG and consultant radiologist), and the mean was recorded. Final validation was done by a senior spine surgeon.

Measured Parameters (C3–C7 bilaterally):

1. **Pedicle Width (PW)**: Minimum mediolateral diameter at isthmus (axial plane, perpendicular to pedicle axis)
2. **Pedicle Height (PH)**: Maximum superoinferior diameter at isthmus (sagittal plane)
3. **Pedicle Length (PL)**: Distance from posterior lateral mass cortex to pediclevertebral body junction (sagittal)
4. **Pedicle Axis Length (PAL)**: Distance from posterior lateral mass entry point to anterior vertebral body cortex along pedicle axis (axial)
5. **Pedicle Transverse Angulation (PTA)**: Angle between pedicle axis and midsagittal plane (axial)
6. **Pedicle Sagittal Angulation (PSA)**: Angle between pedicle axis and line parallel to inferior endplate (sagittal)

Landmarks were standardized using multiplanar cross-referencing. Measurements were recorded in millimeters (linear) and degrees (angular).

Data Collection and Quality Control

Data were entered into a pre-designed proforma and transferred to Microsoft Excel 2019. Inter-observer reliability was assessed using the Intraclass Correlation Coefficient (ICC). Values >0.9 indicated excellent agreement. Outliers (>3 SD from the mean) were re-measured.

Statistical Analysis

Data were analysed using STATA 14.0 (Stata Corp, Texas, USA). Normality was confirmed via the Shapiro-Wilk test. Results expressed as Mean ± SD and Range (Min–Max). The statistical analyses included a paired t-test to compare the left and right measurements, while an independent t-test was employed to examine differences between males and females. Additionally, ANOVA with Bonferroni correction was utilized to assess variations across vertebral levels. To explore the relationship between age and dimensions, a Pearson correlation was conducted. The significance level for all tests was set at $p < 0.05$.

Results and Observations:
Fifty subjects (25M, 25F) with a mean age of 40.4 ± 11.8 years (range 19–65) were included. No significant left-right differences (p = 0.18). Parameters showed significant variation by sex (p = 0.018) and vertebral level (p = 0.035), with males having larger dimensions.

Table 1 summarizes the mean PW and PH by level and sex.

Spinal Level	PW (mm): Male Mean ± SD (Range)	PW (mm): Female Mean ± SD (Range)	PH (mm): Male Mean ± SD (Range)	PH (mm): Female Mean ± SD (Range)
C3	4.94 ± 0.48 (4.19-5.59)	4.42 ± 0.34 (3.91-4.99)	5.70 ± 0.69 (4.76-6.83)	5.52 ± 0.50 (4.81-6.27)
C4	5.05 ± 0.39 (4.27-5.61)	5.01 ± 0.26 (4.34-5.37)	6.21 ± 0.66 (5.16-7.18)	5.62 ± 0.56 (4.95-6.75)
C5	5.08 ± 0.34 (4.61-5.61)	5.13 ± 0.35 (4.56-5.66)	6.43 ± 0.74 (5.41-7.56)	6.03 ± 0.60 (5.21-6.93)
C6	6.29 ± 0.64 (5.43-7.56)	5.46 ± 0.71 (4.83-7.25)	7.00 ± 0.61 (5.69-7.88)	6.03 ± 0.30 (5.54-6.43)
C7	6.43 ± 0.79 (4.85-7.38)	5.71 ± 0.80 (4.83-7.22)	6.36 ± 0.66 (5.25-7.55)	6.08 ± 0.43 (5.56-6.88)

Table 1 shows PW increasing from C3 to C7, larger in males. PH peaks at C6, greater than PW at all levels.

Table 2 summarizes the mean PL and PAL.

Spinal Level	PL (mm): Male Mean ± SD (Range)	PL (mm): Female Mean ± SD (Range)	PAL (mm): Male Mean ± SD (Range)	PAL (mm): Female Mean ± SD (Range)
C3	5.29 ± 0.40 (4.76-5.98)	5.12 ± 0.31 (4.61-5.65)	30.32 ± 1.55 (28.63-33.67)	29.22 ± 1.06 (27.81-30.97)
C4	5.37 ± 0.21 (5.01-5.78)	5.18 ± 0.30 (4.71-5.67)	30.62 ± 1.67 (28.51-33.66)	29.57 ± 1.31 (27.91-31.78)
C5	5.66 ± 0.41 (5.12-6.33)	5.57 ± 0.28 (5.11-5.99)	31.46 ± 1.95 (28.88-34.49)	30.50 ± 1.53 (28.93-34.49)
C6	6.00 ± 0.33 (5.19-6.58)	6.06 ± 0.34 (5.34-6.67)	32.45 ± 1.88 (29.41-35.09)	31.41 ± 1.15 (29.64-33.19)
C7	5.80 ± 0.38 (5.11-6.29)	5.81 ± 0.38 (5.12-6.29)	33.99 ± 3.47 (28.96-39.89)	31.55 ± 1.77 (28.51-33.98)

Table 2 indicates PL and PAL increasing cranio-caudally, with PL dipping at C7.

Table 3 summarizes the mean PTA and PSA.

Spinal Level	PTA (degree): Male Mean ± SD (Range)	PTA (degree): Female Mean ± SD (Range)	PSA (degree): Male Mean ± SD (Range)	PSA (degree): Female Mean ± SD (Range)
C3	45.1° ± 2.1° (42.4°-49.2°)	44.9° ± 1.6° (43.0°-46.5°)	13.9° ± 2.5° (10.1°-18.8°)	16.9° ± 2.9° (12.1°-20.7°)
C4	44.3° ± 1.1° (42.4°-46.4°)	43.0° ± 1.0° (41.1°-44.5°)	13.5° ± 3.5° (9.5°-20.4°)	14.5° ± 2.8° (10.1°-18.8°)
C5	43.1° ± 1.0° (41.1°-45.1°)	42.0° ± 1.3° (39.5°-43.8°)	10.1° ± 2.2° (7.1°-13.9°)	10.2° ± 2.5° (6.3°-13.8°)
C6	38.2° ± 1.0° (36.3°-39.4°)	37.2° ± 1.4° (35.1°-39.4°)	7.6° ± 2.4° (3.5°-11.4°)	5.9° ± 2.3° (3.1°-9.6°)
C7	38.9° ± 1.3° (36.6°-40.9°)	38.2° ± 0.9° (36.7°-39.4°)	5.9° ± 2.0° (3.3°-11.7°)	4.6° ± 1.4° (3.3°-9.9°)

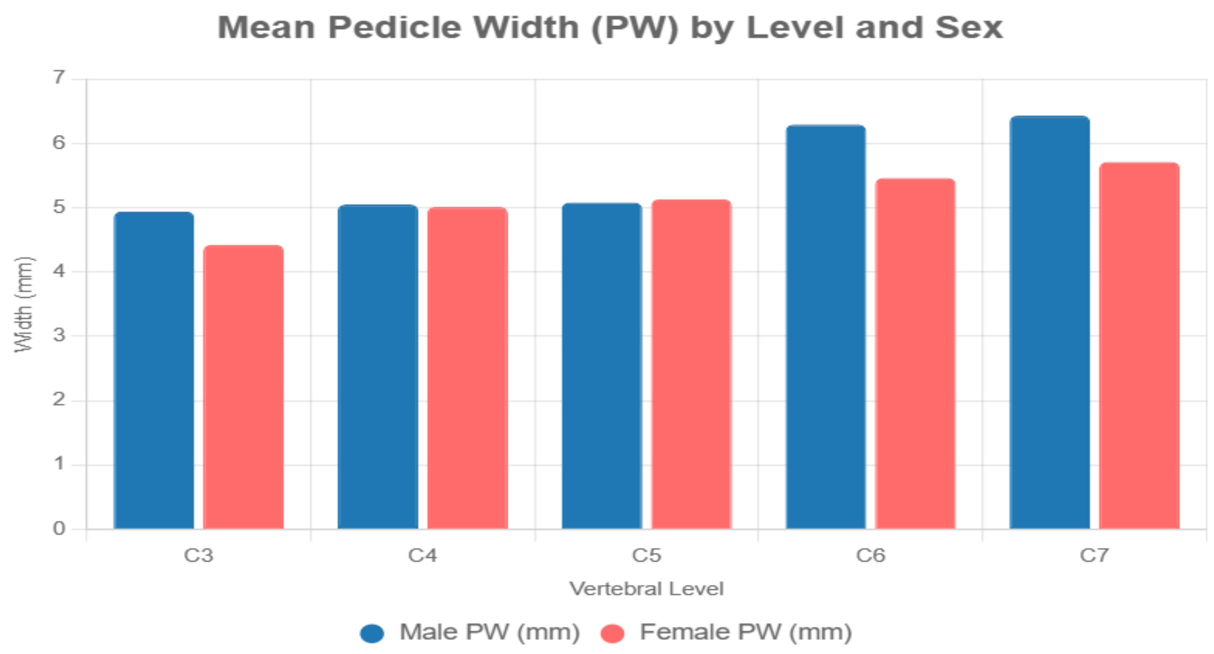
Table 3 shows PTA and PSA decreasing cranio-caudally.

Table 4 provides overall descriptive statistics.

Variable	Obs	Mean	Std. Dev.	Min	Max
PW3	50	4.678	0.488	3.925	5.57
PW4	50	5.032	0.335	4.275	5.64
PW5	50	5.109	0.348	4.54	5.665
PW6	50	5.87	0.793	4.845	7.56
PW7	50	6.059	0.868	4.845	7.37
PH3	50	5.611	0.606	4.775	6.83
PH4	50	5.911	0.678	4.945	7.185
PH5	50	6.228	0.699	5.225	7.56
PH6	50	6.504	0.686	5.525	7.865
PH7	50	6.221	0.562	5.235	7.545
PL3	50	5.209	0.37	4.64	5.965
PL4	50	5.275	0.274	4.73	5.77
PL5	50	5.616	0.33	5.13	6.16
PL6	50	6.03	0.333	5.35	6.64
PL7	50	5.81	0.394	5.13	6.285
PAL3	50	29.755	1.415	27.82	33.655
PAL4	50	30.086	1.569	27.935	33.655
PAL5	50	30.996	1.666	28.655	34.445
PAL6	50	31.912	1.638	29.44	35.065
PAL7	50	32.746	2.973	28.525	39.88
PTA3	50	44.941	1.715	42.65	49.15
PTA4	50	43.681	1.231	41.3	46.25
PTA5	50	42.579	1.286	39.6	44.4
PTA6	50	37.695	1.283	35.25	39.25
PTA7	50	38.508	1.141	36.75	40.6

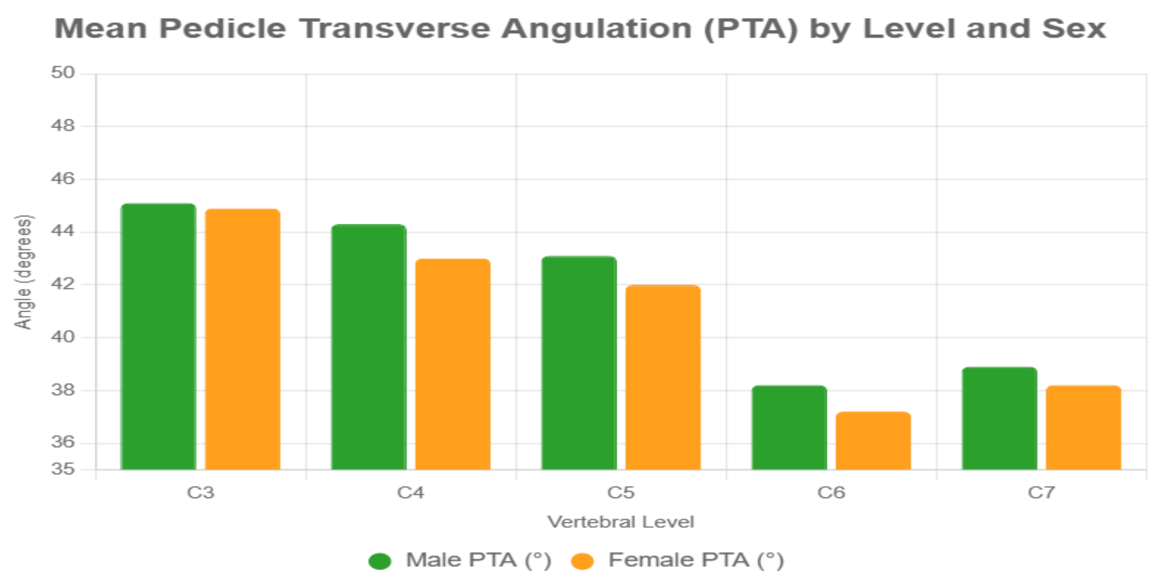
PSA3	50	15.446	3.093	10.3	20.6
PSA4	50	13.966	3.154	9.55	20.35
PSA5	50	10.127	2.365	6.4	13.7
PSA6	50	6.737	2.459	3.25	11.4
PSA7	50	5.167	1.768	3.3	11.55

Table 4 offers comprehensive parameter distributions.



Bar Diagram 1: Mean Pedicle Width (PW) by Level and Sex

The bar chart-1 demonstrates a cranio-caudal increase in pedicle width, with the most significant jump at C6–C7. Males consistently show wider pedicles ($p<0.05$), except at C5. The narrowest pedicles are at C3 in females (mean 4.42 mm), raising concerns for 3.5 mm screw placement.



Bar Diagram 2: Mean Pedicle Transverse Angulation (PTA) by Level and Sex PTA shows a progressive decrease from C3 (≈45°) to C6 (≈37°), with a slight increase at C7. Males have marginally higher angulation at upper levels. This cranio-caudal convergence necessitates increasing medial angulation during screw insertion from rostral to caudal.

Discussion:

The sub-axial cervical spine (C3–C7) is a critical segment for surgical stabilization, particularly with cervical pedicle screw (CPS) fixation, which offers superior biomechanical stability compared to lateral mass screws. However, the narrow pedicle isthmus and proximity to neurovascular structures demand precise preoperative morphometric data. This study provides the first comprehensive CT-based morphometric analysis of sub-axial cervical vertebrae in the adult Kashmiri population, revealing smaller pedicle dimensions than most global cohorts, with significant implications for implant selection and surgical safety.

Pedicle Width (PW)

Pedicle width is the primary determinant of screw feasibility. A minimum PW of ≥4.5 mm is generally required for safe placement of a 3.5 mm CPS with a 1 mm cortical margin [9]. Our results show a cranio-caudal increase in PW from 4.68 ± 0.49 mm at C3 to 6.06 ± 0.87 mm at C7, with males consistently larger ($p<0.05$ except at C5). The narrowest pedicles were observed at C3 in females (mean 4.42 ± 0.34 mm, range
3.91–4.99 mm), with 32% < 4.5 mm, indicating high risk for pedicle breach.

Study	Population	PW C3 (mm)	PW C4 (mm)	PW C5 (mm)	PW C6 (mm)	PW C7 (mm)	Method
Present Study	Kashmiri	4.68	5.03	5.11	5.87	6.06	CT
Saluja et al. [10]	North Indian	5.10	5.30	5.40	5.90	6.40	CT
Gupta et al. [11]	North Indian	4.90	5.20	5.50	6.10	6.50	CT
Yusof et al. [12]	Malaysian	4.70	5.00	5.40	5.90	6.10	CT
Reinhold et al. [13]	German	5.80	6.10	6.40	6.80	7.20	CT
Ruofu et al. [14]	Chinese	4.60	4.90	5.30	6.00	6.50	Cadaver

Our C3–C5 PW values are smaller than North Indian [10,11], Chinese [14], and German [13] populations, but comparable to Malaysian [12]. At C6–C7, Kashmiri dimensions align with Asian cohorts but remain 0.5–1.0 mm smaller than Caucasians. This suggests ethnic variation in pedicle morphology, with Kashmiri and South Asian populations having narrower upper cervical pedicles, likely due to smaller vertebral body size and genetic factors.

Pedicle Height (PH)

PH consistently exceeded PW at all levels ($p<0.001$), peaking at C6 (6.50 ± 0.69 mm).
Males had greater PH ($p<0.05$).

Study	PH C3 (mm)	PH C6 (mm)	PH C7 (mm)
Present	5.61	6.50	6.22
Saluja [10]	5.80	6.70	6.50
Yusof [12]	5.50	6.40	6.10
Reinhold [13]	6.20	7.10	6.80

Our PH values are smaller than Western populations but similar to Asian populations, reinforcing the trend of reduced vertical pedicle space in South Asians.

Pedicle Axis Length (PAL) and Pedicle Length (PL)
PAL increased from 29.76 ± 1.42 mm (C3) to 32.75 ± 2.97 mm (C7), with PL peaking at C6 (6.03 ± 0.33 mm) before a slight reduction at C7.

Study	PAL C3 (mm)	PAL C7 (mm)
Present	29.76	32.75
Gupta [11]	31.20	34.50
Reinhold [13]	32.10	35.60

Our PAL is shorter than all reported cohorts, likely due to smaller vertebral body depth in Kashmiris. This has implications for screw length selection—standard 30–35 mm screws may be excessive, increasing the risk of anterior cortical perforation.

Pedicle Transverse Angulation (PTA)
PTA decreased from 44.94° ± 1.72° (C3) to 37.70° ± 1.28° (C6), with slight increase at C7 (38.51°).

Study	PTA C3 (°)	PTA C5 (°)	PTA C7 (°)
Present	44.94	42.58	38.51
Saluja [10]	44.44	41.11	36.91
Reinhold [13]	46.50	43.20	38.00
Karaiikovic [15]	45.00	42.00	37.00

Our PTA at C3–C5 is higher than Chinese [13] but lower than German [15]. The craniocaudal convergence ($\Delta \approx 7°$) is consistent across studies, but absolute values differ, necessitating population-specific entry point and medialization adjustments.

Pedicle Sagittal Angulation (PSA)
PSA showed a dramatic shift from cephalad tilt at C3 (15.45° ± 3.09°) to caudad at C7 (5.17° ± 1.77°).

Study	PSA C3 (°)	PSA C5 (°)	PSA C7 (°)
Present	+15.45	+10.13	+5.17
Liu [4]	+10.70	+3.50	−10.60
Reinhold [6]	+13.60	+5.80	−3.00
Karaiikovic [8]	+12.00	+4.00	−2.00

Our PSA remains cephalad at all levels, unlike Chinese and Western populations, where C6–C7 becomes caudad. This unique sagittal profile in Kashmiris may reflect differences in cervical lordosis or vertebral body shape. Surgeons using standard trajectories (e.g., Abumi technique) risk superior endplate breach at C7 if caudad angulation is assumed.

Clinical Implications
Screw Feasibility: 3.5 mm CPS requires PW ≥4.5 mm [13]. Feasible in >90% of Kashmiris, except C3 females (32% <4.5 mm). Use lateral mass screws or skip the C3 pedicle.

Trajectory Planning: PTA decreases from 45° to 37° → increase medialization caudally. PSA remains cephalad at all levels → avoid caudad tilt, especially at C7.

Implant Design & Navigation: Recommend 3.0–3.2 mm screws or variable-angle systems. High PSA variability (SD up to 3.1°) supports intraoperative 3D navigation to reduce breach risk.

Strengths
The study used a standardized CT protocol with 1 mm reconstructions and dualobserver measurements (ICC > 0.92), ensuring high accuracy. Pathology was strictly excluded to reflect true anatomy. It provides the first population-specific morphometric data for Kashmiris.

Limitations
The sample size is small (n=50) and CT-based without cadaveric validation. Age stratification was not performed (though r < 0.2). As a single-center study, it may not fully represent all Kashmiri subgroups.

Conclusion
Sub-axial cervical pedicles in adult Kashmiris are smaller than Western populations but similar to other Asian populations. C3 in females poses the highest risk for pedicle breach. 3.5 mm CPS is feasible in most levels, but C3 may require lateral mass fixation. PTA and PSA decrease cranio-caudally, necessitating level-specific trajectory adjustment. These data enable safer cervical pedicle screw placement and support the development of region-specific implants.

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