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3D Quantitative Analysis of Normal Clitoral Anatomy in Nulliparous Women on MRI

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Abstract:

Introduction and Hypothesis

We present a 3D computational approach for automated clitoral measurements. We hypothesized that computationally derived measurements would be comparable and less variable than reported manual measures.

Methods

In this retrospective study, MRIs of 22 women (age 20-49 years) with normal pelvic anatomy were collected. Manual segmentations were performed to reconstruct 3D models of the whole clitoris, glans, body, crura, bulbs, and vagina. The length, width, and volume of the clitoral components and the distance between the vagina and clitoral structures were calculated. Computed clitoral morphometrics (length, width) were compared to median [range] from a previously published cadaver study (N=22) using the Median test and Moses extreme reaction test. Calculated distances were compared to mean (±SD) reported by a 2D MRI study (N=20) using independent t test and Levene's test.

Results

Overall, computed clitoral morphometrics were similar to manual cadaver measurements, where the majority of length and width measures had ~1-2 mm difference, and had less variability (smaller range). All calculated distances were significantly smaller and had smaller SDs than manual 2D MRI values, with 2-fold differences in the means and SDs. There were large variations in volumetric measures in our cohort.

	Conclusions The proposed 3D computational method improves the standardization and consistency of clitoral measurements compared to traditional manual approaches. The use of this approach in radiographic studies will give better insight on how clitoral anatomy relates to sexual function and how both are impacted by gynecologic surgery, where outcomes can assist treatment planning.
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3D Quantitative Analysis of Normal Clitoral Anatomy in Nulliparous Women on MRI

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ABSTRACT (247/250 words, including headings):

Introduction and Hypothesis: We present a 3D computational approach for automated clitoral measurements. We hypothesized that computationally derived measurements would be comparable and less variable than reported manual measures.

Methods: In this retrospective study, MRIs of 22 women (age 20-49 years) with normal pelvic anatomy were collected. Manual segmentations were performed to reconstruct 3D models of the whole clitoris, glans, body, crura, bulbs, and vagina. The length, width, and volume of the clitoral components and the distance between the vagina and clitoral structures were calculated. Computed clitoral morphometrics (length, width) were compared to median [range] from a previously published cadaver study (N=22) using the Median test and Moses extreme reaction test. Calculated distances were compared to mean (±SD) reported by a 2D MRI study (N=20) using independent t test and Levene's test.

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Conclusions: The proposed 3D computational method improves the standardization and consistency of clitoral measurements compared to traditional manual approaches. The use of this approach in radiographic studies will give better insight on how clitoral anatomy relates to sexual function and how both are impacted by gynecologic surgery, where outcomes can assist treatment planning.

KEY WORDS (5/6 key words):

Clitoral Anatomy; Clitoris; Dimension; Morphometrics; Pelvic MRI

BRIEF SUMMARY (25/25 words):

The novel 3D computational approach developed automates clitoral measurements and improves upon traditional methods of clitoral analysis by reducing the variability associated with manual measurements.

ABBREVIATIONS:

BMI Body Mass Index

MRI Magnetic Resonance Imaging

SD Standard Deviation

MAIN TEXT (2773/3000 words):

INTRODUCTION:

Sexual dysfunction (including but not limited to disorders of desire, arousal, orgasm, and pain) is a highly prevalent and complex quality of life issue that disproportionately affects women [1]. In the United States alone, the rate of sexual dysfunction is 25%-63% for women, while it ranges from about 10%-52% among men [2]. In addition, the incidence and patterns of sexual dysfunction have been shown to differ with age and race, respectively, where younger women and black women are more likely to experience sexual problems [1, 2]. Despite the longstanding evidence and recognition of these disparities, there is a paucity of research on female sexual dysfunction, especially concerning its relationship with female sexual anatomy [3, 4].

Of the female sexual organs, the clitoris is the pivotal anatomical structure involved in the physiological changes that occur during sexual arousal and orgasm [5–7]. The clitoris is a complex organ comprised of internal and external components, including the glans, body, bulbs, and crura, and lies in close proximity to the distal vagina [8–10]. Together with the vagina, the clitoris plays a key role in sexual function [11]. It is believed that clitoral size and location are key determinants of sexual function, as a smaller clitoris and clitoral components further away from the vagina have been associated with poorer orgasmic function in previous studies [7, 12].

Thorough knowledge of the clitoris and its components is necessary to understand anatomy and physiology of the female sexual response and the pathophysiological mechanisms of female sexual dysfunction [3]. In particular, having a normative standard of the anatomic variation of the clitoris (e.g., shape, dimensions) would help reduce surgical complications associated with gynecologic procedures that can impact genital sensation and sexual function and may illuminate anatomical differences underlying sexual complaints[7, 13]. However, there is little quantitative data on clitoral anatomy in literature, especially in the live state. To date, clitoris research have primarily focused on qualitative descriptions of the anatomy using cadaveric dissections and magnetic resonance imaging (MRI) [14–16]. The few studies that have quantified clitoral anatomy have been mostly constrained to manual or 2D measurements with varying definitions, limited reproducibility, and little consensus in numerical findings [7–9, 13, 17, 18]. As a result, clitoral anatomy remains poorly characterized. A more objective, automated method that quantitatively assesses clitoral anatomy in the live state and in 3D is needed.

The objective of this study was to develop a standardized 3D computational approach for in vivo quantification of clitoral dimensions (i.e., length, width, volume) and distance to related anatomic structures associated with sexual function (i.e., vagina). To validate the proposed computational method, computed measurements were compared to manual measurements reported in literature [9, 13]. We hypothesized that the computed measures would be similar to and show less variation than the manual measurements.

MATERIALS AND METHODS:

Participant Recruitment

This retrospective descriptive study involved MRI examination of 22 nulliparous women 20-49 years of age with no prior surgery who underwent pelvic imaging for medical indications (e.g., pelvic pain, urethral diverticulum/pain, stress incontinence) as prescribed by their physician at the *University of Pittsburgh Medical Center* Magee-Womens Hospital. This study received Institutional Review Board approval from the University of Pittsburgh (19050362) to perform a retrospective chart review of electronic medical records between 2005 and 2018 in which demographic, medical history, and pelvic MRI data of women with normal pelvic anatomy (i.e., uncompromised gastrointestinal, genitourinary, and reproductive systems) were collected. Acceptable abnormalities for inclusion were the following: non-infected urethral diverticuli <3cm, uterine fibroids ≤3cm, simple or paratubal ovarian cysts ≤ 3cm, intrauterine device, thrombosed pelvic vein, thickened endometrial stripe, Bartholin's cyst, hydrosalpinx and similar findings. Exclusion criteria were abnormalities that fell outside the inclusion criteria, history of pelvic surgery and scans that failed to fully capture the clitoral anatomy. Women were imaged in the supine position at rest in the axial plane using either 1.5T or 3T systems with a pelvic phased-array coil.

MRI Segmentation & 3D Reconstruction

Manual segmentations were performed using 3D Slicer v4.10.0 (www.slicer.org).

First, the whole clitoris was segmented in the axial plane. Next, the clitoral segmentation was partitioned into the following clitoral structures: clitoral glans, clitoral body, crura (left and right crus), and bulbs (**Figure 1a**). A visual description of the anatomical partitioning of the clitoris on MRI is shown in **Appendix 1**.

The axial segmentations across multiple slices were then overlayed to reconstruct aliased (i.e., jagged or staircase effect that occurs at the edges of an object) 3D models of the clitoral anatomy (**Figure 1b-c**). In addition, the vagina was also segmented and modeled. Then, the 3D models were exported to Blender v2.83.2 (Blender Foundation, Amsterdam, Netherlands) to smooth the aliased geometries (**Figure 1d**). The final 3D reconstruction of the whole clitoris and clitoral structures is shown in multiple views in **Figure 2**.

Clitoral Morphometric & Distance Measurements

All morphometric and distance measurements were computationally derived from the MRI-based 3D models using custom-written code. First, the 3D models of the clitoris and vagina were imported into Mathematica v12.2.2.0 (Wolfram Research, Champaign, IL, USA). Next, an optimal bounding region, given by a minimum volume-oriented cuboid, was fitted on the 3D models of the clitoral glans, clitoral body, and left and right crus; the dimensions of the cuboid were used to calculate the lengths and widths of clitoral structures. For the clitoral glans and body, the length was measured along the inferior-superior direction and the width was measured at the midpoint along the medial-lateral direction in the frontal plane (**Figure 3**). For the crura, the length was measured from the elbow of clitoral body-glans junction to the end of the lateral end of the crus and the width was measured at its widest point such that it was perpendicular to its length in the axial plane (**Figure 3**). The volume of the clitoral glans, clitoral body, crura, bulbs and whole clitoris were calculated from their respective 3D model. Finally, the minimum surface-to-surface distance between the 3D models of the vagina and the following structures was calculated: glans, body, and crura (**Figure 4**).

Validation of the Computational Approach

To validate the computational method, the calculated clitoral morphometrics and distance measurements were compared to manual measurements from previous literature. The magnitude and variability of the computed clitoral morphometrics (i.e., length, width) were evaluated against caliper and ruler measurements reported by Jackson et al. (2019) that were obtained from 22 unembalmed female cadavers with no history of prior vulvovaginal surgery or vulvar malignancies [13]. There were no other comparable literature values available for the volumetric measures of clitoral structures. The value and consistency of the calculated distance measures were assessed with respect to manual measures described by from Vacarro et al. (2014) that were quantified from 2D MRIs of 20 sexually active women with normal pelvic anatomy [9]. Using random sampling from a triangular distribution based on the reported medians and ranges from the cadaver study and a normal distribution with means and standard deviations given in the 2D MRI study, datasets of patient demographics, clitoral morphometrics, and distance measures in line with literature values were generated to perform statistical comparisons.

Statistical Analysis

The data were analyzed using IBM SPSS Statistics v26.0 (IBM Corp., Armonk, NY, USA). Descriptive statistics are reported and missing demographic data were excluded. Patient demographics (i.e., age, BMI, race) were compared between the present and previous studies using Wilcoxon rank-sum test (nonparametric) and independent t-test (parametric) for continuous variables and Fisher's exact test for categorical variables. The median and range of morphometric measures computed from MRI-based 3D models vs measures taken manually from cadaveric dissections were compared using the Median test and Moses extreme reaction, respectively. The independent t-test and Levene's test were used to evaluate differences in the mean and variance of distance measurements derived computationally from MRI in 3D vs manually from MRI in 2D. All statistical tests were two-sided and performed at significance level of 0.05.

RESULTS:

Study Population Demographics

Demographic characteristics across all studies are given in **Table 1**. A total of 22 women were included in this study; 22 were in the cadaver study and 20 were in the 2D MRI study [9, 13]. Compared to the subject populations of the two literature studies, the present cohort was significantly younger than that of the cadaver study (median, 30 vs. 70 years; $p<.001$) and 2D MRI study (mean, 30 vs. 42 years; $p<.001$). Conversely, the BMI was similar among our cohort and the cadaver cohort (median, 23 vs. 22 kg/m^2; $p=0.24$), as well as the 2D MRI cohort (mean, 26 vs. 28 kg/m^2; $p=0.40$). While there was no significant difference in race between the present study and cadaver study ($p=1.00$), there was a higher proportion of black women in the 2D MRI cohort (30%) than our cohort (0%) (p=.007).

Morphometric Measurements

The clitoral morphometric measures derived (i.e., present study) computationally vs manually (i.e., previous literature) are presented in **Table 2**. For the clitoral glans, the computed and literature values were similar for the length (median, 6 vs. 8 mm; p=0.76) and width (median, 5 vs 4 mm; p=0.13); the variability of the calculated length was similar (range, 5-12 vs. 5-12 mm; p=0.50), while the computed width measurements were more consistent (range, 4-7 vs. 3-12 mm; p<.001) than the manual measures previously reported. The clitoral glans volume varied greatly, where the mean ± standard deviation (SD) was 222 ± 125 mm^3.

Comparison of the clitoral body computational versus manual measurements demonstrated that the calculated length was smaller (median, 18 vs 29 mm; p<.001) and had a narrower range (range, 9-24 vs 13-59 mm; p<.001) than previous literature, whereas the computed width was slightly larger (median, 11 vs 9 mm; p=0.04) and showed similar variation (range, 5-16 vs 5-14 mm; p=0.95). The volume of the clitoral body was also highly variable in our study cohort (3090 ± 1028 mm^3).

For the crura, the calculated length was smaller (median, 36 vs 50mm; p<.001) and more consistent (range, 23-54 vs. 25-68 mm; p<.001) than the literature value and measurements. The computed width was similar (median, 7 vs 9 mm; p=0.37) and had a smaller range (range, 5-11 vs. 2-13; p=0.02) than the reported manually measures.

There was considerable variation in the crura volume compared to the mean (1945 ± 970 mm^3).

Lastly, the volume of the bulbs (4897 ± 2124 mm^3) and whole clitoris (10014 ± 3692 mm^3) varied greatly in the study population.

Distance Measurements

When derived computationally versus manually, there were smaller distances between the vagina and the following: clitoral glans (mean, 37 vs 49 mm; p<.001), clitoral body (mean, 15 vs 30 mm; p<.001), and crura (mean, 9 vs 18 mm; p<.001). In addition, all calculated distance measurements had similar or better consistency (i.e., smaller standard deviation) compared to manual measurements of the clitoral glans (SD, 8 vs 11; p=0.29), clitoral body (SD, 4 vs 8 mm; p=0.02), and crus (SD, 2 vs 7 mm; p=.001).

DISCUSSION:

Primary Finding in Context of Literature

The computational approach presented in this retrospective study was able to provide comparable and consistent measurements of normal clitoral morphometry and anatomical distances that improve upon traditional methods [7–9, 13], regardless of the differences present in the subject populations.

Overall, the computed clitoral dimensions were similar to those derived from manual caliper and ruler measurements from gross dissections of cadaveric specimens [13], where the differences in the median between the two methods for most dimensional measures was about 1-2 mm. The only significant differences observed were the lengths of the clitoral body and crura where the 3D MRI model-based measures were smaller than their reported values [8, 13]. This could be attributed to the resolution, slice thickness, and choice of plane of the MRI scans which can limit the ability to accurately delineate the structures of the clitoris, particularly between (1) the glans and body, (2) body and crura, and (3) crura and ischiocavernosus muscles that insert into each crus [14, 16, 19]. There was also less variability in most of the computed clitoral morphometrics, as shown by their narrower ranges. This could be due to the older and broader age range of the cadaver study cohort and age-related differences in clitoral anatomy often associated with menopause (e.g., atrophy) [7, 17, 20].

Alternatively, all of the calculated distances were significantly less than their literature values, with nearly 2-fold differences in magnitude when compared to the manual 2D MRI measures [9]. This is because the manual measurements were straight-line distances approximately perpendicular (when possible) to the structures of interest in a single slice [7, 9]; the estimation involved in this method of quantifying distances introduces a high degree of subjectivity that limits the accuracy and consistency of measurements. This is evident by the majority of the manual distance measures having standard deviations ~2 times greater than the computed distances. Additionally, differences in patient position in the MRI scanner, slice acquisition angle, and choice of slice for performing measurements adds more variability in distance measures [9, 21].

Significance & Implications

The 3D computational method developed for quantifying clitoral morphometrics and distances to adjacent pelvic anatomy in vivo improves upon conventional, manual approaches that are constrained to caliper and ruler measurements of cadaveric dissections (i.e., ex vivo) or a single, 2D plane on MRI in vivo. Through the automation of measurements in 3D MRI, the proposed computational approach is the first of its kind to provide more consistent, accurate, in vivo morphometric analysis of the entire clitoris by reducing the variability associated with manual measurements and avoiding limitations inherent to cadaver studies (e.g., spatial manipulation, tissue dehydration, elasticity differences from living subjects) [7–9, 22]. The quantitative analysis of the whole 3D clitoral geometry will give more comprehensive, accurate data on clitoral morphology and anatomic variation that are currently lacking and essential for (1) surgical planning (e.g., avoidance of surgical complications) and (2) identifying pathological conditions related to vulvar anatomy and sexual dysfunction [13]. Future prospective studies with well characterized cohorts are needed that asses clitoral anatomy via radiographic imaging in order to establish a normative standard of clitoral anatomy and to identify morphometric factors of the clitoris associated gynecologic surgical outcomes and sexual function.

Strengths & Limitations

The major strength of this study is that all clitoral and distance measurements were automated, thereby constraining the sources of error to the segmentation and smoothing of clitoral anatomy and other anatomical structures which are minimal when performed by observers with adequate radiology experience in pelvic MRI. In addition, the computational method allows standardized, quantitative characterization of the clitoris and spatial relationships of anatomical structures in vivo and in 3D-space. Thus, it provides a robust and more objective quantitative analysis of the entire clitoris and its relationship to other pelvic organ structures.

A notable limitation of this study is its retrospective design. Additional limitations include the small sample size, homogeneity of the patient population (e.g., age, race, parity), and scarcity of demographic and clinical data on some patients that restrict the generalizability of the results in defining normal clitoral anatomy. However, similar studies on clitoral anatomy on cadavers and MRI had comparable sample sizes and subject population characteristics [7, 9, 13, 22]. The quality and specifications of the MRIs (e.g., number of images, slice thickness) obtained varied across patients and were limited to only axial scans, which made standardization of the clitoral segmentations, particularly those of the smaller clitoral structures, more difficult [19]. Lastly, the MRIs were taken in the supine position, which may affect the distance measurements between the clitoris and pelvic organ structures by not fully accounting for the impact of gravity and posture on anatomic position [23].

Conclusions & Future Work

In conclusion, we present a novel and valuable semi-automated approach that allows for standardized measurements of the clitoris in 3D from MRI. This computational method provided in vivo measures of the clitoris and its components, as well as distances from the clitoris to neighboring pelvic organ structures, that were comparable and more consistent than those obtained from traditional manual techniques used in cadaveric (ex vivo) and 2D MRI studies.

Future work will use this 3D computational approach, along with statistical shape analysis, to quantitatively characterize lifetime changes in normal clitoral anatomy and its relationship to demographic and clinical characteristics in a larger, more diverse patient population and to prospectively evaluate the impact of gynecologic surgery (i.e., apical prolapse and mid-urethral sling procedures) and outcomes on clitoral morphology (e.g., morphometrics, position, shape) and sexual function [24]. Findings will assist surgical planning and diagnosis of clitoral abnormalities by establishing a normative standard of clitoral anatomy and providing a better understanding of how conventional surgical procedures affect the clitoris and its relationship with postoperative sexual function.

REFERENCES:

1. Walsh KE, Berman JR (2004) Sexual dysfunction in the older woman: An overview of the current understanding and management. Drugs and Aging 21:655–675. https://doi.org/10.2165/00002512-200421100-00004/FIGURES/TAB4
2. Laumann EO, Paik A, Rosen RC (1999) Sexual Dysfunction in the United States: Prevalence and Predictors. JAMA 281:537–544. https://doi.org/10.1001/JAMA.281.6.537
3. Berman JR, Berman L, Goldstein I (1999) Female sexual dysfunction: incidence, pathophysiology, evaluation, and treatment options. Urology 54:385–391. https://doi.org/10.1016/S0090-4295(99)00230-7

4. Mazloomdoost D, Pauls RN (2015) A Comprehensive Review of the Clitoris and Its Role in Female Sexual Function. Sex Med Rev 3:245–263. https://doi.org/10.1002/smrj.61

5. Jannini EA, Buisson O, Rubio-Casillas A (2014) Beyond the G-spot: clitourethrovaginal complex anatomy in female orgasm. Nat Rev Urol 2014 119 11:531–538. https://doi.org/10.1038/nrurol.2014.193

6. Maravilla KR, Yang CC (2008) Magnetic Resonance Imaging and the Female Sexual Response: Overview of Techniques, Results, and Future Directions. J Sex Med 5:1559–1571. https://doi.org/10.1111/J.1743-6109.2008.00839.X

7. Oakley SH, Vaccaro CM, Crisp CC, et al (2014) Clitoral size and location in relation to sexual function using pelvic MRI. J Sex Med 11:1013–1022. https://doi.org/10.1111/jsm.12450

8. Kelling JA, Erickson CR, Pin J, Pin PG (2020) Anatomical Dissection of the Dorsal Nerve of the Clitoris. Aesthetic Surg J 40:541–547. https://doi.org/10.1093/ASJ/SJZ330

9. Vaccaro CM, Fellner AN, Pauls RN (2014) Female sexual function and the clitoral complex using pelvic MRI assessment. Eur J Obstet Gynecol Reprod Biol 180:180–185. https://doi.org/10.1016/j.ejogrb.2014.02.024

10. O’Connell HE, Eizenberg N, Rahman M, Cleeve J (2008) The anatomy of the distal vagina: Towards unity. J Sex Med 5:1883–1891. https://doi.org/10.1111/j.1743-6109.2008.00875.x

11. Yang CC, Cold CJ, Yilmaz U, Maravilla KR (2006) Sexually responsive vascular tissue of the vulva. BJU Int 97:766–772. https://doi.org/10.1111/J.1464-

410X.2005.05961.X

12. Wallen K, Lloyd EA (2011) Female Sexual Arousal: Genital Anatomy and Orgasm in Intercourse. Horm Behav 59:780. https://doi.org/10.1016/J.YHBEH.2010.12.004

13. Jackson LA, Hare AM, Carrick KS, et al (2019) Anatomy, histology, and nerve density of clitoris and associated structures: clinical applications to vulvar surgery. Am J Obstet Gynecol 221:519.e1-519.e9. https://doi.org/10.1016/j.ajog.2019.06.048

14. O’Connell HE, Sanjeevan K V., Hutson JM (2005) Anatomy of the clitoris. J Urol 174:1189–1195. https://doi.org/10.1097/01.ju.0000173639.38898.cd

15. Suh DD, Yang CC, Cao Y, et al (2003) Magnetic resonance imaging anatomy of the female genitalia in premenopausal and postmenopausal women. J Urol 170:138–144. https://doi.org/10.1097/01.ju.0000071880.15741.5f

16. O’Connell HE, DeLancey JOL (2005) Clitoral anatomy in nulliparous, healthy, premenopausal volunteers using unenhanced magnetic resonance imaging. J Urol 173:2060–2063. https://doi.org/10.1097/01.ju.0000158446.21396.c0

17. Basaran M, Kosif R, Bayar U, Civelek B (2008) Characteristics of external genitalia in pre- and postmenopausal women. Climacteric 11:416–421. https://doi.org/10.1080/13697130802366670

18. Verkauf BS, Von Thron J, O’Brien WF (1992) Clitoral size in normal women. Obstet Gynecol 80:41–44

19. Botsikas D, Djema A, Picarra M, et al (2018) Clitoral Anatomy, Physiology and Pathology Demystified by Imaging. Curr Med Imaging Rev 14:366–373.

https://doi.org/10.2174/1573405613666170126124117

20. Kreklau A, Vâz I, Oehme F, et al (2018) Measurements of a ‘normal vulva’ in women aged 15–84: a cross-sectional prospective single-centre study. BJOG An Int J Obstet Gynaecol 125:1656–1661. https://doi.org/10.1111/1471-0528.15387

21. Hoyte L, Ratiu P (2001) Linear measurements in 2-dimensional pelvic floor imaging: The impact of slice tilt angles on measurement reproducibility. Am J Obstet Gynecol 185:537–544. https://doi.org/10.1067/mob.2001.116751

22. Abdulcadir J, Botsikas D, Bolmont M, et al (2016) Sexual Anatomy and Function in Women With and Without Genital Mutilation: A Cross-Sectional Study. J Sex Med 13:226–237. https://doi.org/10.1016/j.jsxm.2015.12.023

23. Abdulaziz M, Stothers L, Macnab A (2018) Effects of Posture and Gravity on Pelvic Organ Prolapse. Pelvic Floor Disord. https://doi.org/10.5772/INTECHOPEN.77040

24. Bowen ST, Moalli PA, Abramowitch SD, et al (2021) Defining Mechanisms of Recurrence Following Apical Prolapse Repair Based on Imaging Criteria. Am J Obstet Gynecol. https://doi.org/https://doi.org/10.1016/j.ajog.2021.05.041

25. Einstein G (2008) From Body to Brain: Considering the Neurobiological Effects of Female Genital Cutting. Perspect Biol Med 51:84–97. https://doi.org/10.1353/PBM.2008.0012

FIGURE LEGENDS:

Figure 1. Workflow of the 3D reconstruction method. (**A**) Segmentation and partitioning of the clitoral anatomy on an axial MRI scan. (**B**) Overlaying of contiguous slices of the segmented axial MRI. (**C**) 3D reconstruction of whole clitoris (**top**) and clitoral structures (**bottom**) from the MRI segmentations. Clitoral structures include the glans (orange), body (blue), left and right crus (purple), and bulbs (white). The initial 3D models appear aliased due to the MRI slice thickness. (**D**) Smoothing of the 3D clitoral models to remove aliasing.

Figure 2. Three-dimensional models of the whole clitoris (**top**) and clitoral structures (**bottom**) in the axial, sagittal, coronal, and oblique view. The entire clitoris (red), glans (orange), body (blue), crura (purple), and bulbs (white) are shown.

Figure 3. Visualization of clitoral morphometric measurements in the frontal (**left**) and axial view (**right**). From left to right, the length, width, and volume of the glans (orange), body (blue), crura (purple), and volume of the bulbs (white) and whole clitoris (red) were computed from their respective 3D models.

Figure 4. Schematic view of the clitoral and vaginal anatomy and distance measurements. (**A**) The 3D models of the clitoral glans (orange), body (blue), crura (purple), bulbs (white), and vagina (gray) are shown. (**B**) Visual example of the distance calculation method, where the color mapping indicates the surface-to-surface distance between the clitoris and vagina (gray) given in mm. The color bar and mapping demonstrate the range (i.e., distribution) of distances with the minimum (red), mean (green), and maximum (red) values represented.

TABLES:

Table 1. Comparison of patient demographics between present and past studies.

Demographics	**Present Study** (*n*=22)	**Jackson et al.** [13] (*n*=22)	***P* Value**[a]	**Present Study** (*n*=22)	**Vaccaro et al.** [9] (*n*=20)	***P* Value**[b]
Age, years	30 (20-47)	70 (48-89)	**<.001**[c]	30 ± 7	42 ± 12	**<.001**[c]
BMI, kg/m^2	23 (19-38)	22 (13-34)	.24	26 ± 6	28 ± 6	.40
Race, n (%)			1.00			**.007**[c]
White	22 (100)	21 (95)		22 (100)	14 (70)	
Black	0 (0)	1 (5)		0 (0)	6 (30)	

Data are presented as median (range) or mean ± standard deviation for continuous data and number (percentage) for categorical data.

BMI, body mass index

[a] *P* values are based on Wilcoxon rank-sum test.
[b] *P* values are based on independent t-test.
[c] *P* values of <.05.

Table 2. Clitoral measurements in present study versus previous literature.

Measurement	Present Study	Previous Literature	*P* Value[a]	*P* Value[b]
Morphometrics[c]				
Glans				
Length (mm)	6 (5-12)	8 (5-12)	.76	.50
Width (mm)	5 (4-7)	4 (3-10)	.13	**<.001[d]**
Volume (mm^3)	222 ± 125	--	--	--
Body				
Length (mm)	18 (9-24)	29 (13-59)	**<.001[d]**	**<.001[d]**
Width (mm)	11 (5-16)	9 (5-14)	**.04[d]**	.95
Volume (mm^3)	3090 ± 1028	--	--	--
Crura				
Length (mm)	36 (23-54)	50 (25-68)	**.001[d]**	**.001[d]**
Width (mm)	7 (5-11)	9 (2-13)	.37	**.02[d]**
Volume (mm^3)	1945 ± 970	--	--	--
Bulbs				
Volume (mm^3)	4897 ± 2124	--	--	--
Whole clitoris				
Volume (mm^3)	10014 ± 3692	--	--	--
Distances[d]				
Glans to vagina (mm)	37 ± 8	49 ± 11	**<.001[d]**	.29

Body to vagina (mm)	15 ± 4	30 ± 8	**<.001[d]**	**.02[d]**
Crus to vagina (mm)	9 ± 2	18 ± 7	**<.001[d]**	**.001[d]**

Data are presented as median (range) and mean ± standard deviation.

[a] *P* values are based on Median test for morphometric measures and independent t-test distance measures for comparing medians and distributions, respectively.
[b] *P* values are based on Moses extreme reaction for morphometric measures and Levene's test for distance measures for comparing ranges and variances, respectively.
[c] Morphometric literature values taken from Jackson et al.[13].
[d] *P* values of <.05.
[e] Dimension literature values taken from Vaccaro et al.[9].

APPENDIX:

Appendix 1. Partitioning of the clitoris on MRI where the unsegmented MRI (**left**), segmented MRI (**middle**), and diagram (**right**) of the clitoris and adjacent pelvic anatomy are shown. (**A**) Axial view of the clitoral body (*B*), left and right crus (*C*), and bulbs (*Bu*) in relation to the pelvic organs such as the urethra (*U*), vagina (*V*), and rectum (*R*). These clitoral structures lie anteriorly and laterally to the pelvic organs, where the body is formed by the paired corpora and diverge into the crura. For this study, the clitoral body and crura were separated at the elbow (angle) of the clitoris as done by Vaccaro et al [9]. Each clitoral crus is covered by the ischiocavernosus muscle (*IM*), a paired muscle originating from the ischial tuberosity (*IT*) that contracts to compress the crura to erect the clitoris during sexual arousal and orgasm [25]. (**B**) Sagittal view of the clitoral glans (*G*), body (*B*), and bulbs (*Bu*) with respect to the pubic symphysis (*PS*), urethra (*U*), bladder (*B*), vagina (*V*), uterus (*Ut*), and rectum (*R*). The clitoral glans is a small button-like structure that lies distally to the clitoral body. Together, the glans and body form a boomerang-like shape in the sagittal plane and their midline septum are clearly visible in the axial plane [14].

Figure 1

Click here to access/download;Figure;Figure_1.tif

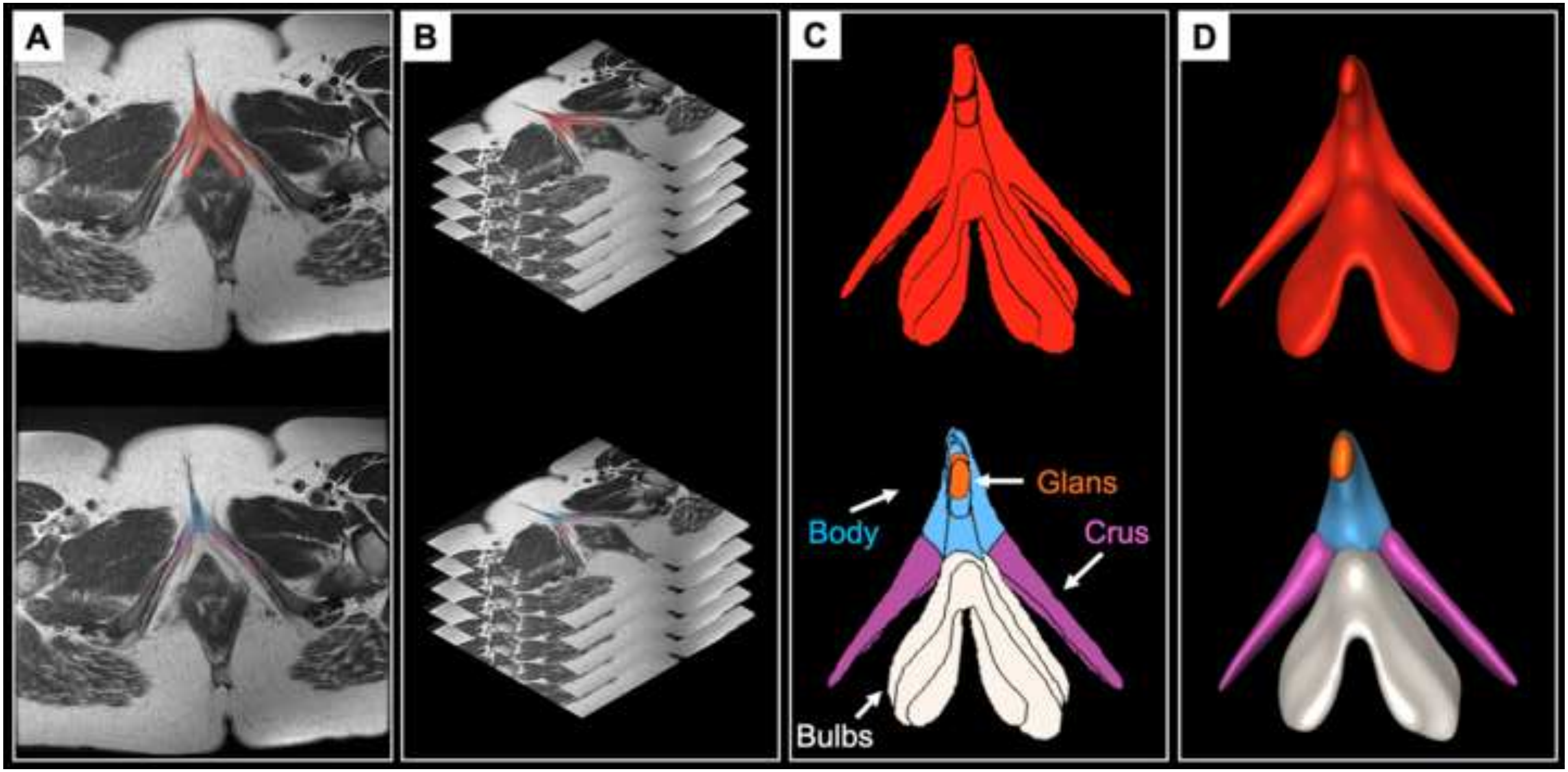


Figure 2

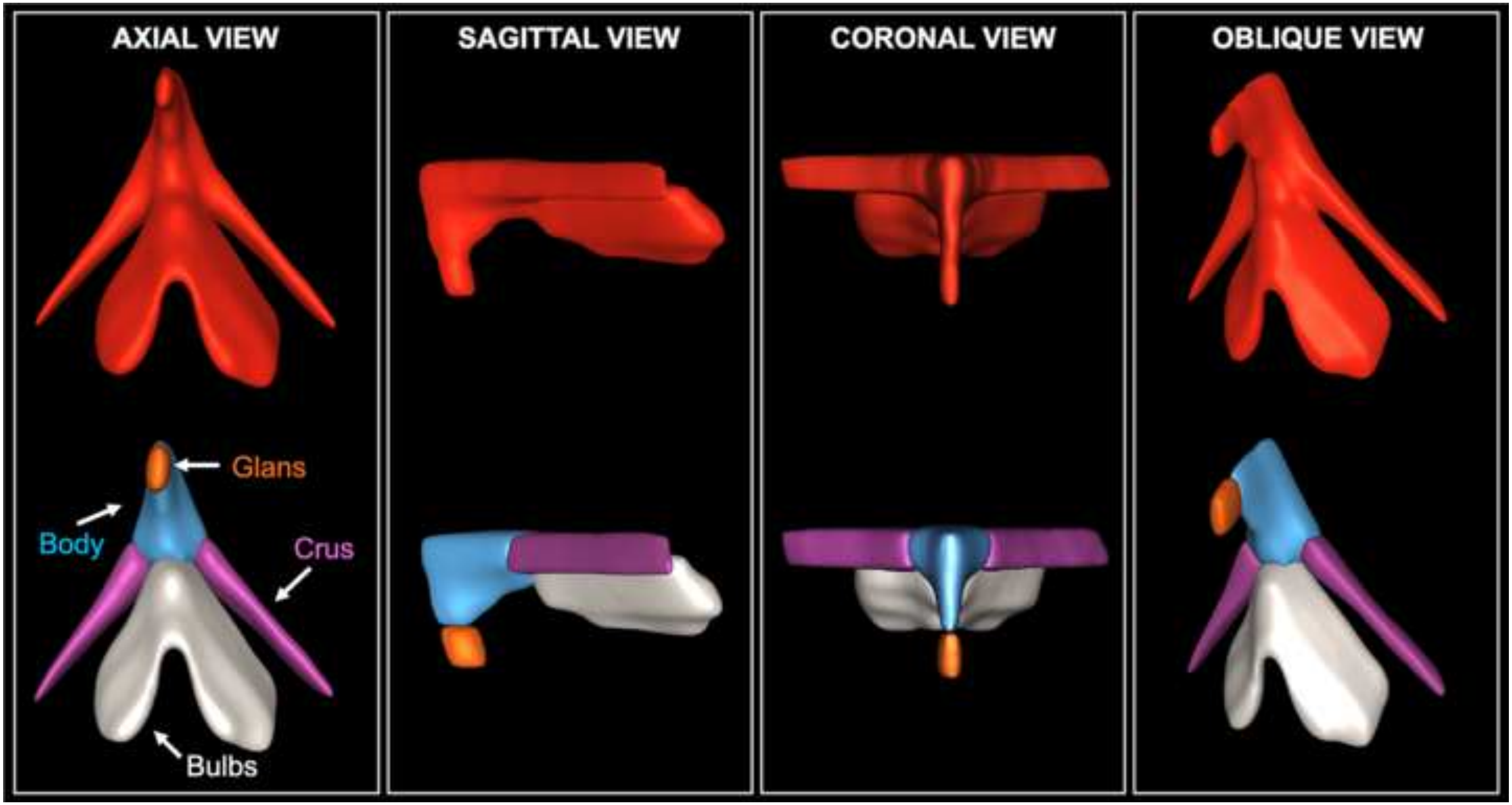

AXIAL VIEW
SAGITTAL VIEW
CORONAL VIEW
OBLIQUE VIEW
Glans
Body
Crus
Bulbs

Figure 3

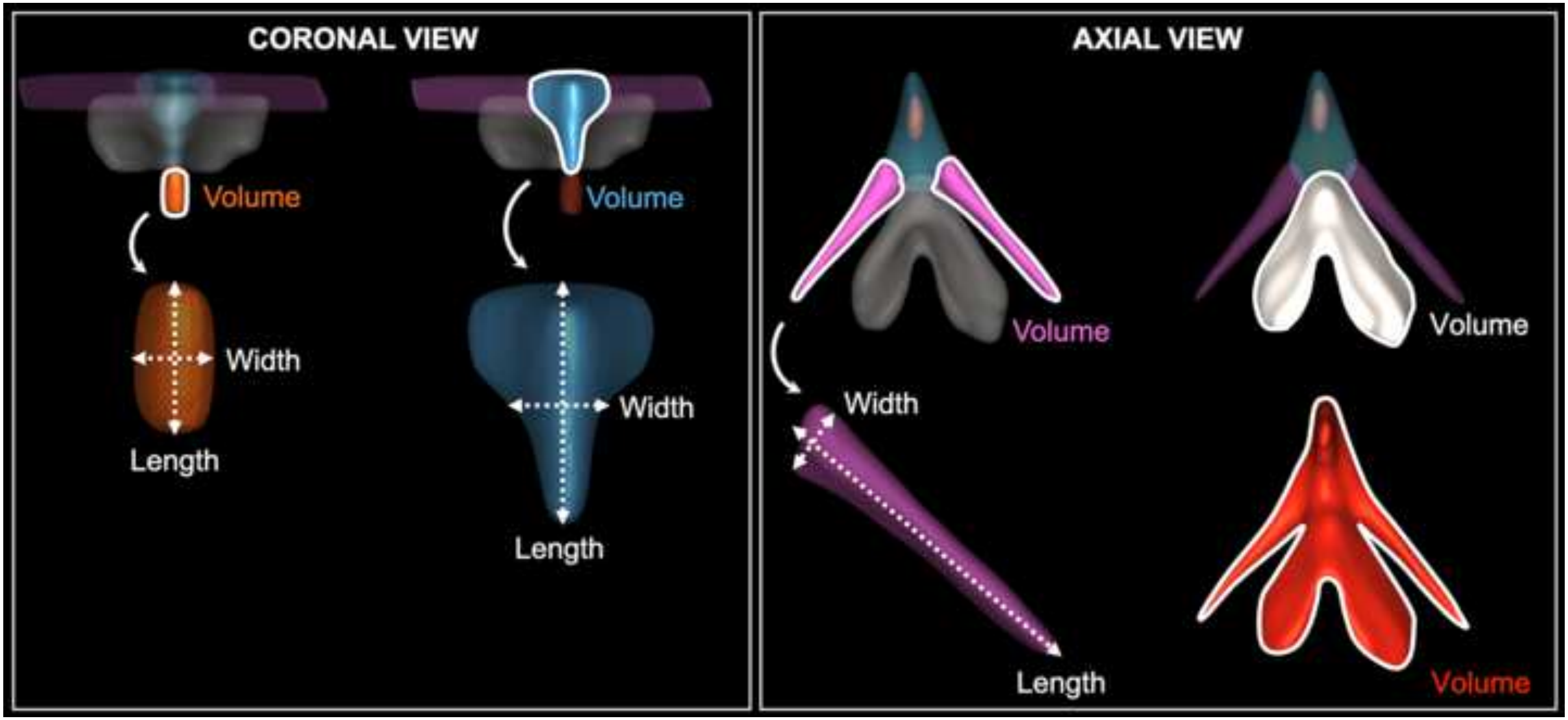
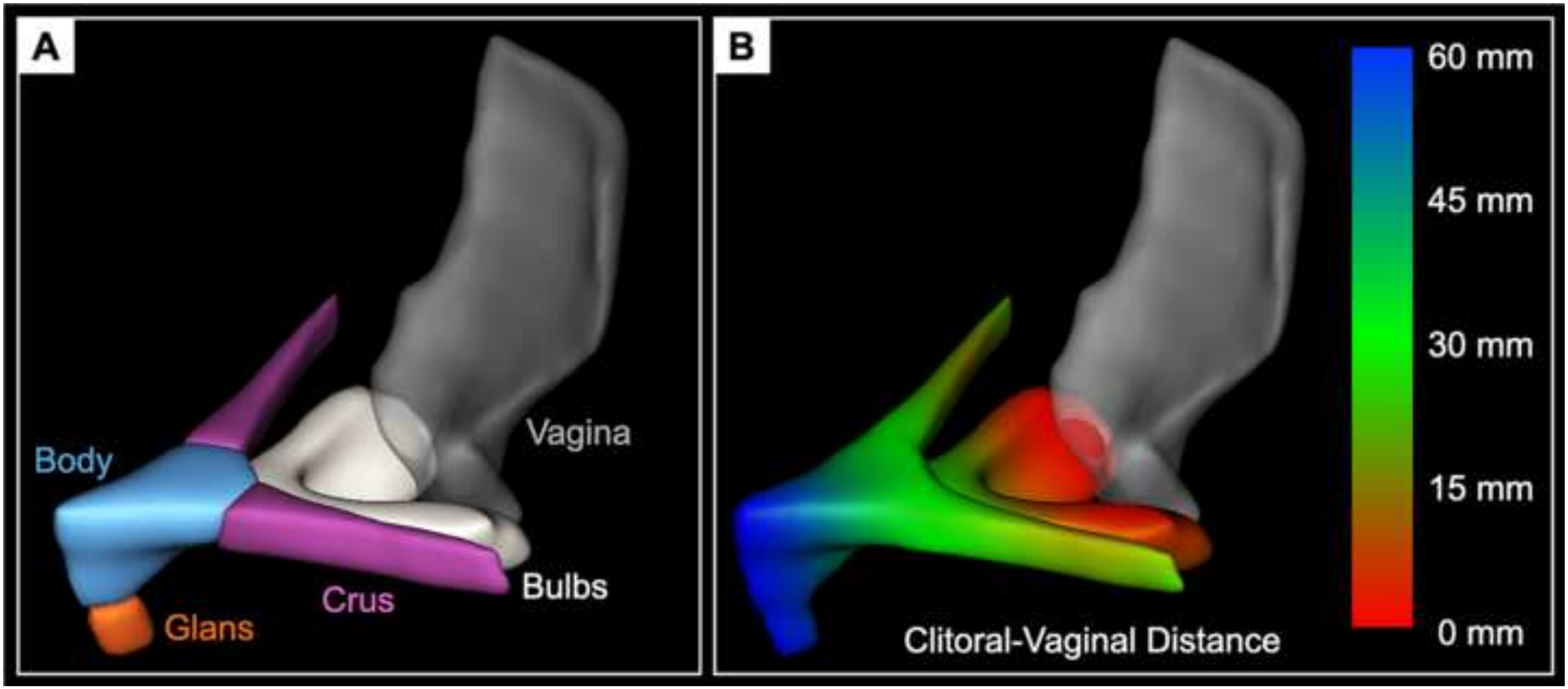

CORONAL VIEW
Volume
Width
Length
Volume
Width
Length
AXIAL VIEW
Volume
Volume
Width
Length
Volume

Figure 4


A
Body
Vagina
Bulbs
Crus
Glans
B
60 mm
45 mm
30 mm
15 mm
0 mm
Clitoral-Vaginal Distance