Published in final edited form as:

Fertil Steril. 2009 July ; 92(1): 19–34. doi:10.1016/j.fertnstert.2008.04.041.

Physiologic Measures of Sexual Function in Women: A Review

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Abstract

Objective—To review and describe physiologic measures of assessing sexual function in women

Design—Literature review

Setting—Studies that utilize instruments designed to measure female sexual function

Patients—Women participating in studies of female sexual function

Interventions—Various instruments that measure physiologic features of female sexual function

Main Outcome Measures—Appraisal of the various instruments, including their advantages and disadvantages.

Results—Many unique physiologic methods of evaluating female sexual function have been developed over the last four decades. Each method has its benefits and limitations.

Conclusions—Many physiologic methods exist, but most are not well-validated. Additionally, there has been an inability to correlate most physiologic measures with subjective measures of sexual arousal. Furthermore, given the complex nature of the sexual response in women, physiologic measures should be considered in context of other data, including the history, physical exam, and validated questionnaires. Nonetheless, the existence of appropriate physiologic measures is vital to our understanding of female sexual function and dysfunction.

Keywords

Psychophysiological Testing; Female Sexual Function; Female Sexual Dysfunction

Introduction

The ability to measure physiologic parameters of sexual function in women has lagged far behind that in men. In 1944, Ohlmeyer first described the phenomenon of nocturnal penile tumescence (1). Though Dickinson studied genital morphology of women during gynecologic examinations to make inferences about their sexual behavior in the 1920's (2), the first published objective physiologic correlate of female sexual response did not occur until Shapiro's studies of the effect of vaginal acidity in 1968, more than 40 years later (3)! Kinsey, Masters, and Johnson are credited with breaking some of the societal taboos associated with

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This paper reviews and describes physiologic methods of assessing female sexual function. Although many methods exist, more research needs to be done to understand the physiologic components of female sexual function and dysfunction.

the study of female sexology, however, it was the success of sildenafil for erectile dysfunction in men that led to a renewed interest in research dedicated to the study of the physiology of the female sexual response.

The purpose of this paper is to review the currently available tools used in the physiologic assessment of female sexual function, and to delineate their advantages and limitations.

Sexual Response in Women

Historically, the “normal” sexual response in women has been described as a linear sequence of physiologic events that involves four stages including excitement/arousal, plateau, orgasm and resolution. Sexual response in women is clearly more complex than this, and involves psychologic, emotional, and social factors in addition to physiologic events. However, there are definitive physiologic changes that occur. During sexual arousal, there is increased blood flow to the genitalia, resulting in vasocongestion. Vaginal lubrication occurs as a result of several processes including the transudation of plasma through the vaginal epithelium onto the surface of the vagina, and secretions from the uterus, and vestibular and Bartholin’s glands. The vagina lengthens and dilates due to relaxation of smooth muscle. Increased blood flow to the clitoral cavernosal and labial arteries result in increased clitoral intracavernous pressure, tumescence, protrusion of the glans clitoris, and eversion and engorgement of the labia minora. During orgasm, rhythmic muscle contractions occur in the vagina, uterus and anus. While other physiologic processes are involved in the process (i.e., hormonal) they are beyond the scope of this article, which focuses on anatomic assessments (4).

Based on normal anatomy and physiology, some etiologies of female sexual dysfunction can be inferred. Aberrations of physiologic processes may involve decreased blood flow, as in the clitoral and vaginal vascular insufficiency syndromes (5). Pelvic muscle weakness or hypertonicity can result in less intense orgasm or vaginismus, respectively. Lack of lubrication and genital atrophy may also interfere with sexual functioning.

Methods and Materials

PubMed was used to search for articles that used instruments designed to measure physiologic aspects of female sexual function. Key words included sexual function, sexual arousal, psychophysiology, sexual physiology and neuroimaging. References in the identified manuscripts were also examined.

Results

Methods Used to Measure Physiologic Sexual Response in Women

The physiologic parameters of sexual response in women that have been investigated can be broken down into several categories: blood flow, volume/pressure/compliance, lubrication, muscular, and neural. Data from coital imaging studies will also be discussed (see Table 1 and Table 2).

Genital Blood Flow

The bluish discoloration of the cervix and vagina that occurs as a result of venous congestion during pregnancy was described by the French doctor Etienne Joseph Jacquemin in approximately 1836 (6). James Read Chadwick also (1896) recognized blood flow changes in female genitals associated with pregnancy (7). However, It was not until many years later that the concept of adequate blood flow being a necessity for adequate sexual response was appreciated. Indeed, recent research using rabbit models have shown that vaginal engorgement

and clitoral erection depend on increased blood flow, and that atherosclerosis causes engorgement insufficiency and clitoral erectile insufficiency (8).

Since it is difficult to measure vaginal blood flow directly, many indirect methods have been devised which will also be discussed below.

Vaginal Photoplethysmography—Vaginal photoplethysmography has been the primary method used to assess female genital arousal. It is the most common and most validated physiologic instrument used in the study of female sexual function. Palti and Bercovici developed the first vaginal photoplethysmograph in 1967. They mounted a light source and photosensitive cell on a gynecologic speculum and recorded vaginal pulse waves (9). In 1975, Sintchak and Geer improved upon this model by adding a vaginal probe. This became the first “modern vaginal photoplethysmograph.” This device generated considerable research interest; subsequent improvements were made by Hoon et al in 1976, and Wagner and Levin in 1977.

The modern day version consists of a tampon-sized acrylic device that contains a light emitting diode and a phototransistor to detect light (Figure 1). The light source illuminates the entire microcirculation of the vaginal wall; the theory behind its use is that the amount of light that is backscattered is directly related to the transparency of engorged versus unengorged tissues (vasocongestion). The signal that results has two components; when it is coupled to a direct current amplifier, a measurement of vaginal blood volume (VBV) is obtained. This is thought to represent slow changes in pooling of blood in the vaginal tissues (10). When the signal is connected to an AC amplifier, the vaginal pulse amplitude (VPA) is measured. The VPA is thought to represent the phasic changes in vaginal engorgement with each heartbeat (11). The VPA appears to be the most reliable, specific and sensitive measurement with larger amplitudes reflecting higher levels of blood flow.

Although it is an indirect measure of vaginal blood flow, the vaginal pulse amplitude has been found to be reliable in assessing the increase in blood flow during sexual arousal (12). While vaginal photoplethysmography has been used extensively in studies of the female sexual response, it is difficult to compare between studies and interpret results because of differences in subjects, stimuli, methods of measurement and analysis (13). Whether vaginal photoplethysmography can differentiate between normal women and women with subtypes of FSD is debatable; one study found no difference in VPA between women with female sexual arousal disorder (FSAD) and controls (14). Additionally, a study by Meston and Gorzalka found no differences in VPA between a group of 12 women with hypoactive sexual desire, a group of 12 anorgasmic women, and a control group of 12 women (15). The correlation between VPA readings and subjective sexual response has also been debated. One study showed a correlation between VPA and subjective arousal (16). Interestingly, another study showed a positive correlation between genital and subjective arousal in older pre- and postmenopausal women, but not young premenopausal women (17). Reasons for these discrepancies may be that response may be situation-specific or stimulus-specific, and does not necessarily correlate with subjective feelings. Additionally, these measurements must be done in the context of adequate stimulation, which may vary between women (18).

Advantages to using the vaginal photoplethysmograph are that it can be easily inserted by the woman in private and can provide moment-to-moment measurements over long periods of time without harm or discomfort to subject. Additionally, there is a short period of time required for VBV and VPA levels to return to normal, allowing for multiple sequential recordings. Disadvantages include movement artifact, which may ultimately interfere with analysis. Thus, it cannot be used during physical stimulation or orgasm. It also cannot be used during menstruation. Additionally, there is a lack of basis for what the signal actually means—it is not certain that blood flow is the only parameter being measured. In fact, it has been postulated

that the signal may actually reflect multiple physiologic processes and events, including restriction of venous drainage; Levin and Goddard comment that the VPA may be the result of vasomotion, which is the oscillation of vascular tone in capillaries. They suggest that different capillaries are recruited at different levels of arousal (19). Furthermore, it also does not provide any anatomic information and the units of measurement are arbitrary and relative, not absolute. Therefore, between-subject comparisons are difficult to make (20).

Clearance Techniques: Xenon-133 Washout and the Oxygen-Temperature

Method—In 1980, Wagner and Ottesen assessed vaginal blood flow and the changes in flow during sexual arousal in 7 normal young women using a xenon-133 washout technique (21). They injected the tracer intraepithelially in the posterior vagina. The measurement of the xenon gamma emission was performed using a scintillation detector. They found an approximately 3-fold increase in the magnitude of blood flow with self-stimulation. Although a good indirect measure of blood flow, its use has been limited by its invasiveness, and use of a radioactive substance.

One of the first instruments designed to measure vaginal blood flow was designed by Cohen and Shapiro in the 1960's (22). They developed a thermoflometer that consisted of a diaphragm with its center cut out; two thermistors were mounted to the diaphragm with one being in contact with the vaginal wall and the other in the center of the diaphragm, so that it recorded core temperature. The amount of current needed to keep the first thermistor at a constant temperature above the second was recorded via polygraph. This reflected heat dissipation, which is a function of blood flow (23). They used this to record vaginal vasomotor response during REM sleep and sexual fantasy. Although the apparatus appeared to work well, its complexity (fragile instrumentation and the need for a trained clinician to custom fit the diaphragm) limited its clinical use.

In 1977, Wagner and Levin developed an additional means to indirectly measure vaginal blood flow through heat dissipation. They fitted a heated oxygen electrode into a suction cup that was applied to the vaginal wall and held there by vacuum. The silver disc electrode was heated by an electric current to a set temperature of 43 degrees Celsius. They measured the changes in heat loss to assess the changes in blood flow under the electrode (24).

The oxygen-temperature method provides an indirect measure of vaginal blood flow by measuring skin temperature directly or indirectly by measuring the changes in skin temperature relative to baseline. A heated oxygen electrode is applied to the vaginal wall and held by suction (25). The electrode is kept at a constant temperature by an electric current, which is monitored. Increased blood perfusion under the electrode increases its heat loss, resulting in a need for greater output to maintain the electrode at the preset temperature. The change in the amount of power needed provides an indirect measure of the changes in blood flow under the electrode, reflecting the pooling of blood in the vascular bed. In addition, the electrode records oxygen diffusion across the skin, reflecting transient changes in blood flow (26). Wagner and Levin's studies have documented that these measures are sensitive to sexual arousal and orgasm (24, 27,28). This method has been found to be a specific indicator of sexual arousal and the method of choice for measuring orgasm (26)

Subsequently, Levin and Wagner adapted the technique of Midttun et al to measure vaginal blood flow (the "wash-out method") (29). They used a Radiometer heated electrode that was held against the vaginal surface and heated it to 41-43 degrees Celsius and then switched it off. The cooling curve of the electrode's temperature was followed until it reached its previously recorded unheated state. The initial basal temperature was subtracted from each of the cooling temperatures and plotted to obtain the slope of the linear portion of the cooling curve. As expected, there was greater heat clearance during sexual arousal. To minimize heat loss not

due to blood flow, a simplified Sheffield heat electrode was developed. This electrode featured a disk, heater, and temperature sensor housed in a ceramic holder that also had a second shield heater circuit behind the disk that was driven to the same temperature as the disk; this reduced heat loss to the outside environment (30).

Sommer et al reported use of a device to indirectly measure vaginal and minor labial blood flow, however, this device was not novel except that they also applied an electrode to the labia; otherwise it was the same as that developed previously by Levin and Wagner (31). Transcutaneous pO₂ was measured using 2 Clark oxygen electrodes. One was attached to the right lateral wall of the vagina approximately 4 cm from the introitus and the other on the right minor labium. These provided continuous oxygen measurements. They found that an increase in oxygen tension occurred immediately during the initiation of masturbation and continued throughout the course of stimulation. Just before orgasm a further increase was noted (32). Their results were similar to those in previous studies using this methodology. The authors concluded that this device could provide quantitative measures from which normograms could be created.

Advantages to use of the oxygen-temperature method include the fact that it provides two measures of blood flow and it is relatively free of movement artifacts. It can be employed throughout all phases of arousal—even to orgasm and can be used during menstruation. Most importantly, in the heat washout mode, it can be used to calculate absolute vaginal blood flow in ml/100g tissue/minute so that data can be compared over days, between subjects and between treatments. Repeated measures can be obtained by allowing the device to cool and reheat. Furthermore, it is safe, minimally intrusive and inexpensive. Disadvantages include the need for the investigator to attach the devices and the inability for prolonged recording (the heated electrode can potentially burn the vaginal mucosa if applied for too long). Furthermore, the Sheffield requires at least 3-5 minutes of temperature cooling, which makes it unable to follow rapid changes in blood flow.

Vaginal and Labial Thermistors—An attempt was made by Fisher and Osofsky to measure vaginal temperature, however, they observed that vaginal temperature reflects core temperature and is insensitive to changes in sexual arousal (33). A subsequent study using a radiotelemetric transducer mounted on a diaphragm revealed decreases in vaginal temperature during masturbation and intercourse. The authors attributed this decreases to vaginal wall edema (34). Given this conflicting data, the vaginal thermistor will need to be assessed in future studies to determine its usefulness as a measure of sexual response.

Hensen attempted to measure sexual response in women by measuring changes in temperature of the labia using a thermistor clip to determine the degree of vaginal congestion (35). He used two surface thermistors, one to measure ambient room temperature and another, which was attached to a clip and placed on the subject's labia minora. He found that the labial temperature increased and that the change was significantly correlated with subjective ratings of arousal during the viewing of erotic films. However, there was great inter-subject variability. Advantages to this method is that it provides an absolute scale of measurement, is less subject to movement artifact and can be used during menstruation. It is also noninvasive, which allows study of women with sexual pain disorders. However, care must be taken to properly position the patient and menstrual cycle status should be noted, as labial temperature has been found to vary during different phases. A previous study showed that labial temperature was higher during the follicular phase (36). Disadvantages include the requirement for ambient temperature control and that the clip does not consistently return to baseline levels (20). While the labial thermistor clip has been shown to be a reliable method that correlates with subjective self-report ratings and VPA, it has not been commonly used in current research. However, a recent study using the labial thermistor clip has shown similar results, demonstrating increases

in labial temperature during arousal as well as a significant correlation between temperature and self-report of arousal. In addition, it was tolerated well (37). Given this success, there may be some increase in its use (Figure 2).

Thermography—Seeley and Abramsom used the concept of thermography, a “noninvasive means of detecting and photographing individual infrared generation patterns to indicate physiological condition and functional changes within” (38) to measure sexual arousal in terms of the four phases of sexual stimulation as outlined by Masters and Johnson. They took thermographic photos of the subjects during initial masturbation, prior to orgasm, at the time of orgasm, and then after orgasm. Using these photos, they created a quantitative temperature profile. They discovered that in the female subject, the labia become warmer during the plateau phase and that the clitoris becomes warmer during the orgasm phase (39).

In a later study, this group confirmed its discriminant validity by examining differences in thermographic measures of the genitals as a function of erotic, emotional and no-treatment control conditions. They also demonstrated the convergence between thermographically assessed genital vasocongestion and self-report of sexual arousal (40).

Though promising at the time, research efforts using this technique were largely abandoned and many researchers questioned the validity of this technique since it was only performed on a few subjects. More recently, thermography has been used to assess sexual arousal in a larger study and it was found that men and women showed that genital temperature was significantly higher during sexual arousal and furthermore, genital temperature was significantly and highly correlated with subjective ratings of sexual arousal. Advantages of thermography include generation of easily quantitative data, its noninvasiveness and the ability to compare results between genders. Disadvantages include cost and the need for an expert to interpret to read the thermograms. In spite of these, thermography appears to be a promising technique to assess sexual arousal (41).

Clitoral and Labial Photoplethysmography—Tart developed a clitorophotoplethysmograph that was used to measure blood flow to the clitoris. A photocell was used to record blood volume changes in the clitoris, while a separate rod with another photocell was used to measure vaginal blood flow. The device also contained silver cloth electrodes for impedance photoplethysmography voltage or resistance measurement (42). Fisher and Davis modified the Tart apparatus by using a photocell only in the vagina and adding a thermistor to measure temperature changes and a strain gauge to indicate intravaginal movement (42). These instruments have not been commonly used in female sex research.

Subsequently a labial photoplethysmograph was developed (43). It consists of a small plastic clip that is attached to the labia minora. Its measurements have been shown to be consistent with those of the vaginal photoplethysmograph in terms of specificity and it correlates with subjective arousal. It is less subject to movement artifact and demonstrates a higher correspondence with subjective measures of sexual arousal. However, it is less comfortable for the subject and more difficult to place (20).

Duplex Doppler Ultrasound (Grey-scale and Color)—Duplex ultrasound uses standard ultrasound methods to produce a picture of blood vessels and surrounding organs. A computer is used to convert the Doppler sounds into a graph that provides information about the speed and direction of blood flow through the blood vessel being evaluated. Lavoisier was the first to use it to evaluate female genital hemodynamics by measuring clitoral blood flow. He showed that clitoral blood flow increases in response to vaginal pressure stimulation (44). Using ultrasound, investigators have shown that there is a difference in clitoral peak systolic and end diastolic velocity after topical administration of alprostadil between women with sexual

dysfunction versus healthy controls (45). Duplex Doppler US has also been used to measure labial (vestibular bulb), urethral, and vaginal arterial peak velocity and end diastolic velocity. Berman used duplex Doppler ultrasound to show that older women had a lower baseline vaginal blood flow, but there was no difference in blood flow after stimulation between older and younger women (46). In a later study, Berman used this method to show a significant increase in genital blood flow as a result of stimulation and sildenafil (47).

Color doppler ultrasound employs standard ultrasound methods to produce a picture of a blood vessel. However, a computer then converts the Doppler sounds into colors that are overlaid on the image of the blood vessel and that represent the speed and direction of blood flow through the vessel. Khalife et al first showed that clitoral blood flow in women who are not sexually aroused could be reliably assessed using this modality. In that study evaluating clitoral blood flow, they observed high positive correlations between examiners for measurement of maximum velocity, resistance, and pulsatility (48). However, subsequent studies showed that measurement of clitoral blood flow using this method has not been successful in differentiating sexual arousal from a humor control condition. Furthermore there weren't any significant correlations between clitoral blood-flow measures and subjective sexual arousal (49). However, one study has revealed a positive correlation between labial and clitoral blood flow and subjective arousal in women with Type I diabetes who are treated with Sildenafil (50).

Ultrasound is a quick, relatively easy, and noninvasive technique that provides a continuous, real time, anatomic assessment. It can also be used to assess changes in clitoral and labial diameter associated with sexual stimulation (51). Movement artifact can be minimized. Most importantly, it can provide measurements in absolute units that can be used for comparisons in research studies. It has also been useful in diagnosing sexual dysfunction due to trauma by determining the presence of genital calcifications (19). Disadvantages are that it requires the examiner to be in the room and there is a lack of standardization in terms of proper technique (i.e., placement of the probe). Vasoactive agents may be required to facilitate smooth muscle relaxation that yields optimal vascular responses. Analysis of data necessitates experienced interpretation. At this time, normative data have not been established, and low values have not been shown to correlate with sexual dysfunction.

Laser Doppler Perfusion Imaging—Laser doppler perfusion imaging (LDPI) is a noninvasive method of assessing superficial skin microcirculatory blood flow. It can detect flow in capillaries as small as 11 micrometers and as deep as 2 mm below the skin surface. Sarrel employed this technique to measure vaginal blood flow in post-menopausal women receiving estrogen versus estrogen-androgen treatment. No significant differences in blood flow were found between the two groups (52). Later, this device was used to measure clitoral blood flow in response to pelvic nerve stimulation in rabbits. A laser Doppler flowmeter with a needle probe was inserted longitudinally into the clitoral cavernosal tissue. Pelvic nerve stimulation was found to increase clitoral blood flow; however this was significant only at higher levels of stimulation (53). Another study in rabbits used the same technology to show that clitoral and vaginal flow decreased in lower estrogen states (54). Laser Doppler flowmetry has also been used to assess vaginal blood flow in eight healthy women undergoing benign hysterectomy (55). No significant differences were found in blood flow before and after the procedure. The authors promoted this method as an objective, reproducible measure of vaginal blood flow.

It has also recently been used to measure vulvar blood flow changes during sexual arousal (56). In this study, the LDPI scan was performed before and after reading a chapter of erotic fiction. The percentage change in flux significantly increased at the clitoris, labia, and posterior fourchette. One advantage of this method is that it is noninvasive, requiring minimal genital contact. It is also reproducible and easy to perform. However, it is subject to movement artifact

and the scans must be performed in a dark environment that may preclude simultaneous measurement of other parameters. It also requires that a technician be present to place the probe during the experiment, and is operator dependent. Finally, it does not measure absolute perfusion and the flow is expressed in arbitrary laser Doppler flow units (57). Though this method is an easy way to assess vaginal blood flow, subsequent studies are needed to determine its specificity, validity, and correlation with subjective measures of sexual function.

Dynamic Contrast and Non-contrast MRI—Dynamic MRI generally involves the acquisition of serial images before, during and after the injection of an MR contrast agent (58). With this process, the functionality of a particular organ may be assessed. Deliganis used MRI with a contrast agent (MS-325, a gadolinium chelate) to monitor sexual response in healthy sexually functional women; after they watched sexually oriented video clips, the MRI images revealed strong contrast enhancement of the external genitalia and clitoris. In addition, all women reported sexual arousal. As part of this study, the investigators calculated relative blood-flow and demonstrated that there were no difference in the change of blood flow between pre and postmenopausal women (59). Since then, magnetic resonance imaging has been used as a tool to measure the physiologic female sexual response. Suh et al described detailed female anatomy and anatomic changes between premenopausal and postmenopausal women utilizing dynamic MRI with a contrast agent, MS-325 (a gadolinium chelate) (60). The vagina was well visualized in premenopausal subjects but there weren't distinguishable mucosal rugae or clearly separate layers in postmenopausal subjects. Postmenopausal subjects were also found to have smaller labia minora width, vestibular bulb width, vaginal width and wall thickness, and cervical diameter.

Maravilla et al then used dynamic noncontrast MRI and T2-weighted images of female genitalia for quantitative evaluation of female sexual arousal response. In this study, 8 women were shown sexually oriented video clips and MRI images were taken at 3-minute intervals over 45 minutes. All women reported sexual arousal. Images were examined for clitoral volume and percent change in clitoral volume. The investigators showed excellent intrasubject reproducibility between sessions as well as with prior noncontrast studies (61).

Advantages of using MRI to study female sexual response include its excellent visualization of anatomic detail, noninvasiveness, and reproducibility. Newer techniques don't require use of contrast, limiting the risk to patient, decreasing expense, and eliminating the need to establish vascular access. Disadvantages include high expensive, time requirement, and machine unavailability. Subjects also must be appropriate candidates for MRI (no metallic substances in/on the body) and be able to remain motionless during the testing session.

Laser Oximetry—Changes in hemoglobin content provide a direct assessment of blood flow. Laser oximetry has been used to measure changes in hemoglobin content in rabbits as a response to pelvic nerve stimulation. The laser oximeter consists of a probe with one detector and eight light sources that are attached to the clitoris. Using this device, Min et al found that clitoral concentrations of total and oxygenated hemoglobin increased while levels of deoxygenated hemoglobin decreased in response to pelvic nerve stimulation (53).

Advantages to this procedure include its noninvasiveness, reproducibility and low operator dependency. Disadvantages are that the readings may be affected by high hematocrit or hypercapnea. To our knowledge, this method has not yet been used in humans.

Clitoral intracavernosal pressure—An attempt to measure clitoral intracavernosal pressure in a rabbit model as a parameter of sexual function was made by Min et al in 2001. A heparinized 21-gauge catheter that was connected to a blood pressure transducer was inserted into the clitoral cavernosal tissue. The tip of needle was placed near the crus. The pelvic nerve

was stimulated. The response was found to be highly variable and it did not consistently increase in response to pelvic nerve stimulation (53). This measure has not been used in women, likely due to its inconsistency and invasive nature.

Pudendal Arteriogram—Arteriography is a procedure in which a contrast material that can be seen using x-ray equipment is injected into one of the arteries, allowing visualization of the vessel. It can be used to assess vascular integrity. Data using this modality to evaluate female sexual function is lacking. There is one report of a female patient with persistent sexual arousal syndrome (PSAS) based on a pelvic arterial venous malformation (AVM) communicating to the arteries of the clitoris. Duplex Doppler ultrasound revealed marked increased blood flow to the clitoris. A selective internal pudendal arteriogram revealed the pelvic AVM. The patient has ultimately achieved great relief from PSAS symptoms after multiple embolization episodes (62).

The advantage of arteriography is that it allows excellent visualization of genital vasculature, however, it is invasive, requires the use of contrast and personnel skilled in angiography. Its risks make it of limited usefulness for clinical and research purposes.

Volume, Pressure and Compliance

There have been a variety of methods used to measure vaginal luminal pressure, volume, and compliance. Bardwick and Behrman are credited with the first attempts to measure intravaginal/intrauterine pressure in 1967. They used a thick-walled polyethylene tube connected to the tip of a rubber balloon that was inserted through the cervix and into the uterus and filled with water. This device consisted of a transducer that measured tonus, amplitude, duration, and frequency of contractions. Although this device worked fairly well, its application to clinical use was limited by its invasiveness and discomfort. Furthermore, it was uncertain whether the changes measured were attributable to sexual arousal versus anxiety (63).

Fox measured intravaginal and intrauterine pressure using a radiotelemetry device during coitus. The radiotelemetry capsule and antenna were placed prior to initiating sexual activity. He found that during ejaculation, the intravaginal pressure decreased to -20 cm H₂O and that during orgasm it increased to +20 cm H₂O. Intrauterine pressure increased to +40 cm H₂O during orgasm initially, and then dropped rapidly to -10 cm H₂O. Fox postulated that this pressure gradient between the vagina and the uterus facilitates sperm transport (64). These “bedroom studies” have not been repeated, probably because they are complicated and labor intensive.

Vaginal luminal pressure has also been measured by using a compliance balloon (Schuster balloon) filled with 30 cc increments. The maximum intravaginal pressure was defined as the maximum vaginal volume that occurred when 300 cc of air was instilled, or once the patient noted discomfort. One study showed a decrease in vaginal pressure and an increase in volume after sexual stimulation; however, there were no significant changes noted with sildenafil (47). Using an animal model, Min et al measured vaginal intraluminal pressure of rabbits in response to pelvic nerve stimulation and found that it caused vaginal luminal pressure changes that were highly variable, but qualitatively different, between the upper and lower regions (53).

Rectal pressure can be used as an indicator of muscular contractions in the rectal vicinity. Rectal pressure patterns have been found to change markedly during orgasm in women (65). Indeed, rectal pressure has been used to objectively assess the occurrence of orgasm in women. In one study, a rectal probe was placed in the rectum by an experienced urologist and women were exposed to 4 conditions: rest, imitation of orgasm, stimulation, and orgasm. Rectal pressure

variability (an important feature of orgasm) was found to be significantly greater during orgasm than at rest or during imitation of orgasm or sexual stimulation (66).

While most of these methods are easy and provide physiologic data, their validity and specificity have not been proven. Furthermore, few studies have been done to assess their correlation with subjective measures of sexual response.

Lubrication

Vaginal lubrication is known to be a component of the physiologic sexual response in women. Sexual arousal increases blood flow, and therefore increases the formation of the transudate that facilitates intercourse (57). It has been measured by a number of methods, including pH, filter papers and tampons.

pH—In 1968, Shapiro performed studies to assess vaginal acidity by measuring secretions from the vaginal wall using a platinum electrode encased in a tampex saturated with hypotonic saline. There was also a reference electrode on the pubic symphysis; using this apparatus, he measured the production of lactic acid in the vagina by measuring pH. This device also had the capacity to measure intravaginal temperature. However, problems with this method included movement/position artifact and premature arousal resulting from placement of the instruments. Furthermore, the changes that occurred were too small to detect with that technology (22).

Masters and Johnson performed pH studies by blindly placing the electrode into the vagina and found that there were small increases in pH (67). They found that pH increased slightly with sexual arousal.

Vaginal pH during coitus has been measured continuously using radio-telemetry (68). A glass pH electrode with a transmitter circuit and battery was encased in a telemetry capsule. The female partner placed the capsule in the posterior fornix. The authors commented that sexual excitement with its concomitant vaginal lubrication did not appreciably change the pH. The lack of change in pH was likely due to two factors: 1) the upper vagina is least responsive to the formation of transudates and 2) the electrode may have been at a site that showed little change (31). This study was only done in 2 couples and subsequent researchers have never followed up these investigations. The advantage is that it gives a measurement of what is actually happening inside the genital tract during coitus, however, it is complex and labor intensive.

Wagner and Levin measured the surface pH of the vagina before and after sexual arousal by self-stimulation in ten healthy women by using a glass electrode attached to a pH meter that was attached to the vaginal surface at multiple sites. They found that clitoral self-stimulation to orgasm generally results in a small increase in pH of up to 1 unit (69)

Increased pH is thought to create a favorable environment for sperm, which cannot survive in an acidic environment; Berman reported use of a digital pH meter inserted into the vagina and found an increase in pH post stimulation, and with sildenafil (47). However, it should be noted that the type of pH electrode used to measure pH during basal state or arousal is critical because certain electrodes (such as those made of antimony) are affected by oxygen tension of the fluids (57).

Carranza-Lira et al proposed a method of assessing vaginal dryness in postmenopausal women placed on 3 different HRT regimens by measuring the moistening of a pH test strip (in mm) and self-report using a visual analog scale. They found that lubrication increased compared to baseline both by pH strip and the visual analog scale and concluded that this method was an

objective way to assess vaginal lubrication (70). This is a simple and inexpensive method, however, it will need to be further validated in subsequent studies.

Filter Papers and Tampons—Levin and Wagner used measurements of sodium, potassium and filter papers to see how human vaginal fluid was modified as a result of sexual arousal. Using weighed filter papers inserted into the vagina, the ionic concentrations on sodium, potassium and chloride were determined after stimulation. They found that compared to baseline, there was an increase in vaginal fluid as well as sodium and potassium, and that the potassium level was variable but greater than that of plasma (71).

In a study of the effects of vasoactive intestinal peptide on vaginal blood flow and lubrication, vaginal transudate was measured using circular preweighed filter papers that were placed on the vaginal surface. The amount of vaginal fluid was calculated from the weight gain of the filter papers. The authors found that VIP significantly increased vaginal lubrication (72).

Min et al measured vaginal lubrication in rabbits in response to sildenafil by using a tampon constructed using a flexible preweighed cotton tip catheter. The amount of vaginal fluid was calculated by determining the difference between pre and post sildenafil values. Using this instrument they were able to show that sildenafil significantly increased the amount of vaginal lubrication in control and estradiol treated animals (73). However, it should be noted that the rabbit vagina has two distinct sections—a columnar cell lined epithelium and a stratified squamous epithelium, which is different from the human vagina that contains only a stratified squamous area. This detail may limit the applicability of these findings to women.

Advantages to these methods are low cost, ease of use and minimal invasiveness. Disadvantages vary with each method; for instance, pH can be altered by bacterial colonization, vaginal site, and estrogen status. Overall, the pH, due to its heterogeneity, is a poor index of normal vaginal function. The other methods of assessing vaginal lubrication may prove to be more useful.

Muscular

The muscles of the pelvic floor and vagina definitely play an important role in the female sexual response. Methods to assess muscular activity include electromyograms and electrovaginograms, though much more research is needed in this area.

Pelvic Floor Electromyogram—Gillan and Brindley performed pelvic floor electromyograms using stainless steel wire electrodes and silver disc electrodes attached to the vaginal wall (74). They noted that the pelvic floor contracted in response to clitoral vibratory stimulation and described a well-sustained tonic reflex that they called, the “tonic glandipudendal reflex.”

Electrovaginogram—An electrovaginogram was used to measure electric waves recorded from the vagina (75). The authors demonstrated the presence of slow waves that were regular in rhythm and interrupted by random action potentials. Using a condom catheter to simulate distension of the vagina during coitus, they showed that after 30 ml of distension, a significant increase in EMG activity occurred; both the slow waves and APs increased in frequency. Based on this electrovaginogram, the authors suggest that abnormalities, if present, may represent inadequacies in vaginal contraction that may interfere with normal sexual function.

Advantages to these procedures are that they are easy, relatively inexpensive and are well tolerated by the patient. However, their ability to provide an objective measure of sexual arousal and its correlation with subjective sexual arousal remains to be determined. Furthermore, it is uncertain whether these measures have any clinical applicability.

Clitoral electromyography—Clitoral electromyography was developed based on the clitoris's histomorphological and physiological resemblance to the penis. The theory is that electromyographic activity arising from the smooth muscle component of the corpus clitoris may have clinical significance in the assessment of female sexual function. In one study, 11 women were recruited and evaluated with clitoral electromyography using a concentric needle electrode placed intracorporally. After recording spontaneous electromyography and electrodermal activity, the left median nerve was stimulated. The data revealed that there was evoked and spontaneous clitoral electromyography that likely indicates a sympathetic tonus of the clitoris, similar to that of the corpus cavernosum of the penis in males (76). The authors concluded that clitoral electromyography might be a useful objective assessment tool for evaluating female sexual dysfunction as well as genital autonomic innervation. More studies will be required to assess if this is clinically useful.

Neural

Autonomic—The autonomic nervous system (ANS) exists to control the body's internal environment. These controls are done automatically, at the unconscious level. The ANS helps control heart rate, blood pressure, digestion, respiration, blood pH, and other bodily functions through a series of complex reflex actions. In addition, it plays a role in coordinating sexual response. Autonomic parameters can be monitored during sexual response (Figure 3).

Galvanic Skin response/Conductance: In 1937, Reich attempted to use skin potential measurements to provide evidence for the theory of electrical nature of sexual excitement based on the belief that certain areas of the body, i.e., "erogenous zones" had higher skin potentials. In his experiments, he applied electrodes to these erogenous zones (which included areas such as the penis, vagina, tongue, lips, and others), measured them, and found that there were differences. However, the scientific community questioned the data he generated (77). Critics of his work objected to his suspect methodology, which included inconsistencies in location of electrodes, inappropriate instrumentation, and lack of control experiments. In fact, efforts to reproduce his bioelectrical experiments were unsuccessful (78).

Galvanic skin response (GSR) is a method of measuring the electrical resistance of the skin. Two leads are placed on the skin and a base measure is acquired. GSR can be performed in 2 ways, active and passive. In active GSR current is passed through the body with the resistance measured. In passive GSR, current generated by the body itself is measured. Studies have shown that GSR varies with sexual arousal but to a small degree (12).

Although it has a long history, its use has declined significantly as better techniques have developed. Though relatively cheap and easy to use, its lack of specificity with regard to sexual response has limited its use in sexual physiologic research. While it is sometimes used in current studies, it is usually in conjunction with other physiologic instruments such as the vaginal photoplethysmograph.

Other Autonomic Parameters—In the 1950's, Kinsey reviewed the autonomic components of sexual arousal, including heart rate, blood pressure, hyperventilation, adrenaline secretion, muscle tension, inhibition of gastrointestinal activity, temperature (non-genital), and pupillary response; though it was noted that many changes were seen in these parameters as a result of sexual arousal and/or orgasm, they were not specific to the sexual response. He noted, however, that parameters such as tumescence, genital secretions, and peripheral vasodilation appeared to be more specific parameters of sexual arousal (79).

Sensation

Sensory Testing: Sensation has been tested using a variety of instruments including monofilaments, the biothesiometer, and digital analyzers. Monofilament sensory testing devices consist of a single strand of nylon of variable thickness (typically attached to a plastic or paper handle) that can produce a characteristic downward force when buckled onto a surface. A single monofilament or a progressive scale of monofilaments can be used for neurologic sensory testing, such as in the screening of diabetic neuropathy. Romanzi et al used monofilaments to compare genital sensitivity at various sites in premenopausal, postmenopausal, normal and abnormally sexually functioning women. There was an association between sensitivity and estrogen deficiency, sexual dysfunction, and neurologic impairment (80). Though they are a low cost sensory screening tool, monofilaments are no longer commonly used in studies of female sexual response due to the development of more advanced instruments that allow better standardization and improved quantification of the stimulus .

A biothesiometer is a small cylindrical instrument that is used to assess the sensitivity of the clitoris and labia to pressure, vibration and temperature. Sensation has been assessed using the standard biothesiometer to measure vibratory perception thresholds from the clitoris and mucosal surfaces of the labia minora. Using this method, Berman et al found that sexual stimulation resulted in decreased clitoral but not labial perception thresholds, and that both were significantly lower after administration of sildenafil (47). Advantages to this procedure are its low cost, noninvasiveness and ease of use. It allows quantification of genital sensation. A disadvantage is that desensitization occurs with prolonged use.

Recently, more sophisticated tools have been developed and include neurosensory and vibratory sensory analyzers, specifically, the Genitosensory Analyzer (Medoc Advanced Medical Systems, Israel, Figure 4). Utilizing a device called a “thermode” which is placed on the patient’s skin, the thermosensory analyzer is capable of heating or cooling the skin as needed. The patient responds to these temperature stimuli by pushing a response button. A sensory threshold is recorded and compared to an age-matched normal population value by the computer. A deviation from the normal range can indicate the existence of peripheral nerve disease or damage due to injury or toxic exposure. The Vibratory Sensory Analyzer is a computerized device offering quantitative assessment of the function of large-caliber, A-beta sensory nerve fibers of the peripheral nervous system. These systems allow superior quantification of the sensory response and enables researcher to compare data to established norms (81). It has been found that the most sensitive parameters for detection of sexual dysfunction of any origin are clitoral and vaginal vibration. Additionally, the GSA was used to demonstrate that competitive female bicycle riders have decreased genital sensation, yet no increase in sexual dysfunction (82). While the GSA offers controlled quantitative testing, this equipment is expensive, somewhat invasive, is subjective in nature and the established norms that have been published have not seemed to make a large impact on the assessment of female sexual function. Further studies are needed to assess its utility.

Somatosensory Evoked Potentials: Somatosensory evoked potentials (SEPs) record transmission of nerve impulses from areas of the body to the brain. Yang and Kromm reported a new technique to measure SEPs of the dorsal nerve of the clitoris and the perineal nerve (83). They placed self-adhesive disk electrodes on either side of the clitoris. Stimulation of the dorsal nerve of the clitoris (DNC) and perineal nerve SEPs were evoked through a vaginal probe. Cortical responses were measured by cup electrodes placed on the scalp. They found that they were able to measure SEPs in greater than 90% of subjects for the DNC, but only 69% for the perineal nerve. They concluded that if SEPs are recorded, the integrity of these nerves could be documented.

An advantage of this procedure is that it is an easy, relatively inexpensive means of documenting the integrity of a specific female genital somatosensory pathway. However, its use is limited by its sensitivity. Other somatosensory nerves are consistently evoked in >98% of healthy subjects while the rate for these 2 particular nerves is much lower. Additionally, more studies will need to be performed to determine its clinical usefulness in its ability to discriminate between women with and without female sexual dysfunction disorders.

Pudendal Nerve Terminal Motor Latency: Pudendal nerve latency is usually defined as the measurement of the time from stimulation of the pudendal nerve at the ischial spine to the response of the external anal sphincter. Normal pudendal nerve terminal motor latency is <2.2 ms (84). Other points besides the ischial spine can be used for the test. While used frequently in the diagnosis of male erectile dysfunction (85,86,87) and urinary and fecal incontinence, (88,89) there is a paucity of data with regard to female sexual function and response. Normative values have been established previously (90). The value of pudendal nerve latency testing remains controversial and its role in the assessment of female sexual function and response remains to be seen.

Neuroimaging

Functional MRI: Functional MRI involves obtaining three-dimensional images of the brain based on changes in blood flow and that can be correlated with brain functions. Park et al utilized functional MRI with the blood-oxygenation-level-dependent (BOLD) technique to identify and quantify brain regions associated with visually evoked sexual arousal in women (91). In this study, they discovered that the inferior frontal lobe, cingulate gyrus, insula gyrus, corpus callosum, thalamus, caudate nucleus, globus pallidus and inferior temporal lobe were significantly activated. A subsequent study used functional MRI to investigate the differences in brain activity in response to sexually oriented visual stimuli between men and women. Subjective ratings of sexual arousal were found to be significantly greater in men than in women. Though significant activation of the medial prefrontal cortex, orbitalfrontal cortex, anterior cingulate cortex, insular cortex, occipitotemporal cortex, amygdala and ventral striatum occurred in both sexes, males exhibited a significant activation in the thalamus and hypothalamus while females did not. Furthermore, a positive correlation between subjective arousal and the magnitude of hypothalamic activation in men was observed, but this correlation was not seen in women (92). Using fMRI, it has been revealed that the activated brain center associated with visually evoked sexual arousal showed qualitative and quantitative differences between premenopausal and menopausal women (93). Another study showed that women in the mid-luteal phase exhibit differences in cerebral activation than women outside the luteal phase; however gender differences with women in both phases remained the same (94). A recent study using fMRI showed that prescribing estradiol and testosterone to surgically menopausal women led to an increase in brain activation and enhancement of the limbic response to erotic visual stimulation, compared to baseline (95).

Advantages of fMRI are that it is a safe, noninvasive means by which to examine sexual arousal in terms of the central nervous system. But, it is also expensive, time-consuming, and limited in its ability to measure absolute neural activity (96). Standardization protocols must be developed to determine what strength of scanner should be used. Furthermore, more studies are needed to validate this method before it can be of practical use in clinical research studies.

Positron Emission Tomography: Positron Emission Tomography (PET) provides a computerized image of the metabolic activity of body tissues to localize functional response. Most PET studies of sexual arousal to date have been performed in men (97,98). However, Whipple and Komisaruk performed a PET-MRI study on two women with complete spinal cord injury and one woman with no injuries. They observed that cervical self-stimulation

increased activity in the region of the nucleus of the solitary tract, which is the brainstem nucleus to which the vagus nerves project, suggesting that the vagus nerves can convey genital sensory input directly to the brain in women, completely bypassing SCI at any level (99).

Georgiadis et al employed PET to measure regional cerebral blood flow in 12 healthy women during rest, clitoral-induced orgasm, sexual clitoral stimulation and imitation of orgasm (66). They discovered that during sexual stimulation, there was activation of the left secondary and right dorsal primary somatosensory cortex while during orgasm, there were decreases in the neocortex--especially the left lateral orbitofrontal cortex, inferior temporal gyrus, and anterior temporal pole. They hypothesized that decreases in the left lateral orbitofrontal cortex signified behavioral disinhibition during orgasm and that deactivation of the temporal lobe is directly related to high sexual arousal.

The advantage of PET is that it allows visualization of how the body is functioning. However, a disadvantage of this modality is that it is invasive, and necessitates the use of radiolabeled compounds. Furthermore, its resolution is inferior to that of fMRI, limiting its clinical use.

Coital Imaging Studies

Ultrasound: Imaging studies have been performed to assess anatomy during coitus. Initial anatomical suppositions were based on assessment using artificial penises (100). In 1992, Riley and Riley utilized ultrasound to assess an intravaginal barrier contraceptive during human coitus in 10 couples. In 9 out of 10 couples, there was an indentation and stretching of the anterior wall of the vagina and no direct impact on the posterior wall in any coital position. In 2 out of 9 couples engaged in rear-entry position, there was cervical impact (101). However, this study had several important limitations: images were of poor-quality and the subjects were required to self-scan.

MRI: In a subsequent MRI study, 3 out of 4 couples with complete penetration showed a preferential contact of the penis with the anterior fornix and vaginal wall (102). Faix also used MRI, which revealed that in the missionary position, there was preferential contact of the penis with the anterior vaginal wall and anterior fornix (103). In a subsequent study, he used MRI to study anatomical difference during coitus between two different positions in the same couple. He found that in the missionary position, the penis reached the anterior fornix with preferential contact of the anterior vaginal wall. The posterior bladder was pushed forward and the uterus was pushed upward and backward. During the rear-entry position, the penis reached the posterior fornix with preferential contact of the posterior vaginal wall, with the bladder and uterus pushed forward (104). While these results are interesting, it should be noted that this observation was only done in one couple; thus more studies will need to be carried out to determine coital anatomy.

MRI is advantageous because it allows observation of the anatomy of the female genital tract during coitus. It also provides better detail than ultrasonography. However, it is expensive and time-consuming. Subjects must be selected appropriately. Furthermore, sexual performance may be inhibited in the scanner environment.

Discussion

Significance and Utility of Physiologic Measurements

Obtaining physiologic measures of female sexual function can provide us with information that helps us to understand female sexual physiology as well as yield insight to the problem of female sexual dysfunction. Given the extensive number of tools that are available to assess physiologic aspects of female sexual function, one might ask which is the most suitable one

to use. This is a difficult, if not impossible, question to answer given the lack of data on this subject. Certainly, each method has its obvious advantages and disadvantages. In addition, one method may be particularly fitting for a specific population of women (i.e., thermography instead of vaginal photoplethysmography in women with dyspareunia). Based on our experiences, we find vaginal photoplethysmography to be the most appropriate instrument to employ due to its relatively low cost and ease of use. Furthermore, it is the most widely utilized method of measuring sexual arousal, making it easier to interpret data in comparison to other studies. The genitosensory analyzer, though expensive and somewhat invasive, may play an important role in evaluating women with neurologic impairment such as multiple sclerosis. Interest in functional neuroimaging during sexual arousal has increased dramatically, indicative of the attempt to make a connection between the “mind and body.” The exciting findings in studies using fMRI may herald a paradigm shift in how we assess female sexual function, possibly making it the most promising instrument developed thus far.

At this time, these measures are mainly employed in the research setting and are not utilized in the clinical arena, mainly because we do not have normative data for most of these techniques.

Limitations of Physiologic measurements

Obtaining valid and reliable measures of sexual response has always been one of the most difficult problems in sex research (105). Although many physiologic measures of female sexual function show some promise, there are some limitations that can limit their clinical and research usefulness. In addition, the research laboratory probably does not provide the optimal setting for eliciting sexual response. Women may experience increased levels of anxiety, fear, or discomfort that would interfere with the ability to make accurate measurements. Attempts should be made to make the study environment as comfortable and aesthetically pleasing as possible (Figure 5).

Along the same lines, many of the current modalities require presence of the investigator to fit and/or interpret the device. This obviously interferes with the sense of privacy and may be inhibitory to a woman's sexual response. As a result, the findings may not reflect the woman's true sexual state.

Furthermore, we are not certain of the clinical significance of many of these measures. For example, a small study of women who had a radical hysterectomy showed that even though they had a lower VPA than controls, they did not report an increased incidence of sexual dysfunction (106). For many of the instruments, there is a lack of normative values, making it difficult to interpret what individual values represent and mean.

One problem that has plagued sexual research is the lack of correlation between subjective arousal and physiologic genital response for many of these instruments (107). There may be many reasons for this. Given the complex nature of the female sexual response, factors such as the environment, details of the relationship and emotional state simply aren't accounted for by these methods. Sometimes there is a temptation to focus on physiology and anatomy, but we must not forget that the brain with all its psychological, social and emotional components, may be most important organ in female sexual function. This is different from men, who largely depend on physiologic feedback. It has been hypothesized that women are often unaware of their genital response and that their cues are more emotionally/psychologically based. Furthermore, correlations may not have been found due to limitations of the methodology employed and the statistical analyses used. Chivers et al performed a metaanalysis of 109 studies and found that studies that included and used similar methods with both female and male samples showed no sex difference in agreement between self-reported sexual arousal and actual genital response, suggesting methodological characteristics significantly moderate the degree

of agreement between measures (108). In contrast, Rellini et al used hierarchical linear modeling (HLM) to reveal a significant concordance between continuous measures of physiological and subjective sexual arousal as assessed during exposure to erotic stimuli in a laboratory setting (109).

Given all of these limitations, some argue that physiologic measures lack standardization and are not suitable for use in large-scale clinical trials, citing that there are a number of validated surveys and questionnaires that are better suited for this purpose (110). In a study comparing event logs, the Female Sexual Functioning Index (FSFI), vaginal photoplethysmography and continuous subjective arousal, only the FSFI significantly predicted whether women improved after treatment (111). Indeed, the FDA recommendations for the conduct of clinical trials in FSD call for appropriate definitions of FSD, appropriate study populations, validation of questionnaires and self-report measures, and use of endpoints “based on the number of successful and satisfactory sexual events or encounters over time” (112). However, objective physiologic genital measures are still needed to achieve a better understanding of female sexual function.

Future direction and research goals

A lack of well-developed instruments and well-defined measures has limited clinical trials. Although many advances have been made in the development of instruments for use in the field of female sex research, there is still a long way to go. While these tools develop a foundation and basis, more investigation is needed to understand what the data obtained means and its clinical significance and application.

To make further progress in the field, future research efforts will need to focus on developing “normative data” for physiologic instruments and defining appropriate endpoints for studies. In addition, efforts should be made to simulate the natural environment as much as possible in the research setting. Lastly, we need to remember that the dogma used in male sex research is not necessarily applicable to sex research in women. Validated questionnaires should be used to complement physiologic findings.

Conclusion

The nature of the female sexual response is highly complex and is influenced by many factors that incorporate psychosocial as well as physiologic entities. This makes assessment even more challenging. There are a variety of tools that exist to measure sexual response within both of these realms, however many of these tools are limited by their invasiveness, lack of correlation with subjective response and lack of validation. Further investigation is needed in this area. If well-developed, physiologic measures would provide objectivity and the possibility of continuous sampling. Furthermore it is important to realize that physiologic causes are rarely the only source of dysfunction; to truly assess sexual function and dysfunction in women, it is imperative that physiologic measures be interpreted in the context of the history, physical, and the patient’s psychosocial and emotional issues.

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Figure 1.
A vaginal photoplethysmograph. The subject easily inserts the probe into the vagina.

Figure 2.
A labial thermistor clip. The thermal electrode is gently attached to the labia minorum and secured in place by a sliding lock mechanism.

Figure 3.

The Biopac MP150 is a machine that allows acquisition and signal processing of physiologic and autonomic parameters such as vaginal pulse amplitude, temperature, pulse, respiratory rate, and skin conductance.

Figure 4.
The Genitosensory Analyzer (GSA) is used to measure temperature and vibratory sensation of the genitalia.

Figure 5.
Psychophysiological studies of sexual response should be done in a comfortable, well-designed laboratory to minimize subject anxiety and discomfort.

Table 1**Methods for Physiologic Assessment of Sexual Function in Women****Genital Blood Flow***Vaginal Photoplethysmography**Clearance Techniques**Xenon-133 Washout**Oxygen-Temperature Method**Vaginal and Labial Thermistors**Thermography**Clitoral and Labial Photoplethysmography**Duplex Doppler Ultrasound**Grey Scale**Color**Laser-Doppler Perfusion Imaging (LDPI)**Dynamic Contrast and Non-contrast MRI**Laser Oximetry**Clitoral Intracavernosal Pressure**Pudendal Arteriogram***Volume, Pressure, and Compliance***Pressure/Compliance Balloons**Radiotelemetry Devices**Pressure Catheters***Lubrication***pH**Filter papers**Tampons***Muscular***Pelvic Floor Electromyogram**Electrovaginogram**Clitoral Electromyography***Neural***Autonomic**Galvanic Skin Response/Conductance**Other Autonomic Parameters (heart rate, blood pressure, hyperventilation, pupillary response)**Sensation**Sensory Testing**Monofilaments**Biothesiometer**Genitosensory Analyzer**Somatosensory Evoked Potentials (SEPs)**Pudendal Nerve Terminal Motor Latency**Neuroimaging**Functional MRI (fMRI)**Positron Emission Tomography (PET)***Coital Imaging Studies***Ultrasound**MRI*

Table 2

Some Advantages and Disadvantages of Select Methods for Physiologic Assessment of Sexual Function in Women

Physiologic Measure	Advantages	Disadvantages
Vaginal Photoplethysmography	Gives moment to moment measurements over long periods of time Easily inserted by subject in private Comfortable for subject Can do multiple, sequential recordings Provides 2 measurements of blood flow	Subject to movement artifact Uncertain what signal represents Lack of absolute measurements Doesn't provide anatomical information
Oxygen-Temperature Method	Free of movement artifacts Calculates absolute blood flow Minimally intrusive Has absolute scale of measurement	Inability for prolonged recording Requires cooling Unable to follow rapid changes in blood flow
Labial Thermistor	Less subject to movement artifact Can be used during menstruation Noninvasive Has absolute scale of measurement	Requires ambient temperature control Does not return consistently to baseline levels
Thermography	Noninvasive Allows comparison between genders Provides continuous, real-time assessment of anatomy and blood flow	Expensive Need for expertise for interpretation of thermograms Operator-dependent
Duplex Doppler Ultrasound	Measurement in absolute units Quick Minimally invasive	Requires examiner to be in close proximity to patient Vasoactive substances may be needed to yield optimal responses No normative data
Dynamic Contrast and Non-contrast MRI	Excellent visualization of anatomic detail Non-invasive Does not require use of contrast	Expensive Dependence on machine availability Patients must be appropriate candidates (no metal or claustrophobia)
Genitosensory Analyzer	Allows controlled quantitative testing Allows comparison to previously established norms	Expensive Somewhat invasive Subjective in nature
Functional MRI (fMRI)	Assesses brain regions associated with sexual function High resolution Noninvasive	Expensive Limited in ability to measure absolute neural activity Dependence on machine availability Patients must be appropriate candidates (no metal or claustrophobia)
Positron Emission Tomography (PET)	Provides functional data about the brain with regard to sexual function	Requires use of radiolabeled compounds Resolution inferior to MRI