Research Article

Bilateral Ventricular Papillary Muscle Variations - A Morphometric Study

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Background: Papillary muscles (PM) are vital, especially in cases of atrioventricular (AV) valve prolapse. Bilateral and population-specific variations in PM length are among the several factors that influence the failure of AV valve replacement surgeries. PM morphometric variations between ventricles necessitate a thorough understanding of the effective surgical interventions.
Aim: This study aimed to measure PM variations in the South Indian population to determine appropriate preventive measures, i.e. to compare PM morphometric parameters in both side heart ventricles and correlate the findings with baseline characteristics.
Methods: This 2-year autopsy-based prospective study involved 171 fresh adult heart samples. The PM was classified by position and measured for length, breadth, and thickness, with the anterior PM being the largest in both.
Results: The study outcomes showed statistically significant and consistent differences in the PM dimensions between the left and right ventricles. The left ventricular anterior PM were longer, broader, and thicker than their right ventricular counterparts (P <0.05). The PM morphometric characteristics of the South Indian Population, when compared with the baseline characteristics, showed a significant but variable degree of difference.
Conclusion: The findings of this study emphasize the importance of considering ventricular-specific PM morphometric data to optimize surgical strategies and prevent treatment failures.

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Introduction

The atrioventricular (AV) valves of the heart contain a critical functional component known as the subvalvular (SV) apparatus, which includes the papillary muscles (PM) and chordae tendineae[1]. The clinical significance of the PM is paramount, especially in cases of AV valve prolapse. The success of AV valve replacement procedures can be significantly influenced by variations in PM length, breadth, and thickness, which may differ among individuals and populations. A thorough grasp of the morphometric differences in PM between ventricles is essential for conducting effective surgical procedures[1][2][3].

The proper function of AV valve leaflets depends on the normal structure of the SV apparatus. Deviations in the typical morphology or dimensions of the SV apparatus can result in varying degrees of AV valve prolapse. The PM are conical muscular projections from the ventricular wall that contract just before ventricular systole, tighten the chordae, and pull the AV valve leaflets towards the apex at the start of ventricular contraction. This action prevents blood from flowing back into the atria[2].

A significant consequence of myocardial infarction is severe AV valve regurgitation, often caused by subsequent rupture of the PM[3]. Various surgical techniques can restore the normal structure and function of the ruptured PM. Understanding the variability, length, and thickness of the PM is crucial for cardiac surgeons during corrective procedures[4]. The anatomy of the PM differs significantly among individuals, much like fingerprints[5]. Thus, surgical procedures should be tailored to each patient's specific PM pattern to enhance surgical outcomes and prevent postoperative disease recurrence[4]. Additionally, there are notable differences in the morphometry of the PM between the RV and LV[4][6][7]. For effective surgical reconstruction or repair, it is essential to have comprehensive information on the variations in PM morphometry in both ventricles. However, few studies have compared PM morphometry with baseline characteristics, and there is a lack of data in the literature on PM morphometry in both ventricles of autopsied human hearts. Therefore, this study aimed to compare PM morphometry in both the right and left ventricles of autopsied hearts and to analyze its relationship with age, sex, BMI, and heart weight.

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Materials And Methods

- *Study Design*: This descriptive cross-sectional study analyzed 171 adult human heart specimens (127 males and 44 females) collected from cases of hospital deaths with known cause and duration of the death, viz. traffic accident, head injury, etc. All cases were medically certified for the provisional cause of death. These specimens were obtained from routine autopsies conducted at the Department of Forensic Medicine and Toxicology over a two-year period (2022-2023). Heart samples were selected based on specific inclusion and exclusion criteria.
  i. *Inclusion and Exclusion Criteria:* Fresh adult heart samples from patients aged ≥ 18 years were included. Only heart samples with signs of primary or secondary flaccidity in the cardiac muscles were used to overcome the postmortem artifact due to rigor mortis.
  ii. *Exclusion*: Patients diagnosed with known cardiac disorders, heart specimens with evidence of direct trauma, congenital malformations, signs of pathology (including valvular defects and cardiomyopathies), history of cardiac disease or surgeries, unidentified bodies, unknown diagnosis, or cause of death were excluded from the study.
- *Data Collection*: Baseline demographic data of the deceased were extracted from postmortem records, hospital case files, and police records. Heart specimens were removed *en bloc* from the deceased, washed under running tap water, and examined for external damage.
- *Dissection and Measurement*: The right atrium was opened, and the tricuspid valve was cut at its anteroposterior commissure, extending the incision to the apex of the right ventricle (RV) without damaging the underlying PM (Figure 1).[6][8][9] Similarly, the left atrium was opened with an inverted U-shaped incision, and the posterior mitral leaflet was cut in its middle, extending the incision to the apex of the left ventricle (LV) (Figure 2).[5][8][10] The AV valve and SV apparatus were examined for abnormalities, and the ventricles were checked for hypertrophy. The heart specimens were weighed using an electronic weighing machine. PM was classified based on its position in the ventricular cavity as anterior PM (APM), posterior PM (PPM), or septal PM (SPM). The length, breadth, and thickness of the PM in both ventricles were measured using digital Vernier calipers and a wooden scale. The length (in centimeters) was measured from the basal attachment on the ventricular wall to the apex, where they attached to the chordae tendineae (CT) (Figure 3). Breadth and thickness (in millimeters) were measured at the midpoint between the base and apex, with breadth measured in the anteroposterior direction and thickness measured in the mediolateral

direction (Figures 4 and 5). When multiple PM were present in a particular position, measurements were taken, and their average was considered. All observations were recorded by a single observer using a data-collection protocol. After data collection, heart specimens were returned to the body at the end of the autopsy.

- *Sample Size Estimation*: The sample size was estimated considering an expected average number of chordae tendineae of 3, with a standard deviation (SD) of 3, at a 5% level of significance and 15% relative precision. This estimation yielded the largest sample size, which was adopted for all variables.
- *Statical Analysis*: Data were tabulated and analyzed using descriptive statistics, presented as mean with standard deviation (SD) or median with interquartile range (IQR) according to the normality assumption. Comparisons of PM morphometry between RV and LV were performed using paired/Wilcoxon signed-rank sum tests. Gender-based morphometric analyses utilized independent t-tests/Mann-Whitney U tests, and age/BMI group analyses used one-way ANOVA/Kruskal-Wallis tests, depending on data normality. Statistical analyses were conducted using SPSS version 19.0, with a p-value of less than 0.05 considered statistically significant. The results are summarized and presented in the tables.
- *Ethical Considerations:* This study was conducted according to the guidelines prescribed by the Indian Council of Medical Research (ICMR) and the research ethics norms of the Helsinki Declaration for Human Studies. Ethical clearance and prior approval were obtained from the *Institute Ethics and Research Monitoring Committee* (*vide* Ref no. JIP/IEC/2021/343 dated 09 Mar. 2022).

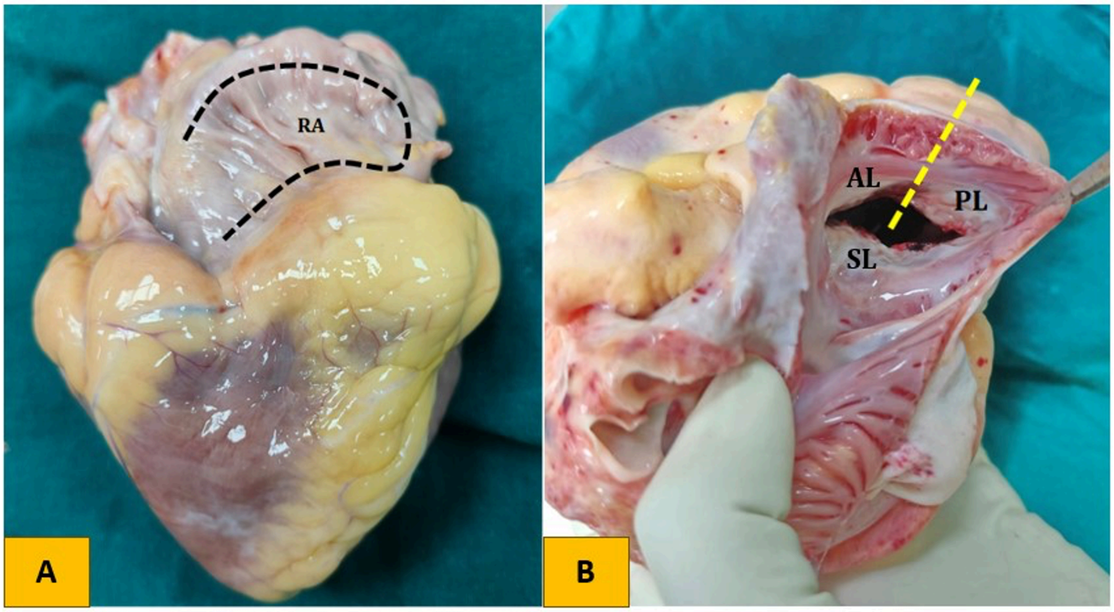

Figure 1. A) Dotted line shows incision used to open right atrium (RA); **B)** Dotted line shows incision used at anteroposterior commissure to open right ventricle. AL-Anterior leaflet; PL-Posterior leaflet; SL-Septal leaflet.

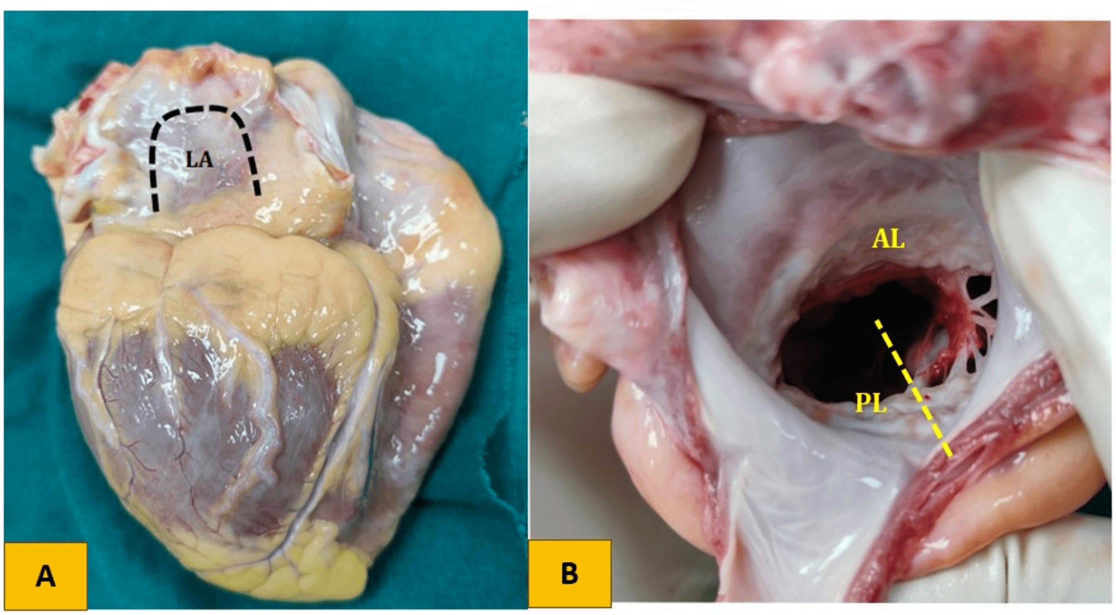

Figure 2. A) Dotted line shows incision used to open left atrium (LA); **B)** Dotted line shows incision used at middle of posterior mitral leaflet to open left ventricle. AL-Anterior leaflet; PL-Posterior leaflet.

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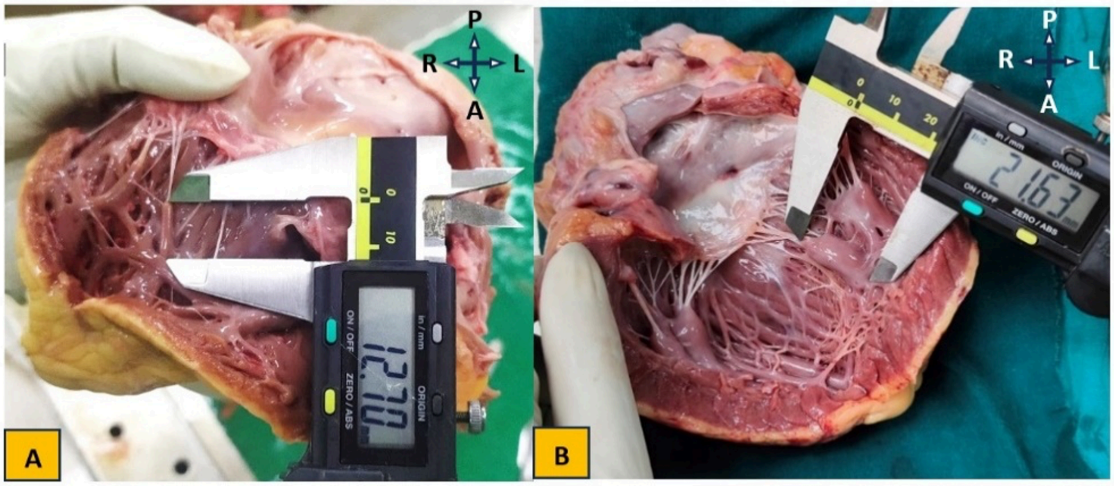

Figure 3. A) Interior of right ventricle showing measurement of length of posterior papillary muscle using Digital vernier calliper; **B)** Interior of left ventricle showing measurement of length of posterior papillary muscle using Digital vernier calliper.

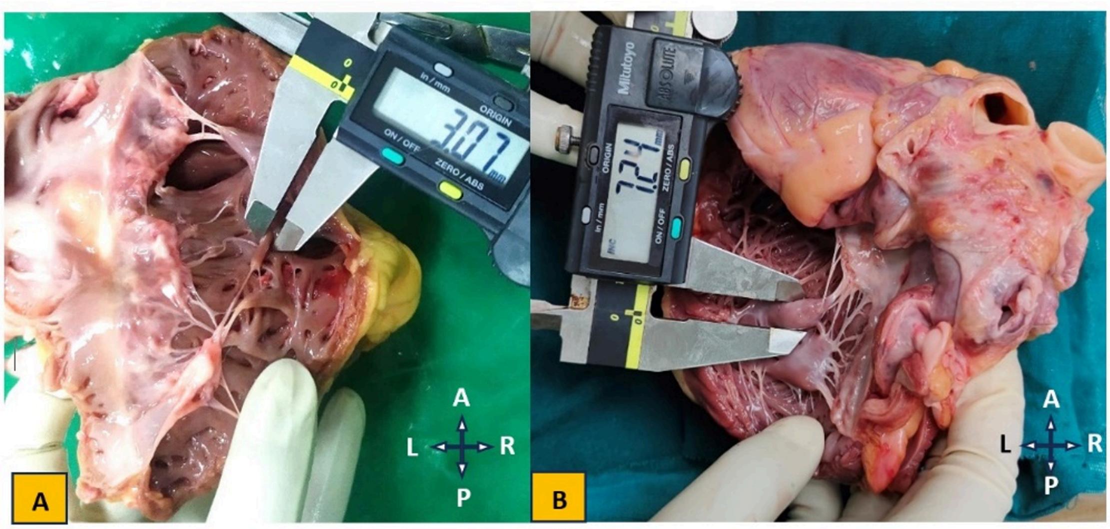

Figure 4. A) Interior of right ventricle showing measurement of breadth of posterior papillary muscle using Digital vernier calliper; **B)** Interior of left ventricle showing measurement of breadth of posterior papillary muscle using Digital vernier calliper.

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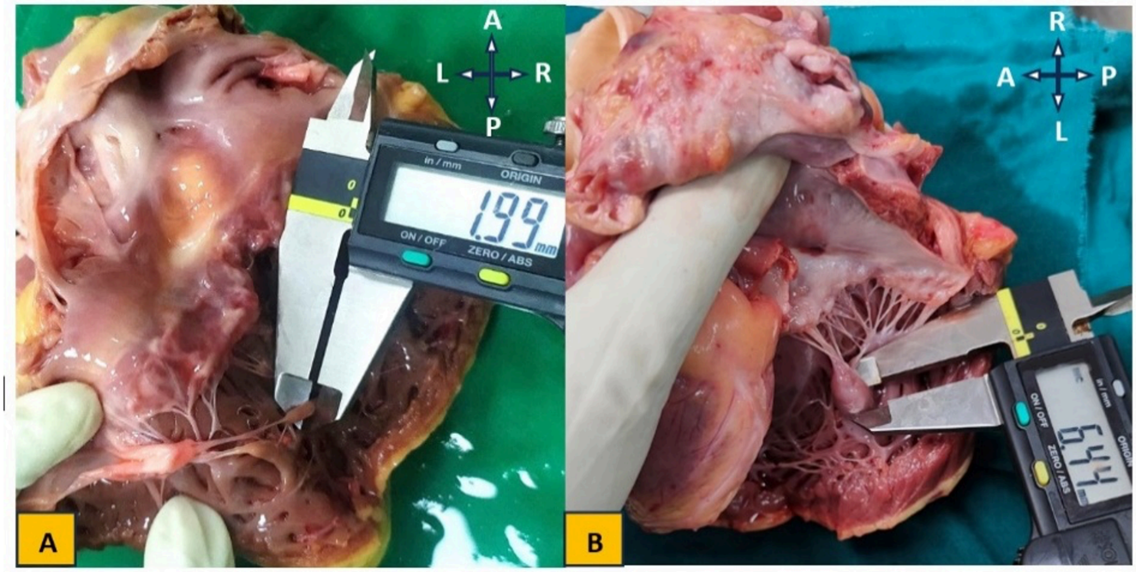

Figure 5. A) Interior of right ventricle showing measurement of thickness of posterior papillary muscle using Digital vernier calliper; **B)** Interior of left ventricle showing measurement of thickness of posterior papillary muscle using Digital vernier calliper.

Results

Of the 171 heart specimens collected, 127 were male and 44 were female. The ages of the subjects ranged from 20 to 80 years (median, 54 years). The BMI of the deceased ranged from 17.1 to 41.1 (Median=24.8). The median heart weight was 274 g (Range=234-356 gm). Heart weight ranged from 261 to 286 g in males and 256 to 286 g in females. Based on the heart weight, the specimens were categorized into two groups (Table1). The median heart weight was higher in males (274 g) than females (265 g); however, the difference was not statistically significant ($p>0.05$). Heart weight significantly increased with an increase in the age of the subjects ($p < 0.05$).

The length (cm), breadth (mm), and thickness (mm) of the PM were measured in both ventricles of the heart and are summarized in Table 2. The APM was the longest, broadest, and thickest in both ventricles. The APM of the LV was greater in length, breadth, and thickness than that of the RV, and the differences were statistically significant ($p <0.05$). Differences in the morphometry of PM among sexes are shown in Table 3. Variations in the morphometry of the PM among the different age groups were analyzed and were not statistically significant (Table4). In each subgroup of age, differences in the morphometry between males and females were noticed and are summarized in tables:5-7. It was

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found that the length of the APM of the RV was greater in males (median =1.64 cm) than females (median =1.08 cm) among subjects in group I (p=0.009). Variations in PM morphometry among different subgroups of heart specimens based on BMI and heart weight are summarized in Tables 8 and 9.

Discussion

In this study, we observed that the APM was the longest (median length = 1.56 cm), broadest (median breadth = 3.58 mm), and thickest (median thickness = 3.61 mm) in the RV. PPM had a median length of 1.35 cm, median breadth of 3.16 mm, and median thickness of 2.57 mm. The SPM were shortest (median length = 0.49 cm), narrowest (median breadth = 2.54 mm), and thinnest (median thickness = 2.27 mm).

Similarly, Harsha et al. studied 96 cadaveric hearts and found that the APM in the RV were the longest (mean length = 1.49 cm), broadest (mean breadth = 0.82 cm), and thickest (mean thickness = 0.64 cm) [11]. Nigri et al. (2000) reported that the APM in the RV (mean length = 1.91 cm) were the longest[6]. Aktas et al. (2004) examined 400 autopsied hearts and noted that the APM (mean length = 2 cm) were the longest among the RVPM[7]. Later, Sinha et al. (2020) examined 40 human cadaveric hearts and found that the PPM in the RV were the longest (1.36±0.52 cm)[12]. A comparison of the morphometry of RVPM in the present study with others is shown in Table 10. Restoring normal morphometry, proper positioning of the PM, and alignment with the chordae are crucial in reconstructive surgeries of the AV valve and SV apparatus[4].

In the LV, the APM was longer (median length = 1.65 cm), broader (median breadth = 5.65 mm), and thicker (median thickness = 5.44 mm) than the PPM. The PPM had a median length of 1.54 cm, breadth of 5.5 mm, and thickness of 5.37 mm. Aulakh et al. examined 30 human cadaveric hearts and found that the APM (2.45±0.82 cm) in the LV were longer than the PPM (1.97±0.82 cm)[13]. Sinha et al. (2020) examined 40 human cadaveric hearts and observed that the APM (2.13±0.44 cm) were longer than the PPM (1.76±0.46 cm)[12]. Ozog et al. (2017) studied the morphometry of the LVPM and found that the APM were the longest (3.23±0.57 cm)[10]. A comparison of the morphometry of LVPM in the present study with others is shown in Table 11.

Overall, the APM were the longest (RV = 1.56 cm; LV = 1.65 cm), broadest (RV = 3.58 mm; LV = 5.65 mm), and thickest (RV = 3.61 mm; LV = 5.44 mm) in both ventricles compared to the other PM. APM in the LV were longer, broader, and thicker than those in the RV. Similarly, the PPM in the LV was longer (1.54 cm), broader (5.5 mm), and thicker (5.37 mm) than that in the RV. Due to their larger size, LVPM is more likely to contribute to left ventricular outflow tract obstruction. The primary treatment for symptomatic left ventricular outflow tract obstruction is usually the surgical repositioning of the PM[12]. The SPM in the RV were the shortest (0.49 cm), narrowest (2.54 mm), and thinnest (2.27 mm). The differences in PM morphometry between the RV and LV were statistically significant ($p = 0.001$) (Table 2). Sinha et al. measured the length of the PM in both ventricles of 40 human cadaveric hearts and noted that the APM in the LV (2.13±0.44 cm) were longer than those in the RV (1.27±0.45 cm) ($p<0.05$)[12]. Bhadoria et al. examined 50 human cadaveric hearts and found that the APM were the longest among all PM in both RV and LV (RV = 1.27±0.38 cm; LV = 1.64±0.43 cm), with the APM in the LV being longer than those in the RV[14].

We observed that the APM length increased with age in both ventricles, but the difference was not statistically significant ($p>0.05$). Ozog et al. examined 100 autopsied hearts from the European population and found that the length of the APM in the LV increased with age ($p<0.05$)[10]. The length of the APM in the RV was greater in males (median length = 1.64 cm) than in females (median length = 1.08 cm) among subjects in group I ($p=0.009$) (Table 5). Aulakh et al. studied 30 cadaveric hearts from the North West Indian population and reported that the length of the APM was greater in males than females ($p<0.05$)[13]. We also observed that the thickness of the PPM in the LV was greater in group B (median thickness = 5.64 mm) than in group A (median thickness = 5.34 mm), with the difference being statistically significant ($p=0.039$) (Table 9). The morphometry of the PM is vital for performing AV valve and SV reconstructive surgical procedures, particularly in the LV[4][12]. Differences in PM morphometry between the ventricles are related to the varying blood pressure and volume in each ventricle[14]. Knowledge about PM morphometry, especially the breadth, is crucial in screening for hypertrophic cardiomyopathy[15].

Conclusion

Significant morphometric differences were identified in the PM between the RV and LV in South Indian population. The APM in both ventricles was the largest, with the LV APM exceeding the RV APM. APM length increased with age in both ventricles, and younger males had longer RV APM than females. Additionally, the thickness of the PPM in the LV increased with the heart weight. The findings from this research, specifically the data on PM morphometric variations, will be valuable for cardiac surgeons in making optimal decisions prior to heart surgery. Future research should focus on the detailed morphometry of individual PM subtypes and compare cardiac and non-cardiac deaths.

Limitations

1. Ethnic and Racial Considerations: This study was conducted with specimens from the Indian population. The findings may not be universally applicable, as ethnic and racial factors can influence the heart and PM size. Future studies should consider these variations when applying these results to different populations.
2. Gender Representation: Gender-based comparisons may be inconclusive due to unequal male and female sample sizes.

Statements and Declarations

Conflicts of interest: none.

Funding: nil.

Ethical approval statement: This study was conducted per the guidelines prescribed by the Indian Council of Medical Research (ICMR) and the research ethics norms of the Helsinki Declaration for human studies. It has obtained ethical clearance and prior approval from the *Institute Ethics and Research Monitoring Committee* (*vide* Project no. JIP/IEC/2021/343 dated 09 Mar. 2022).

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Declarations

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