Sexually responsive vascular tissue of the vulva

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INTRODUCTION

The anatomy of the vulva is typically presented with no unifying theme, i.e. there are numerous but disparate descriptions of the vagina, introitus and its structures, urethra, and clitoris. There is a lack of unity probably because of the perceived differences in function of each of these structures. However, our previous work using MRI of the female sexual response [1] showed the interconnectedness of these structures in the context of sexual function. Previously described vascular changes with sexual arousal occurring in the vagina [2], clitoris [3], labia minora [4] and urethra [5] were corroborated, but we also found vascular changes occurring in the clitoral bulbs [1].

To substantiate these findings, we conducted a gross anatomical and histological study of the vascular tissue of the vulva. We investigated the anatomical structure of the vulva, and changes with sexual arousal, by comparing the gross and histological anatomy with images obtained using MRI.

OBJECTIVE

To better understand the genital changes that occur during the female sexual response, using a gross anatomical and histological study of the vascular tissue of the vulva, supplemented with magnetic resonance imaging (MRI).

MATERIALS AND METHODS

Seven cadaveric vulvectomy specimens were used; they were serially sectioned in coronal, sagittal, and axial planes, and stained with haematoxylin and eosin. Selected blocks were stained with elastic Masson’s trichrome. Axial MR images were taken of two healthy women with intact sexual functioning using a gadolinium-based blood-pool contrast agent. A 1.5 T system was used for all MRI studies, with images taken at baseline and during sexual arousal while viewing an erotic videotape.

RESULTS

There are five vascular compartments of the female external genitalia, found in the clitoris, clitoral bulbs, labia minora, urethra, and vestibule/vagina. Of these five compartments, two distinct types of vascular tissue were identified, i.e. erectile and non-erectile/specialized genital. The erectile tissue compartments had the greatest change in blood volume during sexual arousal, as assessed by MRI.

CONCLUSIONS

The vulva contains a substantial amount of vascular tissue. These specialized tissues show a variable, but unified response to sexual arousal.

KEYWORDS

female genital anatomy, magnetic resonance imaging, female sexual arousal, vulva, perineum

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To better understand the genital changes that occur during the female sexual response, using a gross anatomical and histological study of the vascular tissue of the vulva, supplemented with magnetic resonance imaging (MRI).

MATERIALS AND METHODS

Seven postmenopausal cadaveric vulvectomy specimens fixed in 70% ethanol were used for the study. Because the vulva is a complex three-dimensional entity, the cadaveric specimens were sectioned in three planes: four specimens were sectioned in the axial plane, two in the sagittal plane, and one in an oblique plane, approximating the axes of the urethra and vagina. All were imbedded in paraffin wax and serially sectioned, submitted in 20–40 cassette blocks. The specimens were stained with haematoxylin and eosin, and selected blocks were stained with elastic Masson’s trichrome.

MR images were taken of two healthy women with intact sexual functioning, one premenopausal and one postmenopausal, as part of a larger investigation of the female sexual response. A 1.5 T system (Signa Horizon Echo Speed, General Electric Medical Systems, Waukesha, Wisconsin, USA) was used for all MRI studies. Specially designed phased-array coils built in our laboratory were used for imaging the pelvis, after injection with MS-325, an investigational gadolinium blood-pool contrast agent, to enhance the vascular blood pool compartments. All images were T1-weighted and obtained in the axial plane through the perineum. The details of the imaging protocol were described previously [6]. The women were sexually aroused using audiovisual sexual stimulation with erotic videotapes displayed through a headset.

RESULTS

Specialized vascular tissue was found in the clitoris, clitoral bulbs, labia minora, urethra, and vestibule/vagina. Within these five compartments, there are two distinct types of vascular tissue. One type, the erectile tissue, comprises the corpus cavernosum of the clitoris and the substance of the bulbs (corpus spongiosum). On gross examination of the fixed tissue, large, dilated vascular spaces are apparent. The tissue is light to dark brown in colour, and grossly spongy in appearance. On microscopic examination, the erectile tissue is trabecular, interspersed with smooth muscle bundles surrounding the vascular spaces, with an absence of fatty tissue.
The second type of vascular tissue is found surrounding the urethral lumen, within the labia minora, and beneath the vestibular and vaginal epithelium (although the vagina is not typically considered as part of the vulva). This non-erectile specialized genital vascular tissue has either a spongy or a fibrous appearance on gross examination, but the vascular spaces are not as prominent as in the clitoris and bulb. The tissue is tan or white. Microscopically, the tissue is composed of abundant small, vessel-like structures, interspersed within a loose, fibro-elastic tissue with sparse stromal cells and no significant smooth muscle fibres except around muscular arteries. This has an angiofibromatous appearance. The vascular spaces are of variable shape, with some being large and irregularly shaped, and others having a more regular, rounded shape. The relative density of vessels varies among the three compartments. To appreciate the relationships of the different vascular tissues, each structure will be presented with both gross and histological anatomic descriptions.

CLITORIS

The bulk of the clitoris is located beneath the skin, and superficial to the inferior pubic rami (Fig. 1). The clitoris is composed of two separate erectile bodies, the corpora cavernosa. The corpora are surrounded by a thick fibro-elastic tunica albuginea. The clitoral unit forms a wishbone-shaped structure; the proximal portions are the arms of the wishbone, termed the crura, extending along the anterior aspect of each ischiopubic ramus for several centimetres. They meet in the midline as the body (or shaft) of the clitoris, extending slightly beneath the margin of the inferior pubic ramus, toward the pelvis. They do not outline the introitus, as pictured in some textbooks [7,8], but track proximally along the vagina; they remain as part of the perineum, superficial to the skeletal muscle of the pelvic floor.

Immediately inferior to the convergence of the clitoral crura, the bulbs arch over the distal 1 cm of the urethra and become confluent, extending slightly anteriorly over the urethral meatus (Fig. 7). This connection is...
termed the commissura bulborum [9]. In the midline, where the bulbs are confluent and adjacent to the clitoral body, there appears to be a group of vessels that provide communication between the clitoris and clitoral bulbs. However, it does not appear that the two erectile structures merge with one another. In particular, the bulbar tissue does not merge with the glans clitoris, as reported by some authors [10].

The bulbs are comprised almost exclusively of large, trabeculated vascular spaces. There is no tunica albuginea. The histology of the bulbar erectile tissue is similar to that of the clitoris. The erectile tissue of the clitoris has slightly less smooth muscle and interstitial fibro-elastic tissue, while the bulbs have larger vascular spaces with prominent fibro-elastic tissue and smooth muscle bundles lining the vascular spaces. The bulbocavernosus muscle is not wrapped around the bulbs, but lies as a flat covering on the lateral aspect of each bulb, extending superiorly to the level of the clitoral body. The medial aspects of the bulbs abut the periurethral vascular tissue and vaginal vascular tissue (Fig. 7).

In the neutral state, the enhanced T1 MRI signal intensity of the bulbs is high, just as in the clitoris, indicating a large blood volume within the structure (Fig. 6a). The trabecular tissue is well suited to maintain blood within the bulbs.

The bulbs become engorged and enlarge with sexual arousal (Fig. 6b). As with the clitoris, the bulbar trabecular tissue allows for significant enlargement with increased blood flow to the structure. The absence of a tunica albuginea in the bulb may allow for even greater expansion.

LABIA MINORA

The labia minora are folds of tissue that lie between the introitus and the labia majora.
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The epithelium is thinly keratinized [11] and hairless. The vascular tissue immediately deep to the epithelium is not trabecular, but made up of vessels embedded in fibrous tissue, not smooth muscle (Fig. 8). The labia minora are well demarcated from the labia majora by an interface between the adipose of the labia majora and the absence of adipose in the labia minora.

On MRI, the tissue becomes engorged with blood during sexual arousal (Fig. 9). This engorgement is distinct from that of the bulbs, located deep to the labia minora.

URETHRA

Although the urethra is not considered part of the genital tract in females, it is a structure within the vulva, and the urethral lumen is surrounded by spongy tissue. The tissue is grossly distinct from the vascular tissue of the clitoris and bulbs, and on macroscopic observation, is paler than the dark tissue of the bulbs and clitoris. The bulbs arch over the distal urethra, outlining what might be appropriately called the ‘bulbar urethra’ in women.

The spongy tissue surrounding the urethral lumen is composed of smooth muscle fibres, with multiple small vessels (Fig. 10). Some have termed this the corpus spongiosum [12], as in the male. However, we think that the term corpus spongiosum is more appropriate for the tissue of the clitoral bulbs. There are also glandular structures within the substance of this tissue, comprised of mucinous and low-cuboidal cells. A thin, fibrous septum separates the spongy tissue from the vagina. The functional status attributed to the spongy tissue of the urethra is to provide a compliant lumen for urine passage, as well as helping to create a mucosal seal for the urethral lumen, to aid in continence [13,14].

The urethral lumen is surrounded by tissue with relatively high signal intensity, distinct from the bulbs and anterior vaginal wall. With arousal, there is no significant change in the signal intensity (Fig. 6a,b), although there is engorgement apparent on physical examination [5].

VESTIBULE/VAGINA

There have been numerous reports of the anatomy of the vagina [15–17] so a detailed description is not needed here. The vagina extends from the vestibule to the cervix and uterus. It is composed of four distinct layers: mucosa, lamina propria, muscularis (variable) and areolar connective tissue. The lamina propria and connective tissue layers contain a rich supply of vascular channels (Fig. 11), as does the subepithelial tissue of the vestibule. On MRI, the rugated mucosa is easily distinguishable in the premenopausal female (Fig. 12). With sexual arousal, the vaginal wall signal intensity increases, reflecting increased blood flow.

DISCUSSION

The purpose of the present study was to investigate the gross and microscopic anatomy of the vascular tissue of the vulva, particularly those of the erectile tissue. MRI provides in vivo human correlation with some of the anatomical findings, as well as sexual functional data on blood volume. The primary findings are the identification of five vascular compartments, and two types of vascular tissue, trabecular/erectile and non-trabecular/ non-erectile. In addition, the structure of the bulbs, which have had little emphasis in previous reports, is described.
It is apparent from the anatomical studies that there is a preponderance of vascular tissue in the vulva, and this arrangement of tissue is important in the context of the female sexual response. Masters and Johnson [4], and others [2,3,5], described vascular engorgement of female genital tissues and urethra. However, the histological basis of the tissue engorgement corresponding to sexual arousal has not been cohesively described. The generalized vulvar engorgement that occurs with sexual arousal affects the vaginal/vestibule, clitoris, labia minora, urethra, and bulbs. All of these structures have specialized vascular elements to accommodate increased blood volume during sexual arousal. The designation of 'specialized' is chosen to reflect the changes in blood flow and volume during sexual activity. What significance the engorgement of vascular structures has to female sexual function is still unknown, and this study does not address that issue.

Because of the functional and histological distinction of the trabecular tissue of the clitoris and the bulbs, we and others consider this type of tissue to be erectile vascular tissue [18], very similar to the erectile tissue found in male genitalia [19,20]. We do not think that the differences between the erectile tissue in the clitoris and bulbs are that distinctive. Erickson and Montagna [21] identified two types of cavernosal (erectile) tissue in their dissections, one in the clitoris, and one in the vestibule and labia minora. Based on their descriptions, no mention is made of the bulbs, but it is possible that they were examining bulbar tissue, as it is cavernosal tissue adjacent to the vestibule and deep to the labia minora. We also disagree with Stefani et al. [22], who stated that the glans clitoris is not formed by erectile tissue. Our dissections clearly show glanular vascular spaces, although not as prominent as those in the corpora.

Although not comprised of erectile tissue, the labia minora, the vestibule/vagina and the urethra also engorge during sexual arousal [4], as seen on MRI. The vascular tissue of these structures is not trabecular, and functionally does not appear to accommodate the relative volumes of blood at rest or during sexual arousal that the trabecular erectile tissue does. Some have described ‘erectile tissue’ of the labia minora [11], but the histological features of the labia minora are clearly not the same as in the clitoris and bulb.

The bulbs of the clitoris were originally described as the vestibular bulbs, an acknowledgement of the relative position of the structures to the vaginal vestibule. However, O’Connell et al. [18,23] identified the bulbs as structures in relation to the clitoris. The present studies concur with their findings, as the similarity of the trabecular tissue within the clitoris and bulbs, and the absence of trabecular tissue in other genital organs, supports the relationship of these two structures. These structures are more appropriately named ‘clitoral bulbs’. The recognition of the clitoral bulbs as erectile tissue is not new, but references are scarce. Danesino and Martella cite Anile (1919) describing the bulbs as having large lacunae defined by trabeculae [24]. Baggish and Karram [12] report on the bulbs, but in the context of providing vascular support to the urethra, rather than as sex organs. Except for the recent study by O’Connell et al. [18], other
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Notably, in the present postmenopausal cadaveric specimens (age range 70–80 years) the visible specialized genital vascular tissue was abundant, despite atrophy of the external female genitalia with ageing (loss of vaginal rugae, decreased prominence of labia minora and majora [25]). One of the limitations of the present study is that the dissections were primarily of cadaveric specimens from elderly women, and the functional studies were of younger women (the postmenopausal woman was in her early 60s). Nevertheless, the vascular compartments on the anatomical specimens were still easily identified grossly and microscopically. Further work will need to include histological studies of younger subjects.

The extensive distribution of the bulbar, clitoral and other vascular tissues that are sexually responsive has a bearing on surgical procedures of the vulva. Operations that disrupt or potentially disrupt the female external genitalia include transvaginal procedures for incontinence; radical urethrectomy, vulvectomy and other perineal exenterative procedures for malignancy; female circumcisions; and plastic reconstruction for birth defects, congenital adrenal hyperplasia, or transgender operations. Although typically not addressed in surgical texts, these procedures can potentially affect sexual functioning by ablating some or all of the genital organs, or their innervation. With better knowledge of the anatomy and sexual responsiveness of the external genitalia, clinicians can provide better treatment for urogynaecological diseases, and develop modifications of operative procedures to preserve sexual functioning.

Genital tissues in both males and females arise from the same embryological structures and thus are homologous. Although genital changes with sexual arousal in females are not as externally pronounced as they are in men, the importance of the genital vascular tissues in females should not be underestimated. Recognition of female erectile tissue is not a novel idea, but studies are obscure and very limited, and little interest has been devoted to this area. With the recent developments in the understanding of male erectile tissue and pharmacology, it makes sense to consider female genital vascular tissue as an important component of the female sexual response [26].

FIG. 10. Cross-section of the distal urethra, elastic Masson's trichrome stain. Vascular spaces are interspersed throughout the tissue. Arteries contain a thicker (red) smooth muscle layer than veins. Black elastic fibres are apparent throughout the interstitium, with epithelium lining the lumen in the upper right.

FIG. 11. Cross-section of lateral vaginal wall; haematoxylin and eosin stain. The dilated vascular spaces of the vaginal tissue are much less prominent and more separated than those of the trabecular/erectile tissue. (Compare with the vascular tissue of the labia minora, Fig. 8.) Pelvic floor skeletal muscle is at the top of the photomicrograph, vaginal epithelium at the bottom. Marker 1 mm.

FIG. 12. T1-weighted axial MR images with MS 325 contrast of a premenopausal woman proximal to pubic symphysis, (a) neutral and (b) during sexual arousal. P, pubic symphysis; SR, space of Retzius; U, urethra; V, vagina; R, rectum; IT, ischial tuberosity. The vaginal lumen appears as a 'W'. Increased prominence of vaginal wall is apparent with sexual arousal.
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CONFLICT OF INTEREST

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