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In Vivo Imaging–Based 3-Dimensional Pelvic Prototype Models to Improve Education Regarding Sexual Anatomy and Physiology

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ABSTRACT

Background: Myths, misconceptions, and taboos about sexual anatomy and physiology are common and can affect sexual health and maintain harmful practices and beliefs.

Aim: To construct a female and a preliminary male 3-dimensional (3D) pelvic model on the basis of in vivo imaging, which could be studied in sex education and clinical practice.

Methods: We retrospectively studied the images of 200 female pelvic magnetic resonance examinations and reviewed the literature to choose the optimum magnetic resonance imaging (MRI) protocol for the study of the clitoris and surrounding organs. We also conducted a cross-sectional study of 30 women who were undergoing a pelvic MRI. 15 women had undergone female genital mutilation/cutting involving the clitoris and 15 had not. The best-quality MRI images of 3 uncut and 1 cut clitoris, together with the principal surrounding pelvic organs, were selected to generate 3D reconstructions using dedicated software. The same software was used to reconstruct the anatomy of the penis and the principal surrounding pelvic organs, based on contrast-enhanced computer tomography images. Images of both models were exported in .stl format and cleaned to obtain single manifold objects in free, open source software. Each organ model was sliced and 3D printed. A preliminary feedback was collected from 13 potential users working in urology, gynaecology, sexual medicine, physiotherapy, and education.

Outcomes: The main outcomes of this study are a kit of 3D pelvic models, 2-dimensional figures of female and male sexual anatomy, and files for 3D printing.

Results: We present a kit containing 3D models and 2-dimensional figures of female and male sexual anatomy, based on in vivo imaging and, feedbacks and suggestions received from potential users.

Clinical Translation: Our kit can be used in anatomy and sex education among and by health professionals, teachers, sex educators, students, and the general population.

Strengths & Limitations: The strengths are that the models were based on in vivo imaging, can be dismantled/reassembled, and show analogous anatomic structures of the clitoris and the penis. The female models represent diversity, including women with female genital mutilation/cutting. The limitations are that the male model is preliminary and can be improved if based on an MRI; that imaging-based anatomic representations can differ from anatomic dissections; and that the models represent the sexual organs at rest or during an unknown state of arousal only.

Conclusion: Our kit can be studied in anatomy, biology, and sex education, as well as in clinical practice. **Abdulcadir J, Dewaele R, Firmenich N, et al. In Vivo Imaging–Based 3-Dimensional Pelvic Prototype Models to Improve Education Regarding Sexual Anatomy and Physiology. J Sex Med 2020;17:1590–1602.**

Key Words: Clitoris; Penis; Female Genital Mutilation; Sexual Response; MRI; Clitoral Reconstruction; 3D Printing; Model; Anatomy Education; Sex Education

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INTRODUCTION

There is a significant deficiency in public knowledge regarding human anatomy, which has important implications for health literacy. Anatomic knowledge of the own bodies facilitates the monitoring and explaining the own body and health; the obtaining, processing, and understanding of health information and services; and the ability to make informed decision regarding ourselves or our relatives.[1] General knowledge of genital anatomy, its diversity and sexual physiology, is not only lacking but is also rich in taboos, myths, stereotypes, and misconceptions.[2,3] Moreover, health professionals and medical students are not immune to these beliefs.[2,4,5] Such knowledge gaps and misconceptions are common around the world and can negatively affect sexual health, impair body self-image,[6,7] increase the number of requests for genital cosmetic surgery[8,9] and maintain harmful practices, such as non-consensual genital interventions on minors,[10] including female genital mutilation/cutting (FGM/C). FGM/C is defined by the World Health Organization as the partial or total removal of the female external genital organs for non-therapeutic reasons.[11] In many countries of the world where FGM/C is traditional and prevalent, an uncut clitoris is thought to be able to enlarge like a penis, injure a baby during delivery, cause erectile dysfunction in a male partner, or make a girl hypersexual, unfaithful, and promiscuous.[12] Where infibulation (the narrowing of the vaginal opening by apposition of the labia, with or without cutting of the clitoris and the labia)[11] is practiced, non-closed genitals are imagined to be a large aperture into which the wind could introduce disease or from which a baby could fall during pregnancy.[2]

More than 10 years ago, we started to work in the care of migrant women and girls who had undergone FGM/C. A considerable part of the care offered consists of reproductive and sexual health information and education, involving deconstruction of the myths and misinformation about female sexual anatomy and physiology, without stigmatization. This can take place during pregnancy or at any age of a woman's life and in the presence or absence of her partner. The information provided includes drawings and diagrams of the genitalia. If a gynecologic examination is performed and the woman agrees, she is invited to look at her genitalia using a mirror or colposcope.

Information regarding sexual anatomy and physiology is also provided during psychosexual therapy, involving a gradual deconstruction of myths, before surgeries such as defibulation (opening of infibulation)[13] and clitoral surgery (reexposure of the cut clitoris after the removal of the cutaneous scar)[14] are performed, to promote better self-knowledge and facilitate informed choices to be made regarding the available treatments. Girls and women who have undergone female genital cutting are often told and believe that their clitoris was removed and do not know that most of the organ is still present and can respond to sexual stimuli. In addition, their partners often believe the same.[4] In our clinical experience, the provision of information regarding both female and male sexual anatomy, particularly on the similar anatomy, common embryology, and physiology of the 2 organs, also contributes to the prevention of the practice in future generations and the avoidance of social exclusion of uncut girls, which can occur as a result of some of the beliefs described previously.[2]

Over the years, we have noticed that many taboos, myths, and misconceptions regarding female sexual anatomy and physiology that we have discussed with our patients who have undergone FGM/C and their partners also exist among uncut women and girls and men from communities that do not practice FGM/C and health professionals.[2,5] This is not surprising because education regarding female and male sexual anatomy, embryology, physiological and non-physiological diversity, physiology, sexual pleasure, and the sexual response does not occur or is not comprehensive in school, during sex education classes or in medical curricula.[15] In addition, female sexual organs have been poorly studied for various sociocultural and historical reasons. A PubMed search for the words "clitoris" and "penis" in May 2020 yielded 2,386 and 49,846 publications, respectively. This gap could be also explained, in part, by the fact the penis has sexual, reproductive, and excretory functions, whereas the only known function of the clitoris is related to sexual pleasure.[5]

The general public and health professionals are often ignorant of the precise anatomy and physiology of the clitoris.[5,16] This is one of the reasons why 3-dimensional (3D)—printed models[17,18] or sculptures[19] of the clitoris have become available online. The independent French researcher Odile Fillod first printed a model in March 2016 and printed a second, more anatomically correct, model in December 2016, which was based on published measurements derived from the results of in vivo imaging and cadaveric dissections (Figure 1). In our educational setting and clinical practice, we have also noticed that many students and patients are not aware of the internal anatomy of the bulb and crura of the penis.

3-dimensional—printed anatomic models have been shown to be accurate and suitable in therapeutic procedures and preoperative workup[20] and to facilitate better learning by medical students compared with other methods, with regard to overall knowledge, spatial knowledge acquisition, and long-term knowledge retention.[21] 3-dimensional models of both female and male pelvis, pelvic contents, and perineum based on in vivo or cadaver imaging or on cryosection images obtained from the Visible Human Project have been developed for teaching anatomy to medical students, health professionals, and surgeon trainees.[22−34] However, most of these models are only numerical and mainly focus on the pelvic floor.[33] In addition, the existing female pelvic models do not or only partially include the clitoris. The electronic model by Sergovich et al,[26] created using Visible Human Project cryosection data for medical and laboratory anatomy classrooms, shows the crura and bulbs of the clitoris only. The Sun Shin model shows the body of the clitoris only. Some other commercialized models that are not based on imaging include different pelvic reproductive and/or sexual

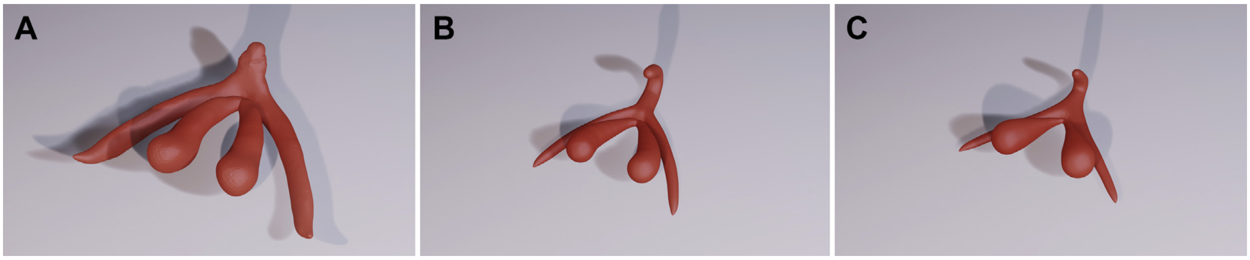

Figure 1. Rendered views of 3D models of the clitoris, available for free on the web. Model (A) was created by Amy Stenzel and models (B) and (C) by Odile Fillod. C is the most recent model. Figure 1 is available in color online at www.jsm.jsexmed.org.

structures and are used in sexual and reproductive health education.[35,36] Among these, only 1 of them includes the whole clitoris.[37]

The aim of this project was to generate a sex educational kit, composed of a female and a preliminary male 3D pelvic model and 2-dimensional (2D) anatomic diagrams, based on the results of in vivo imaging, which could be used in the education of and by health professionals, school teachers, sex educators, students, and the general population, including women who have undergone FGM/C, regarding sexual anatomy and physiology.

The development of this kit is part of a larger ongoing project called "Sciences, Sexes, Identities," started in 2017 at Bioscope (www.bioscope.ch), the public outreach laboratory in Life Sciences of the University of Geneva, in collaboration with the Equality Service of the University of Geneva and Geneva University Hospitals.[38] The project was presented to the state service responsible for sex education in schools in Geneva and the Unit for Sexual Health and Family Planning of the Geneva University Hospitals, who commissioned the future development of up-to-date evidence-based educational tools concerning sexual embryology, anatomy, and physiology, tools that are currently lacking according to the 2017 expert report on sex education in Switzerland.[39]

MATERIALS AND METHODS

Magnetic Resonance Imaging and Computed Tomography Examinations

We chose the optimal magnetic resonance imaging (MRI) protocol (an MRI protocol is a series of image acquisition sequences combined in the appropriate order and paired with a special preparation of the patient including or not administration of drugs, for obtaining optimal conditions for imaging) for the study of the clitoris by reviewing the available scientific literature[40] and by retrospectively studying images of the clitoris and surrounding organs collected during 200 pelvic MRI examinations conducted on women with suspected endometriosis. We then conducted a cross-sectional study of 30 women, who underwent a pelvic MRI, with vaginal ultrasound gel opacification, to study the anatomy of the clitoris (protocol number 12-197).[4] 15 of these women had undergone FGM/C type II (excision of the labia and clitoris) or type III (narrowing of the vaginal orifice by apposition of the labia after excision of the labia and clitoris) and 15 had not. The details of this study have been described previously.[4] The participants were 30 sexually active, non-pregnant adult women who had last delivered a baby at least 12 months earlier. None were taking androgens, estrogens, or hormone replacement therapy, and none had a history of vaginal surgery, episiotomy, vulvar conditions other than FGM/C, hysterectomy, or psychiatric disease. After the participants provided their written informed consent, a gynecologic examination was performed by a gynaecologist with expertise in the care of vulvar disease and FGM/C. An MRI was also performed, which was interpreted by a radiologist with expertise in female pelvic imaging. Participants who had or had not undergone FGM/C were matched for age and parity.

MRI examinations were performed in the supine position, using a 1.5-T MRI unit (Siemens Avanto; Siemens, Erlangen, Germany) and a dedicated surface coil. Sixty milliliters of ultrasound gel were instilled vaginally to facilitate optimal delineation of the adjacent anatomic structures at the level of the clitoris. No intravenous contrast material was administered. Of the various MRI series acquired, only transverse isotropic 3D-space Proton Density (PD) fat-saturated spectral attenuated inversion recovery was used for the 3D reconstructions (field of view 200 mm, slice thickness 1 mm, in-plane resolution 1 × 1 mm, generalized autocalibrating partial parallel acquisition factor 2, echo time 31 msec, repetition time 1,000 msec, mean 1.6, acquisition time 5.08 min). The images obtained were anonymized and sent to a dedicated workstation (OsiriX MD; Pixmeo, Bernex, Switzerland), where the radiologist evaluated the images, paying attention to the following criteria: optimum spatial resolution, image contrast, minimum noise, absence of artefacts, and optimal vaginal filling, permitting accurate organ delineation.

The highest-quality MRI images of the clitoris were selected to create a 3D reconstruction of 3 uncut and 1 cut clitoris, together with the principal surrounding pelvic organs, using dedicated software (Vitrea, Vital version 6.7.6; Canon Healthcare), which permits easy conversion to a 3D volume-rendering image in a.stl file that is compatible with a 3D printer. The same software was used to reconstruct the anatomy of the penis and the principal surrounding organs, following contrast-enhanced computer tomography (CT) examination. We conducted our study in compliance with the ethical standards. The use of anonymized MRI and CT images for the educational kit was approved by our institutional review board (Req-2017-00,987).

For the reconstruction of the preliminary male model, we used an anonymized data set of enhanced CT images of a healthy man. A whole-body CT scan was performed, with the clinical indication of suspected trauma after a motor vehicle accident. The CT examination showed no abnormalities. The examination was performed using a Somatom Force CT scanner (Siemens Healthcare, Forchheim, Germany). The acquisition parameters were DE mode, with 1 tube at 100 kVp and the other at 150 kVp (current modulation, with a reference current of 250 mAs for the 100 kVp tube), field of view 33 cm, rotation time 0.5s, pitch 0.6, and collimation 32 × 2 × 0.625 cm. The series used for the 3D models were reconstructed using Kerne bf40d, slice thickness 2 mm, and interval 1 mm. One hundred ten millilitres of iodine contrast medium (Accupaque 350) was injected at 2 mL/sec.

We did not use an MRI image of a penis at this stage because the main indication for penile MRI in our institution is the staging of cancer, which is associated with anatomic abnormalities. For the purpose of showing the cavernous and spongious structures of the penis in analogy with the clitoral ones in this present study, the anatomy could be easily studied using CT.

3-Dimensional Segmentation

The 3 highest-quality MR images of uncut clitorises, the best-quality MR image of a cut clitoris, and the CT data sets of the penis were transferred to an application for 3D organ segmentation (Vitrea V6.7.6; Canon Healthcare).

The segmentation was performed manually in a slice-by-slice fashion, using a digital tablet (Intuos 3d, Wacom), and the external skin surfaces and vaginal mucosa were automatically segmented by the software. For each organ segmentation, a 3D volume-rendering file was created. These files were then converted to.slt files for processing by the 3D printer.

3-Dimensional Printing and Assembly

The segmented organs were exported in .stl format. The files were edited in Blender (v.2.80), a free, open source 3D modeling, and rendering package, to prepare each organ as a single manifold object without artefacts. Blender was also used for Boolean operations to combine several traced objects into 1. For instance, the vaginal lumen was subtracted from the vaginal outer wall and the prostate was merged with the bladder in the male model, to reduce the number of pieces to be assembled in the kit.

After this "repairing and cleaning" step, the organs were exported again in .stl format and sliced using PrusaSlicer (v2.0.0 based on Slic3r), a free slicing software, using the following parameters: 0.20 mm layer height, a 2-layer vertical shell, 5 layers for the top horizontal shell, 4 layers for the bottom shell, 20% honeycomb infill, and support material when an overhang exceeded 45°.

PrusaSlicer-generated G-codes were used to print organs in polylactic acid, using a Prusa i3 MK2 3D printer. The extrusion temperature was set to 215°C and the bed temperature to 60°C.

We chose different PLA colors for each organ and used the same colors for the homologous tumescent male and female organs, for the bladder, rectum and pelvic bone. When the printing was completed, the support material was removed by hand. Each object was then smoothed by sanding when traces of support material remained. Once all the organs had been printed, small neodymium magnets were glued into holes drilled in the base of each organ to facilitate their assembly.

A 1:2-scale version of the kit was also printed in white PLA. This smaller and more portable kit allowed the printing of the skin, which was a too large structure to be printed at full scale. The scaling was performed in PrusaSlicer, just before printing.

Two-Dimensional Diagrams

2-dimensional sagittal and transverse female and male anatomic diagrams, with legends, were produced in collaboration with a Swiss middle-school biology teacher, a member of the team responsible for generating all the new teachers' books for French-speaking Switzerland (www.ciip.ch), and a sociologist and independent researcher,[41] who has been developing egalitarian and inclusive pedagogical tools for biology teachers in France, supported by the French education ministry (https://matilda.education/app/).

We updated the existing Swiss diagrams (Figure 2) according to the scientific literature and the present imaging data, adopting an approach and a terminology that respect equality across genders. The new diagrams were drawn in a vector format using Adobe Illustrator CC (v23.1.1).

Stylized 3D Models of the Clitoris and Penis

We used our imaging data to create an updated model of the clitoris and create a model of the penis. We modeled these structures de novo using Blender, basing the printing on our MR and CT images, as well as the published mean dimensions, which were based on both in vivo MRI and cadaveric dissections.[42] The position of the penis was modified from bent cranially (as in the CT) to caudally.

Multidisciplinary Feedback on the Kit

The Bioscope advertised locally the need of a preliminary feedback on our 3D male and female models and 2D diagrams from experts, researchers, or professionals working in the field of gynaecology, urology, sexual medicine, and education. Thirteen potential users with no personal relationship with the authors and no involvement in the project were available for a semi-structured interview. They did not receive any funding or

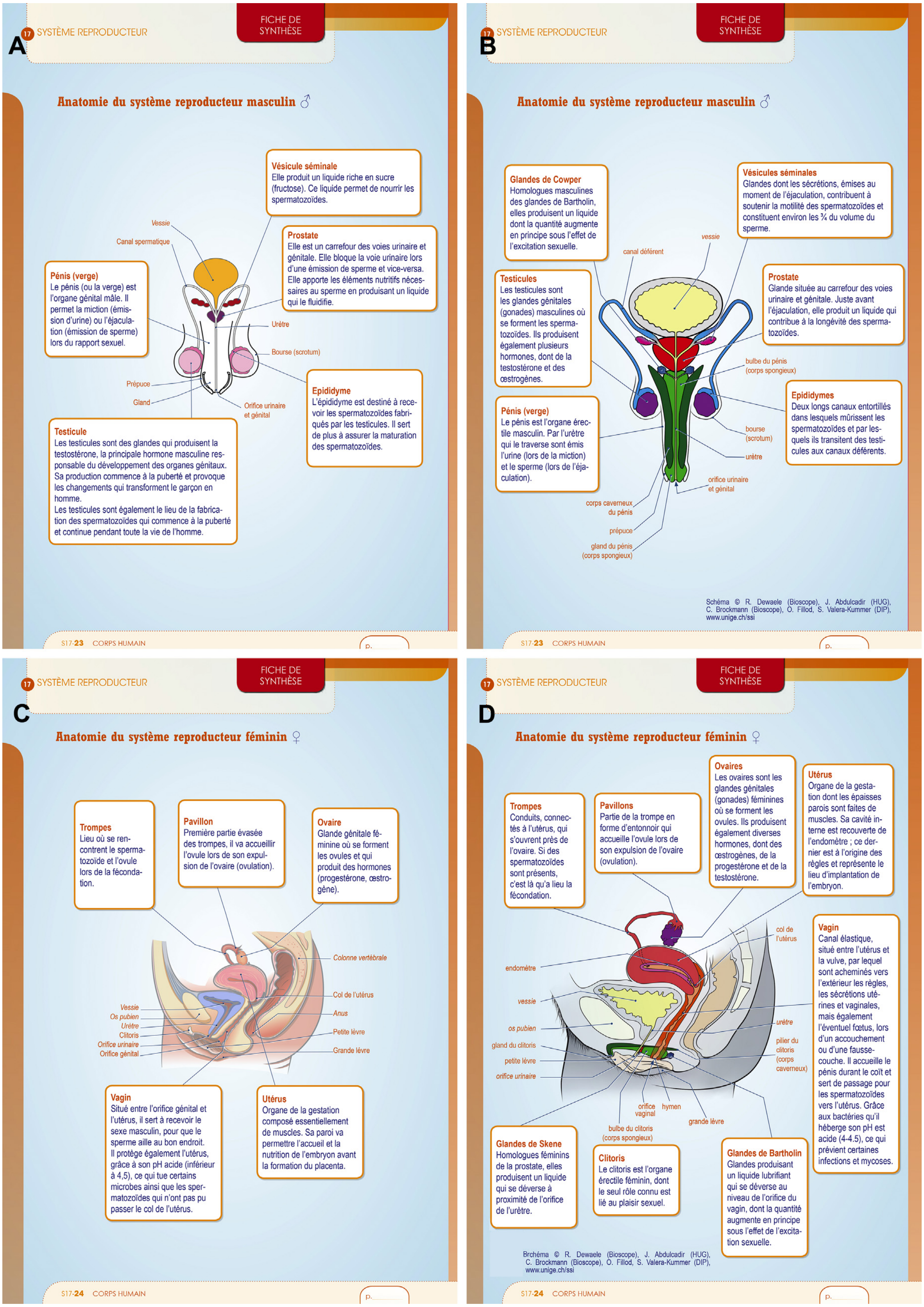

Figure 2. Older (up to 2018–19) and newer (from 2019 to 20) diagrams used in French-speaking Swiss middle schools, showing female and male sexual and reproductive anatomy. Figure 2 is available in color online at www.jsm.jsexmed.org.

compensation. They were health professionals, scholars, teachers, or experts, particularly:

1. A public high-school biology teacher;
2. A physical therapist and sexologist specializing in pelvic floor therapy, who is a member of the Swiss Society of Sexology and routinely teaches at physiotherapy and sexual medicine courses;
3. 2 gynecologists, 1 working in our gynecology division and 1 in private practice, with 1 of them specializing in FGM/C;
4. A pediatric surgeon and scholar specializing in variations of sexual developments, teaching at the University of Lausanne;
5. An anatomist and pathologist, scholar, and teacher, responsible for the anatomy medical school curriculum of the University of Geneva;
6. A team of 5 midwives and sexual counselors based in the Unit for Sexual Health and Family Planning of Geneva;
7. A sex educator, working for the state service for in-school sex education;
8. A sociologist and scholar specializing in variations of sexual developments, teaching at the University of Geneva and Lausanne.

Feedback was collected through 9 semi-structured interviews conducted by 1 of the coauthors in person: 6 were recorded and transcribed with permission and 3 were not recorded (no permission) but transcribed. The information collected included the choice of the organs represented, the need for the inclusion of other structures (eg, the muscles or the male urethra), the materials and colors, the usefulness of the kit for the user, examples of its use, the other models currently in use, and the potential added value associated with the new kit, along with any suggestions for modifications and a possible sale price.

RESULTS

We printed a 1:2- and 1:1-scale female 3D pelvic (Figures 3 and 4) and a 1:2- and 1:1-scale preliminary male 3D pelvic model (Figures 3 and 5). The pelvic models included the pelvic bone, rectum, urethra, and bladder. The female model included the vagina and the whole clitoris (glans, body, crura, and bulbs) (Figure 3A–C). The preliminary male model included the prostate, testes, and penis (corpus spongiosum and corpora cavernosa) (Figure 3D–F). The 1:2-scale models also included some components of the skin included in the MR and CT images. The prepuce was not included in such images.

The segmentation was relatively straightforward and easier to perform for the CT images because of the superior spatial resolution of this modality, compared with MRI, and also because of the use of iodine contrast medium, which facilitated the optimal delineation of structures between the numerous pelvic blood

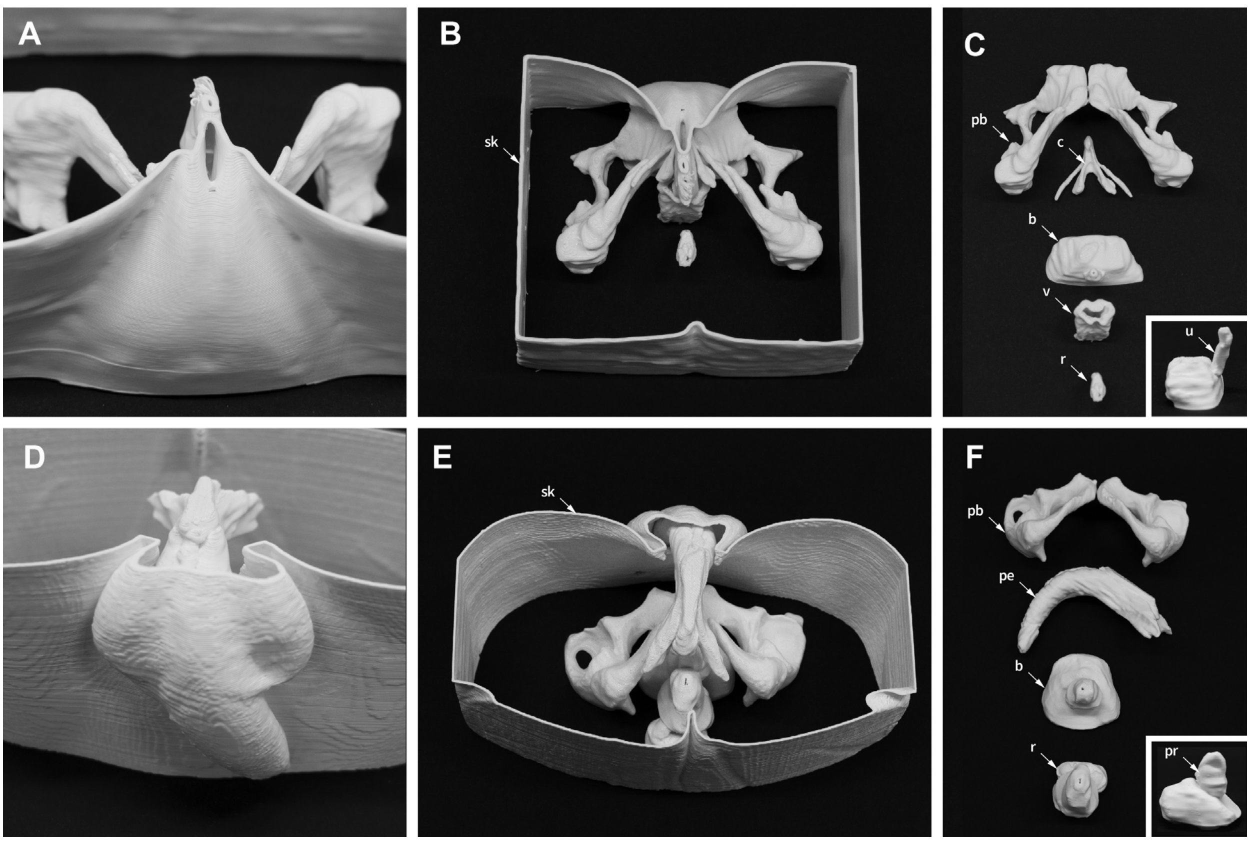

Figure 3. 3-dimensional female (A, B, C) and male (C, D, E) pelvic models, based on the results of imaging. Scale 1:2. b = bladder; c = clitoris; pb = pelvic bone; pe = penis; pr = prostate; r = rectum; sk = skin; u = urethra; v = vagina.

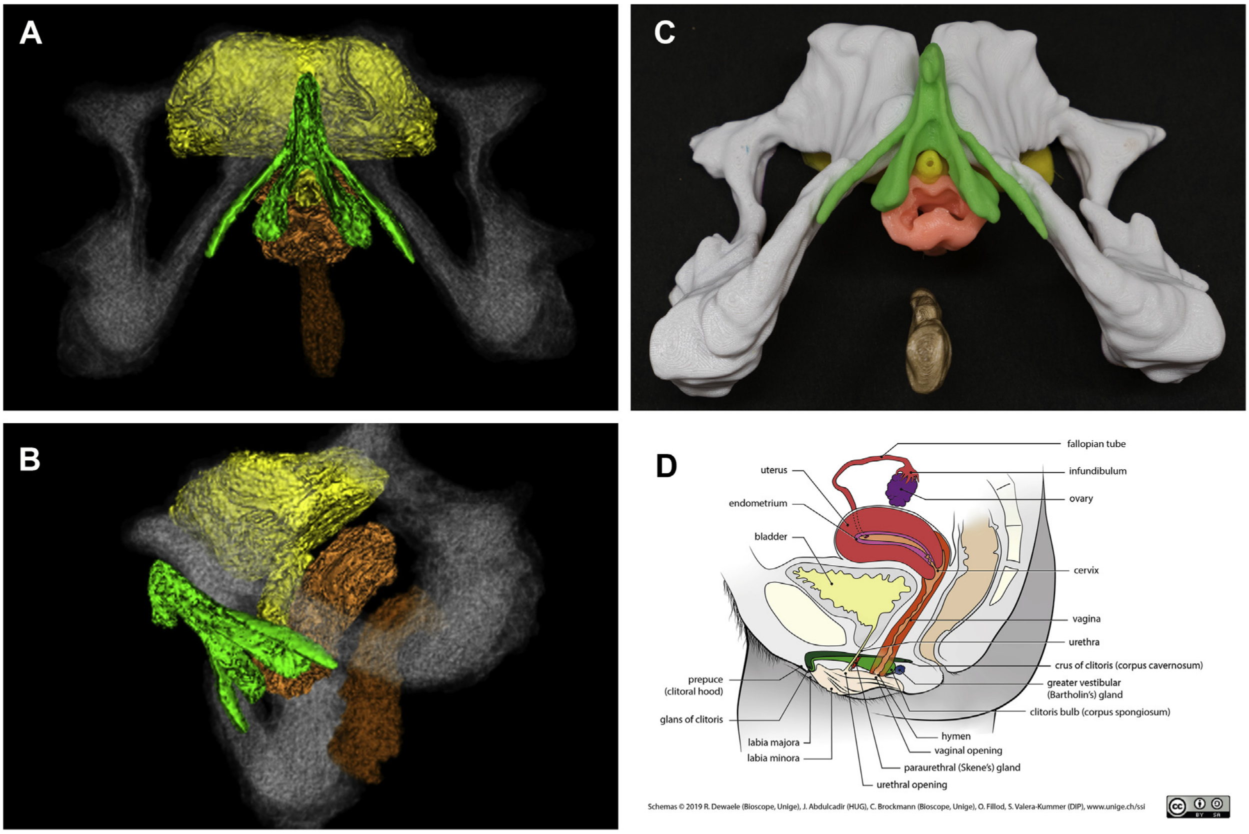

Figure 4. 3-dimensional (3D) Vitrea reconstruction of the MRI images (A and B) and 3D-printed model (C) of the female anatomy. In (A), (B) and (C), green = clitoris; orange = vagina (filled with ultrasound gel in [A] and [B]); yellow = bladder and urethra; brown = rectum; white = pelvic bone. (D) 2-dimensional diagram of the female pelvic anatomy, which includes the same organs as the 3D MRI reconstruction and 3D model, represented in the same colors, plus the uterus, fallopian tubes, and ovary. MRI = magnetic resonance imaging. Figure 4 is available in color online at www.jsm.jsexmed.org.

vessels. In addition, most of the penis is situated outside the pelvis, and the air provided an ideal interface for 3D reconstruction.

Segmentation was slightly more complex for the MRI data sets used for the female models, mainly because of the lower spatial resolution associated with MRI. The use of PD images permitted adequate delineation of the erectile organs, even without the use of a gadolinium contrast agent with the MRI.[40] Filling of the vagina with ultrasound gel permitted optimal delineation of the mucosa, and contrast in the bladder was provided by urine, which is hyperintense in PD sequences. The first phase of the procedure, lasting ~2 h, involved testing and familiarization with the reconstruction software and collaboration between 2 radiologists and a radiographer that specializes in 3D reconstructions. The reconstruction time was estimated to be approximately 8 h per pelvic model (1−2 h per organ).

Figure 4 shows the 3D Vitrea reconstruction of the MR images of the woman, including the pubic symphysis, bladder, clitoris, vagina, and rectum (Figure 4A and B), and the corresponding 3D-printed model (Figure 4C). As explained, the vagina was filled with 60 ml opacification gel to better delineate the vaginal lumen and surrounding structures of the clitoris and bulbs (Figure 4A and B). However, in the printed version, we included the vaginal wall and lumen for didactic purposes (Figure 4C). Figure 4D shows the 2D diagram of the female pelvic anatomy, which includes the same organs as the 3D MRI reconstruction and 3D model, represented in the same colors, plus the uterus, fallopian tubes, and ovary.

Figure 5 shows the 3D Vitrea reconstruction of the contrast-enhanced CT images of the male anatomy, including the pelvic bone, bladder, penis, testes, prostate, and rectum (Figure 5A and B), and the corresponding 3D-printed model (Figure 5C). The man that underwent the CT was lying in a supine position, with his penis flaccid and lying over his pubis. Figure 5D shows the 2D diagram of the male pelvic anatomy, which includes the same organs as the 3D CT reconstruction and 3D model, plus the seminal vesicles and vasa deferentia.

The 2D diagrams were included in official middle-school−teaching materials for the French-speaking part of Switzerland in March 2019 for widespread use by all public middle schools, beginning in the academic year 2019−2020. They are freely available online [43,44] and on Wikimedia commons under a CC BY-SA 4.0 license. The previous drawings have been updated to include all homologous embryological structures in both the

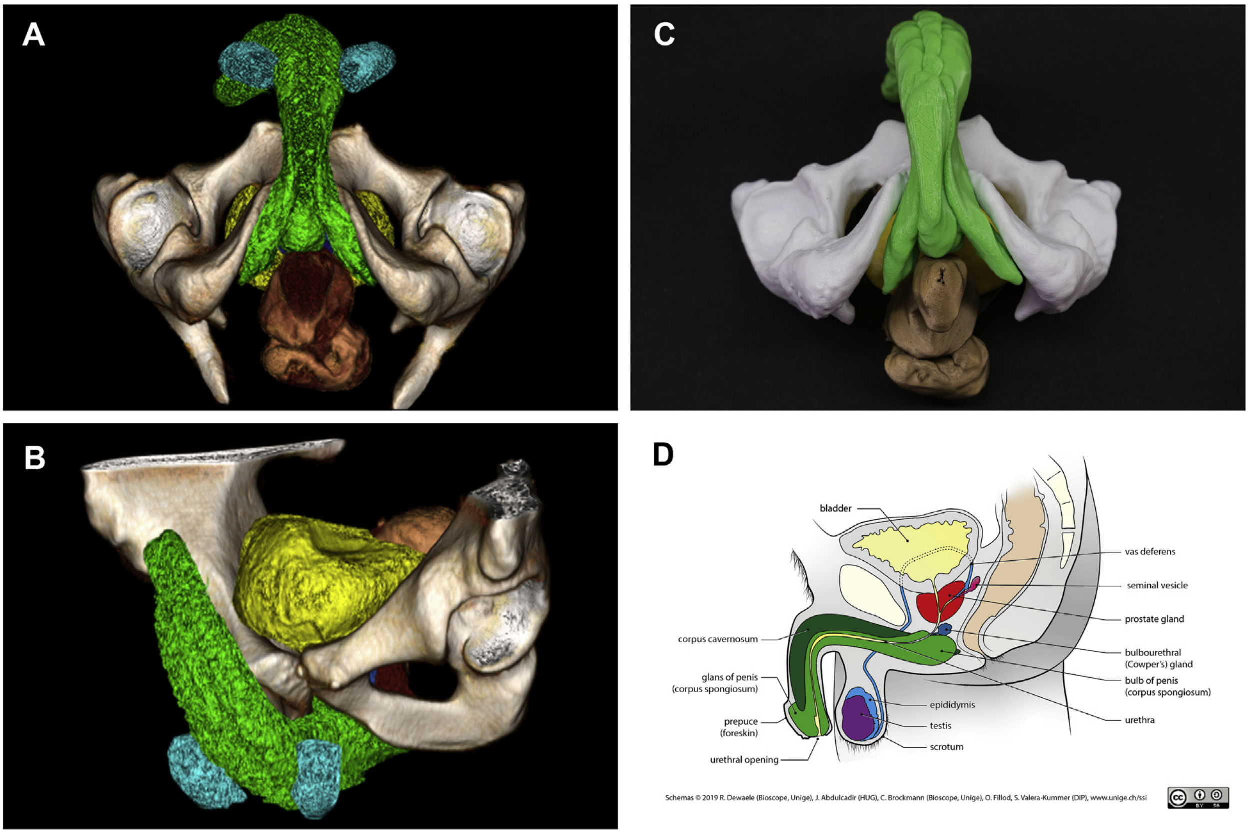

Figure 5. 3-dimensional (3D) Vitrea reconstruction of the contrast-enhanced CT images of the male anatomy. In (A), (B) and (C), green = penis; yellow = bladder and urethra; brown = rectum; white = pelvic bone; light blue = testes; red = prostate. (D) 2-dimensional diagram of the male pelvic anatomy, including the same organs as the 3D CT reconstruction and 3D model, plus the seminal vesicles and vas deferens. CT = computed tomography. Figure 5 is available in color online at www.jsm.jsexmed.org.

female and male diagrams; the relative size and position of the organs has been improved on the basis of the published literature and the present imaging data; and egalitarian language, inclusive for all sexes, genders, and orientations has been adopted for the terminology and legends. Specifically, in the female diagram, the descending body and crura of the clitoris and bulbs of the clitoris, as well as the lesser vestibular glands (Skene) and major vestibular glands (Bartholin) have been added. In the male diagram, only the bulbourethral glands (Cowper) were missing (Figure 2).

We traced and printed 3 clitorises of women who had not undergone FGM/C (Figure 6) and 1 clitoris of a woman who had undergone FGM/C, which involved cutting the clitoris (Figure 7), to show the diversity in shape and dimensions, and for women who had undergone FGM/C, that the part affected by ritual cutting is the external part of the organ: the glans or the glans and part of the body. The models in Figures 6 and 7 show the convergence of the bulbs (commissura[42]) and crura (pseudocommissura[42]) on the posterior view. On the anterior view, the proximity and relationship between the bulbs, the pars intermedia[42] and the body of the clitoris are shown.

Videos of the 3D female and male Vitrea reconstructions (Annexes 1 and 2) as well as of the scale 1:1 female and male models (Annexes 3 and 4) are available to permit visualization of the anatomy from different angles.

Finally, we printed stylized models of the penis and the clitoris (cut and uncut), based on the 3D reconstructions of the 2 organs (Figure 8). Figure 9 shows the similar anatomy of the cavernous and spongious structures of the clitoris and the penis. The differences between these new models and the clitoral models that already exist mostly concern the shapes of the bulbs and their commissura, the pseudocommissura of the crura, the pars intermedia, and its relationship with the clitoral body.

All 13 experts interviewed declared that the kit would be very useful in their clinical or educational practice and that they had never seen or used a similar tool previously. They all preferred the 1:1 instead of the smaller 1:2-scale models, which is why we did not print the latter in colors as well. One sex educator mentioned the potential use of the kit for visually impaired people. With regard to the organs included, all the experts, except the anatomist-pathologist, suggested the inclusion of all the reproductive and sexual organs (all the ducts and gonads) and the skin. The anatomist-pathologist and the paediatric surgeon suggested the addition of the sexual glands (Bartholin, Skene, Seminal, and Cowper). The surgeon also suggested representing the embryological remnants of the Müllerian/

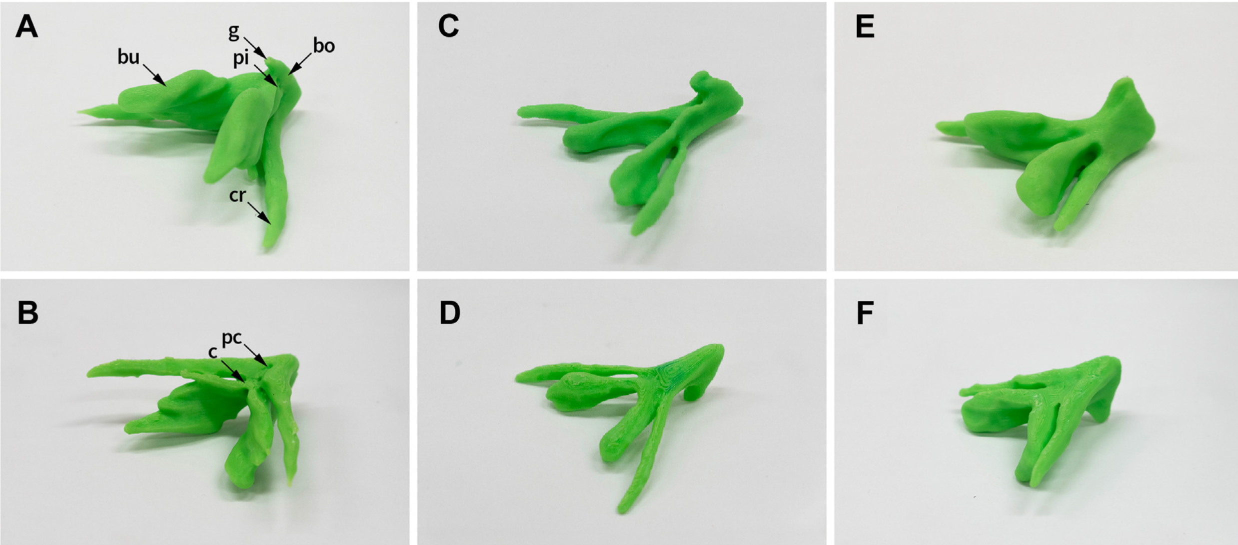

Figure 6. 3-dimensional-printed models of the clitoris of 3 women who had not undergone FGM/C. Anterior (A,C,E) and posterior (B,D,F) views of each clitoris. bu = bulbs; bo = body; c = bulb commissura; cr = crura; FGM/C = female genital mutilation/cutting; g = glans; pi = pars intermedia; pc = crura pseudocommissura. Figure 6 is available in color online at www.jsm.jsexmed.org.

Wolffian ducts (eg, Gartner's duct, the paradidymis and the vas aberrans of Haller). All agreed that a more elastic (silicone-like) material would add great value for the representation of the soft tissues, especially the vagina. The color similarity between spongious and cavernous tissues of common embryological origin and its correspondence with the 2D diagrams were thought to be very useful by all the experts. One sex educator mentioned that she would have preferred the bladder/urethra and rectum to be in a different color to that of urine and faeces, respectively. All suggested that the prostate should be represented with a different color to the bladder/urethra in the printed model. In addition, all the teachers and clinicians greatly appreciated the ability to assemble and disassemble the kit, and suggested that it should be made robust enough to withstand frequent use. One teacher was willing to participate in the development of a stand-alone didactic sequence using the 3D models and diagrams for use by high-school biology teachers. All agreed that if they could buy such a tool, they would, and would pay between 100 and 200 Swiss francs (110−220 USD) for 1 model (female or male).

DISCUSSION

We have described a new educational kit, composed of 3D pelvic models and 3D and 2D figures of female and male sexual anatomy that were created on the basis of in vivo imaging data. These models and figures could be used and studied in education regarding sexual anatomy and physiology by health professionals, teachers, academic educators, and sex educators to use with students, clients, patients, and the general population, including women who have undergone FGM/C. It will be interesting to assess if our tools can significantly improve knowledge of female and male sexual anatomy and physiology, including pleasure, in the context of schools, sex education programs, medical schools, clinical practice, and psychosexual therapy.

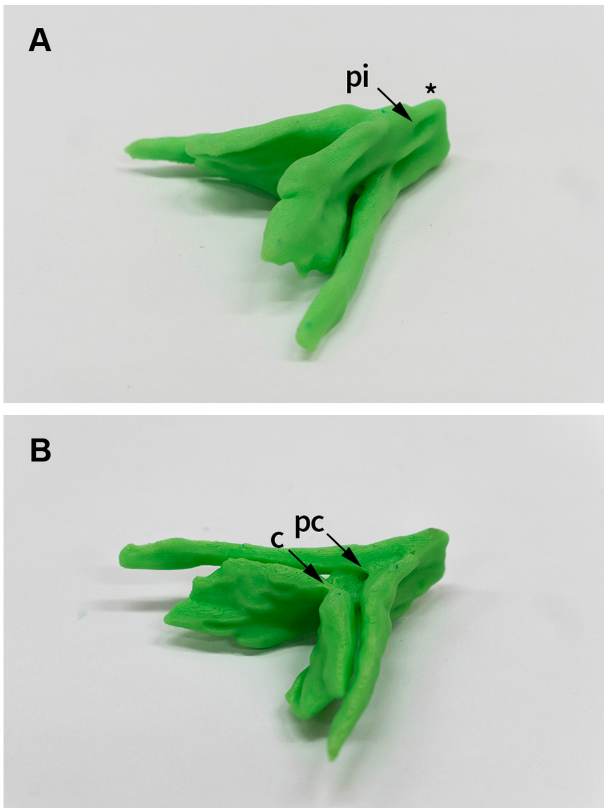

Figure 7. 3-dimensional−printed model of the clitoris of a woman who had undergone FGM/C. (A) Frontal view. (B) Posterior view. c = bulb commissura; FGM/C = female genital mutilation/cutting; pi = pars intermedia; pc = crura pseudocommissura. The asterisk shows the location of the genital cutting. Figure 7 is available in color online at www.jsm.jsexmed.org.

Figure 8. Stylized 3D models of the clitoris, (A) Uncut; (B) cut, and (C) the penis. 3D = 3-dimensional. Figure 8 is available in color online at www.jsm.jsexmed.org.

A comprehensive positive sex education should include information in multiple domains, including anatomy, consent, staying safe, sexual rights, relationship, emotions, violence, gender, orientation, reproductive health, culture, and sexual scripts, but also more positive aspects, such as sexual practices, pleasure, and its benefits.[15] The latter are often lacking in sex education programs. In a recent Swiss study of 7,142 students aged 24–26 years, pleasure and sexual practices were the first topics to be reported as missing from sex education classes by female and the second topics by male respondents.[45] Scientific information regarding the body, its development, and physiological aspects of sexuality and pleasure are crucial,[15,46] but most teaching models and diagrams do not, or only partially, address these aspects, as also reported by the users we interviewed. Sex education is also one of the very first interventions during psychosexual therapy in instances of sexual dysfunction in men and women.[47] Our models could be used to learn, name correctly, and touch the component organs, and to discuss their physiology and pathology. The female 3D model could facilitate understanding of the physiology of provoking or experiencing female pleasure by digital or coital, vaginal or external, stimulation. The model can also clarify the anatomy of the area that some controversially refer to as the "G-spot," which in reality, corresponds to the area of the pars intermedia, pseudocommissura, and commissura (Figure 6).[48]

One sex educator suggested that people with visual impairment could greatly benefit from touching and learning about the internal anatomy of the clitoris and penis and their relationships with surrounding structures.

Our kit could also be used and studied in the context of the care of women who have undergone FGM/C and its prevention. As discussed in the introduction, several sociocultural myths and misconceptions exist with regard to FGMC/C, the female genitals, the clitoris, and female sexual function in practicing and non-practicing communities.[2,12,16,49] The existence of some of these beliefs partly explains the persistence of genital cutting and the stigmatization of both uncut women, often considered promiscuous, and cut women, often and increasingly considered sexually deprived because they lack a complete clitoris.[2,50] Our in vivo imaging–based models can be used (i) to explain how the clitoris and penis have a similar anatomy (Figure 9) because of a shared embryological origin; (ii) that the clitoris and the penis share a common physiology; and (iii) through the comparison between the cut and uncut model, that the clitoris does not enlarge if uncut. It can also been explained that FGM/C does not remove the organ, thereby making a girl less "hypersexual." Therefore, our models could be studied in educational activities for prevention of the practice in future generations. The models could also facilitate better understanding of how the clitoris can be stimulated by the woman herself or her partner after FGM/C. Research conducted on women who requested clitoral reconstruction in France and Burkina Faso has shown that FGM/C-affected women do not have appropriate knowledge of female sexual anatomy and physiology and imagine that the surgery creates a new and larger organ, instead of reexposing the clitoral body under the scar.[2,12,51–54] After sexual counseling and health education, women become aware of unscientific beliefs and their

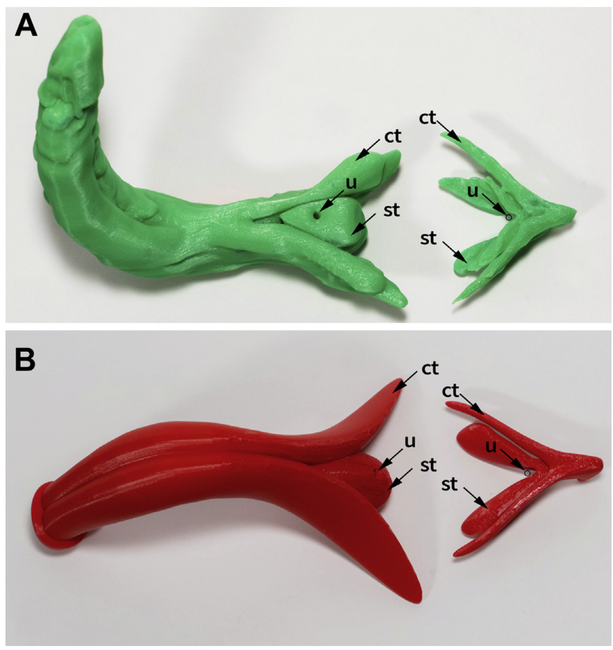

Figure 9. 3-dimensional (3D) and stylized 3D models of the clitoris and penis. ct = cavernous tissue; st = spongious tissue; u = urethra. Figure 9 is available in color online at www.jsm.jsexmed.org.

body and physiology, and they often do not opt to undergo surgery, once they realize they still have a functional clitoris.[2,54] The kit we present in this article could be assessed as an integral part of the preoperative discussion with patients requesting clitoral reconstruction.

Other potential fields of study and development of our kit could be in addressing the diversity of genital/sexual anatomy in individuals with variations in sex development and/or their parents and in explaining how transgender reassignment surgeries are performed on the basis of embryological homologies and how the anatomy and physiology of the sexual organs can change when they are exposed to hormonal therapy.

The strengths of the present study and tools are that the models were based on in vivo imaging, which has permitted the creation of new representations of some structures of the clitoris, such as the relative position of the commissura of the bulbs, the pseudo-ommissura of the crura, and the pars intermedia. The models also clarify the relationship between the clitoris and the other structures of the pelvis. The models of clitorises of 4 different women permit the representation of morphologic diversity in a new way, including that of women who have undergone FGM/C. The comparison of the 3D clitoris with the preliminary model of the 3D penis allows to see how the 2 organs share a similar structure because of the common embryological origin (Figure 9). We think that this information might contribute to an egalitarian and inclusive message regarding female, male and intersex sexual anatomy, physiology, and particularly sexual pleasure.

Another positive aspect of the study was the collection of feedback from clinicians and other experts who work in the fields of sex education, biology, gross anatomy, histology, medical teaching, intersex, FGM/C, sex therapy, school education, and physiotherapy. All mentioned that their existing models lack some details of female anatomy or are relatively inadequate for the discussion of female and male sexual pleasure. The only 3D model on the market that has a whole clitoris, is not based on in vivo imaging, cannot be disassembled, measures 26 × 49 × 23 cm, and costs 700 Euros.[37]

The main limitation of the present work is the preliminary nature of the male 3D model, which was based on a CT and not on an MRI similar to the female one, does not include key structures such as the urethra, which is not visible on the CT and presents the penis lying on the abdomen. Other limitations include the fact that the models were based on imaging alone, without associated anatomic dissections. They also represent the sexual organs at rest or in an unknown state of arousal. We only printed 1 penis; it may be useful to provide a range of examples, as we did for the clitoris, to demonstrate diversity in shape and size. Furthermore, we were unable to precisely visualize and trace the spongious tissue around the female urethra on the MRI scans.[5,42]

Because of this, we are in the process of working on a second generation of male and female models. The male 3D model will be based on an MRI and will include additional structures such as reproductive organs and glands, including the testes and vasa deferentia. In accordance with the feedbacks received, the prostate will not be merged with the bladder and the penis will not be lying on the abdomen. The urethra will be traced and included in the printed model. The female model will include reproductive organs and glands. Gross anatomy and histological data on the glans, pars intermedia, so called infracorporeal spongy part[42] and corpus spongiosum of the urethra could inform structures that are not visible and traceable at MRI. The PLA material used for the 3D prototypes presented in this article could be improved by using a more elastic and user-friendly material such as multitexture 3D impressions. Finally, future models could include flexible skin, prepuce, inner and outer labia, and scrotum components of better quality. Future steps will also be the integration of the user interview data and the testing of such models in educational and therapeutic contexts, in different populations.

As a final note, it is important to underline that the models and figures presented in this article are not a comprehensive representation of the anatomy and the huge diversity of the sexual organs but are an educational model based on in vivo imaging. Such a message should be passed on as a caveat when using and studying these tools.

CONCLUSIONS

The 3D sex-education anatomic kit on female and male sexual anatomy, created on the basis of in vivo imaging data, can be used and studied in learning about female and male sexual anatomy among health professionals, sex educators, teachers, students, and the general public during psychosexual therapy and for presurgical information for a number of groups of clients.

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SUPPLEMENTARY MATERIAL

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