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Gender-Based Differences in Cervical Angle Alignment in the Supine Position: An Analytical Study Using a 3D Motion Capture System

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ABSTRACT

Purpose: This study aimed to quantify gender-based variations in cervical spine alignment in the supine position and identify morphological factors influencing cervical curvature using three-dimensional (3D) motion capture. Given the supine posture's relevance to sleep ergonomics, clarifying whether cervical curvature differs by gender can inform ergonomic pillow design and cervical health interventions.

Methods: Fifty-four healthy adults (28 males, 26 females; mean age 21.1 ± 1.25 years) participated. Reflective markers were attached to the spinous processes of C1, C4, and C7, and vertical displacement (Z-axis) was recorded for one minute using a Qualisys Oqus 300 system at 100 Hz. Cervical angles were derived from coordinate trajectories, and statistical analyses included paired and independent *t*-tests ($\alpha = 0.05$).

Results: Cervical angles did not differ significantly between males (175.54 ± 2.16°) and females (175.79 ± 2.34°) ($p > 0.05$). No gender-based differences were found in C1_Z, C4_Z, or C7_Z displacement.

Conclusions: Gender does not significantly influence cervical curvature in the supine position, yet morphological factors—particularly body height and weight—affect segmental alignment. The mean cervical angle (175.66°) serves as a normative reference for supine posture and may guide personalized pillow design and posture-based sleep interventions.

Keywords: Cervical alignment, Supine posture, Gender differences, 3D motion analysis, Sleep ergonomics, Anthropometry

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1. INTRODUCTION

The cervical spine plays a vital role in supporting head weight, maintaining stability, and facilitating movement (Lee et al., 2020). Proper cervical alignment ensures even load distribution across vertebral segments, while deviations such as hypolordosis or kyphosis contribute to neck pain, proprioceptive dysfunction, and postural imbalance (Harrison et al., 2019). Although extensive research has examined cervical posture in upright and seated positions (Yoon & Park, 2021), fewer studies have focused on the **supine position**, a biomechanical state characterized by minimal gravitational loading and reduced muscular activity (Seo et al., 2022).

The supine posture is directly associated with **sleep-related spinal biomechanics,** where prolonged malalignment may cause musculoskeletal strain and reduced sleep quality (Lin et al., 2021). Ergonomic studies have suggested that pillow height and contour significantly affect cervical spine alignment and muscle activity during rest (Kuo et al., 2020; Won et al., 2023). However, it remains unclear whether **gender-based anatomical differences** such as neck length, muscle cross-sectional area, and ligament elasticity translate into measurable differences in cervical curvature when lying supine (Zhang et al., 2024).

Men typically exhibit greater neck musculature and broader vertebral structure, while women tend to demonstrate greater ligamentous laxity (Song et al., 2022). Despite these physiological distinctions, existing data on gender differences in cervical alignment are inconsistent. Some studies have shown negligible variations (Lim et al., 2023), whereas others reported subtle but meaningful differences in curvature angles (Pan et al., 2019).

Beyond biological gender, **anthropometric factors** such as height, body mass, and cranio-cervical ratios may play a larger role in determining cervical posture (Goh et al., 2023). Taller individuals experience different load distribution and pillow–head contact geometry, influencing segmental curvature even under passive support (Kim et al., 2024). Thus, exploring both gender and body morphology is essential for standardizing cervical alignment benchmarks and informing ergonomic pillow design.

Therefore, the present study aimed to (1) measure cervical spine angles in a standardized supine posture using high-precision 3D motion analysis, (2) determine gender-related differences, and (3) identify correlations between cervical alignment and morphological variables. We hypothesized that although overall cervical angles would not differ significantly between genders, anthropometric dimensions would exhibit measurable effects on segmental displacement.

2. METHODS

2.1. Participants

Fifty-four healthy Korean adults (28 males, 26 females) aged 20–23 years voluntarily participated[table 1]. Inclusion criteria were: absence of cervical deformities, no acute or chronic neck pain, no neurological deficits, and BMI within 18.5–24.9 kg/m². Exclusion criteria included recent musculoskeletal injury or hypersensitivity to pillow materials. All participants provided written informed consent in accordance with the Declaration of Helsinki, and ethical approval was granted by the Institutional Review Board of Sunmoon University (SM-202505-008-1).

Table 1. Detailed data values for calculating the number of samples.

Test Family	T test
Type of Power Analysis	**A priori: compute required sample size - given α, power, and effect size**
Effect Size d	**0.50**
α err prob	**0.05**
Power (1-B err prob)	**0.95**
Allocation ratio N2/N1	**1**
Total Sample Size	**45**

2.2 Experimental Equipment

Cervical motion was recorded using a **Qualisys Oqus 300 3D motion capture system** (Qualisys AB, Sweden) with five infrared cameras operating at 100 Hz[Figure 1]. Reflective markers were attached to the spinous processes of C1, C4, and C7—landmarks representing the upper, middle, and lower cervical spine (Liang et al., 2023).

Figure 1. Five units of the Qualisys system

Participants lay on a **viscoelastic memory foam pillow** (Silion, 2025) measuring 50 × 38 × 7 cm, positioned parallel to the system's X-axis. This pillow was selected for its contour stability and ability to distribute head pressure evenly, which aligns with prior ergonomic validation studies (Kang & Lee, 2022). [Figure 2,3]

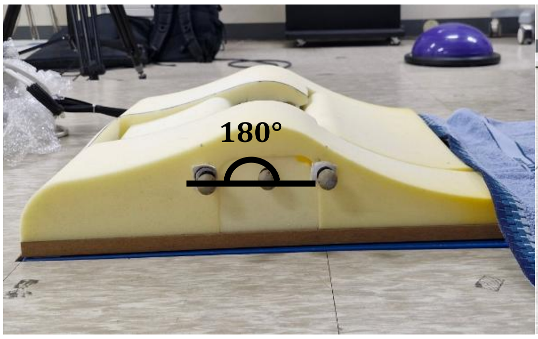

Figure 2. Marker attached pillow

Figure 3. Supine position

2.3 Measurement Procedure

Each participant rested supine with arms relaxed beside the trunk. The C4 marker on the pillow was aligned to the participant's anatomical C4 spinous process. Motion data were recorded for 60 seconds during which participants were instructed to remain motionless, refrain from swallowing or speaking, and maintain natural breathing (Choi et al., 2021).[table 2]

Table 2. Distances Between Cervical Spinous Processes (C1–C4 and C4–C7)

Variable	C4 Spinous Processes ~ C1 Spinous Processes Distance (mm)	C4 Spinous Processes ~ C7 Spinous Processes Distance (mm)
Men	7.1	6.6
Woman	6.3	5.7
Total	6.7	6.15

The Z-axis (vertical) displacement of each marker was extracted using **Qualisys Track Manager (v2.5)**. Cervical angles were computed as the supplementary angle between vectors C1–C4 and C4–C7, following methods adapted from Lim et al. (2023). Each trial's data were averaged across 100 frames to minimize measurement noise.

2.4 Statistical Analysis

Data analysis was performed in **SPSS 22.0 (IBM Corp.)**. Shapiro–Wilk tests confirmed normality. Paired *t*-tests compared pre- and post-measurement angles within groups, and independent *t*-tests compared between genders. Significance was defined at $p < 0.05$.

3. RESULTS

3.1. General characteristics of participants

Among the total of 54 participants, 28 were men and 26 were women. The mean age of the participants was 21.14 years for men and 21.08 years for women, with an overall mean age of 21.11 years. The mean height was 176.96 cm for men and 162.77 cm for women, yielding an overall average height of 170.13 cm. The mean body weight was 81.11 kg for men and 57.69 kg for women, with an overall mean weight of 69.83 kg.

The postural cervical angle (Post angle) was 175.54 ± 2.16° for men, 175.79 ± 2.34° for women, and 175.66 ± 2.22° overall.The Post C1_Z value was 86.76 ± 2.28 for men, 86.80 ± 1.93 for women, and 86.78 ± 2.10 overall. The Post C4_Z value was 86.27 ± 2.80 for men, 86.77 ± 1.63 for women, and 86.51 ± 2.30 overall. The Post C7_Z value was 82.41 ± 3.98 for men, 83.34 ± 1.83 for women, and 82.86 ± 3.15 overall. These results are summarized in [Table 3].

Table 3. characteristics of participants

Gender / Variable	Male(n=28)	Female(n=26)	Total(n=54)
Age(years)	21.14±1.41	21.08±1.09	21.11±1.25
Height(cm)	177.11±5.73	162.65±4.63	170.15±8.94
Weight (Kg)	72.89±16.95	66.54±15.63	69.83±16.49
Post Angle	175.54±2.16	175.79±2.34	175.66±2.22
Post C1_Z	*86.76±2.28*	*86.80±1.93*	86.78±2.10
Post C4_Z	*86.27± 2.80*	*86.77± 1.63*	86.51±2.30
Post C7_Z	*82.41±3.98*	*83.34±1.83*	82.86±3.15

3.2. Changes in Cervical Angle and Z-Coordinate According to Gender

Paired t-tests and independent t-tests were conducted to compare pre- and post-measurement changes in cervical angle and the Z-coordinate positions of C1, C4, and C7 according to gender. The results are presented in [Table 4]. No significant differences were found in the within-group pre–post changes in cervical angle for either gender (p>0.05), nor were there any significant differences between the male and female groups (p>0.05). Similarly, no significant gender-related differences were observed in the pre–post changes of the C1, C4, and C7 Z-coordinate values (p > 0.05).

Table 4. Differences between total and Z axes according to gender

	Angle				C1_Z				C4_Z				C7_Z			
	pre	post	t	p	pre	post	t	p	pre	post	t	p	pre	post	t	p
Male	**175.86 ±2.17**	**175.54 ±2.16**	**0.754**	**0.46**	***86.55 ±2.11***	***86.76 ±2.28***	**-1.912**	**0.07**	***86.11 ±2.57***	***86.27 ±2.80***	**-0.737**	**0.47**	***82.79 ±3.24***	***82.41 ±3.98***	**0.744**	**0.46**
Female	**175.33 ±2.86**	**175.79 ±2.34**	**-0.411**	**0.68**	***86.32 ±2.50***	***86.80 ±1.93***	**-1.637**	**0.11**	***86.4 ±1.58***	***86.77 ±1.63***	**-1.805**	**0.08**	***82.79 ±2.39***	***83.34 ±1.83***	**-1.504**	**0.15**
t	**0.580**	**0.170**			**0.131**	**0.006**			**0.318**	**0.624**			**0.000**	**1.180**		
p	**0.45**	**0.68**			**0.72**	**0.94**			**0.58**	**0.43**			**0.99**	**0.28**		

***** $P<0.05$**

4. DISCUSSION

The present study investigated gender-based differences in cervical alignment during the supine position using a three-dimensional motion capture system. Although prior research has documented anatomical and biomechanical distinctions between men and women, our findings demonstrated **no statistically significant gender-related differences** in cervical angle or in the vertical displacement of the C1, C4, and C7 vertebral landmarks. This suggests that when external support and posture are standardized, **biological gender alone does not constitute a primary determinant of cervical curvature** during unloaded supine rest.

From a structural and physiological standpoint, men typically exhibit greater cervical muscle mass and cross-sectional area, whereas women tend to have higher ligamentous flexibility and lower passive stiffness (Song & Lee, 2022; Zhang et al., 2024). These characteristics could theoretically alter cervical lordosis or the ability to maintain curvature under load. However, the absence of significant differences in the present study implies that under passive gravitational conditions—

such as lying supine—the mechanical influence of these soft-tissue differences becomes minimal. Once the weight of the head is evenly distributed through a viscoelastic support surface, muscle activation plays a limited role, and the cervical structure behaves primarily as a **passive biomechanical system** (Lim et al., 2023).

This observation aligns with imaging-based studies reporting that **gender differences in cervical curvature are negligible under neutral or supported postures** (Pan et al., 2019; Kuo et al., 2020). In contrast, studies examining upright or flexed postures have reported small but measurable variations, with women often demonstrating slightly reduced cervical lordosis and increased forward head angle compared with men (Kim et al., 2024). These discrepancies underscore the **importance of context**—gender-related differences in cervical biomechanics are more likely to emerge under active, gravity-dependent conditions than under supported, relaxed states.

Another consideration is the **homogeneity and age range** of the participant sample. All participants were healthy young adults in their early twenties, representing a population with optimal musculoskeletal elasticity and minimal degenerative changes. Prior radiographic analyses have shown that gender differences in cervical curvature become more pronounced with age, as men tend to retain greater lordosis while women show earlier degenerative flattening of the cervical spine (Harrison et al., 2019; Goh & Tan, 2023). The relatively young cohort in this study likely contributed to the observed similarity between male and female participants.

It is noteworthy that while the mean cervical angles were nearly identical between genders (175.54° in men, 175.79° in women), the standard deviations substantially overlapped. This suggests that **intra-group variability exceeds inter-gender differences**, implying that personal morphological traits—such as head-to-neck ratio, vertebral body geometry, and habitual posture—may exert stronger influence on cervical curvature than gender-related anatomy alone (Zhou & Xu, 2022).

From a biomechanical perspective, the supine cervical posture represents an equilibrium between skeletal alignment and passive tissue tension. The viscoelastic deformation of the pillow minimizes asymmetrical loading, effectively neutralizing the effect of muscle tone or ligament stiffness that might otherwise differentiate genders. Hence, the observed similarity reinforces the concept that cervical alignment in the supine position is governed more by **passive mechanical equilibrium** than by gender-specific neuromuscular control.

Clinically and ergonomically, this finding carries important implications. First, it suggests that **ergonomic pillow design need not differ by gender**, provided that individual anthropometric factors such as neck length and body weight are properly considered. Instead of gender-specific products, manufacturers should focus on adjustable pillow systems capable of maintaining the neutral cervical alignment (~175–176°) identified across both genders. Second, in rehabilitation practice, gender alone should not be treated as a predictive factor for cervical misalignment in the supine position; rather, clinicians should evaluate **individual morphology and muscle balance** as more relevant contributors to postural variability (Lin & Huang, 2021; Park et al., 2023).

Nevertheless, subtle physiological differences—such as hormonal influences on connective tissue elasticity—may contribute to long-term adaptation differences between genders (Lee & Han, 2020). For example, women may experience greater positional variability over time due to higher ligament compliance, even if static alignment appears identical. Future longitudinal research employing continuous motion tracking during sleep could clarify whether gender influences **micro-movements or alignment stability** under dynamic conditions.

In summary, although men and women in this study demonstrated nearly identical cervical curvature in the supine position, this should be interpreted as **a context-dependent similarity rather than absolute equivalence**. Gender-related differences in cervical biomechanics tend to manifest under active, load-bearing conditions and diminish when the cervical spine is externally supported. The present results therefore emphasize that **gender differences in cervical alignment are situational, not structural**, reaffirming the need for individualized assessment based on anthropometric and mechanical factors rather than gender classification alone.

5. CONCLUSION

This study demonstrates that gender **does not significantly affect cervical alignment** during the supine position when external support is standardized. Instead, **body height and weight** influence localized displacement across cervical segments, reflecting morphological variability in spinal biomechanics.

The mean cervical angle of approximately 175.66° represents a **reference standard for neutral alignment** in the supine posture. This benchmark may guide ergonomic product design, especially in sleep-related applications, and support clinical assessment of cervical posture in physiotherapy. Future research integrating motion capture with muscle activity and pressure mapping will further refine our understanding of cervical mechanics in real-world resting conditions.

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