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Cadaver-based 3D pelvic models in anatomy education : assessment among medical and osteopathy students

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Abstract

Background: 3D visualisation techniques and printing are effective in teaching anatomy to students, patients, professionals and the general public. In 2020 we created 3D printed *in vivo* imaging-based prototypes of male and female pelvic and genital organs (V1) to teach reproductive and sexual anatomy and collected feedbacks from potential users.

Aim: To produce and test version 2 of our 3D male and female models of the pelvic and genital organs (V2) with pre-graduate medical and osteopathy students.

Methods: Feedback from the initial V1 3D printed prototypes of male and female pelvic and genital organs informed the development of a second version (V2) based on cadaveric anatomical data traced from Wu et al. Organs were selected for 3D printing, and missing structures were either imported or traced from cadaveric data by our radiology team. The V2 models were subsequently tested with second-year medical students from the University of Geneva and third-year osteopathy students from the *Haute Ecole de Santé* of Fribourg.

Results: Our improved 3D V2 models include new reproductive organs and various sexual glands (such as greater vestibular glands and seminal vesicles) with their ducts; allow for assembly and disassembly; and like V1, present female/male embryologic analogous organs in the same color. Testing with medical and osteopathy students revealed that 90.4% of medical students and 100% of osteopathy students found the kits useful for identifying organs and their anatomical relationships. The 3D anatomy kits were also found useful for identifying embryological analogies between male and female organs and for complementing traditional teaching methods.

Conclusion: The new cadaver-based female and male 3D pelvic models are a faithful, egalitarian and inclusive representation of female and male reproductive and sexual pelvic anatomy that is found useful by the majority of medicine and osteopathy students.

1. Introduction

Anatomy is a central discipline in medicine, and particularly in surgery. Its study started with public dissections at the beginning of the 14th century (1,2) and knowledge of anatomy was disseminated throughout the world, mainly by books, "papier mâchés" models or waxes (3). Nowadays, it is possible to represent and visualize organs and their neurovascular supply extremely precisely and non-invasively thanks to contemporary imaging techniques, such as MRI and CT scans, and 3D softwares and printing (4,5).

Imaging techniques are highly effective for teaching the anatomy of complex and less accessible areas like the pelvis. Incorporating radiological images from CT scans, X-rays, and MRIs into the anatomy curriculum can significantly enhance medical students' comprehension of pelvic anatomy: students exposed to such imaging modalities scored 21% higher on direct questions about pelvic physiology and anatomy compared to others who lacked such supplementary resources (6). 3D online interactive softwares can enrich the anatomy learning experience as they allow to rotating, tilting, zooming in or out, and viewing individual subsets separately (7,8). The integration of 3D technology, in association with traditional methods of teaching anatomy such as textbooks and imaging help students in retaining information through three-dimensional visualisation of anatomical structures (9) and improve how they apply anatomical knowledge into a clinical context (10).

Physical or computer-assisted 3D imaging also improves management, planning, precision and operating time of surgical procedures (11,12) and the way professionals learn about the anatomy of certain complex pathologies where anatomical representation is sometimes complicated and more traditional teaching resources (cadaveric specimens) are limited (13–15). With its immersive capabilities, 3D technology also enhances patient's clinical or surgical experiences particularly in understanding the surgery they are undergoing and awareness of post-operative complications (16,17). 3D models also seem to significantly reduce patients' anxiety before an operation and thus increase their level of satisfaction compared to being educated with 2D diagrams and drawings (18,19). In summary, 3D models appear to surpass traditional methods in various contexts, including therapeutic patient education, medical anatomy education, and surgical procedure planning (20–22).

Despite precise 3D measurement and representation techniques, certain organs such as the vulva and the clitoris remain less investigated (23,24). Adrikopoulou in 2013 reviewed 59 anatomy textbooks and gynecological anatomy textbooks: no anatomy book gave measurements of inner and outer labia and only 3 gynecological anatomy texbooks measured these structures (25). When it comes to the clitoris, there are many knowledge gaps about its anatomy and function and its relationship with adjacent organs such as the urethra and the vagina (26,27). In addition to anatomy, the physiology of the clitoris is also less studied: clitoral engorgement, pleasure and pain remain little investigated (24). When it comes to the female pleasure and orgasm, for example, the lack of research and knowledge, has led to long-debated misconceptions, such as the existence and function of the so-called "G-spot" (28). A recent review of 31 studies comprising imaging, surveys, clinical, neurophysiological, histological and anatomical studies, showed that the authors of these various studies disagree on whether or not the "G-spot" exists (29). The same applies to the question of whether there is a differentiation between vaginal and clitoral orgasm (27,30).

Lacking scientific data and education on female anatomy can lead to knowledge gaps in health professionals and poor health literacy among patients. In Ireland, a recent survey to 50 health professionals of a 9000 delivery maternity (consultants and non-consultant hospital doctors, midwives, midwifery and medical students) show that none of them could name all 5 parts of the clitoris and 38 could not name a single part (31). In a Women's Clinic 269 women were inquired about their own genital anatomy and physiology (32): only 57.2% knew the location of the clitoris and 51.7% its function. There is a need to better educate health professionals and patients about female genital anatomy and physiology.

Knowledge gaps about sexual anatomy and the sexual response do not spare medical faculties and students, as teaching covering these subjects is inadequate due to several reasons, including that the subject is taboo and socially sensitive, and that biomedical sciences take precedence over sex education in the huge mass of subjects to be taught (33). These gaps seem to have an impact on medical students, who therefore do not feel confident in responding to patients' concerns about sexual health because of a lack of knowledge or fear of offending the patient (34,35). On the contrary, patients would like to receive information about sexuality from health professionals who would initiate the conversation themselves, who are aware of sexual concerns and who are comfortable talking about them (36). An American study of 500 young adults showed that 85% of those questioned would talk to their doctor if they had a sexual problem even if they were not receiving any treatment, although 71% thought that their doctor would not respond to their sexual concern (37). A Swiss study carried out in Lausanne showed that 90% of patients would like their doctor to ask them questions about their sexuality in order to receive advice, but only 40.5% of patients said they had ever had a discussion about "their sex life in general" with their doctor (38).

Social changes around gender and sexuality, including the increased visibility of LGBTIQA+ people, highlight the lack of egalitarian and diversity-inclusive content university curricula, particularly around genital anatomy and physiology (2). Genital diversity includes addressing the difference between a person's assigned sex at birth and their gender identity, as well as all practices of genital modifications, whether consented or not (e.g. female genital mutilation/cutting (MGF/C), penile circumcision, intersex surgeries, sex-reassignment surgeries for transgender and gender diverse individuals and cosmetic and/or reconstructive surgeries).

In 2020 we produced a first female and male 3D pelvic model based on *in vivo* imaging, respectively MRI and CT scan (Model version V1) to improve education about the anatomy of sexual and reproductive organs (39). Our aim was to create equalitarian and inclusive 3D models for teaching reproductive and sexual organs for sex educational and clinical contexts. For example, the analogous erectile/tumescent structures of the clitoris and penis were printed in the same color to highlight their shared embryological origin and to underline their common anatomical and physiological features. These prototypic models where tested by 13 education and health professionals. All judged the models to be very useful in their clinical or educational practice (39). Their feedback was collected to define the specific characteristics of the V2 model, which was advised to include all reproductive organs, ducts and glands.

The aims of our present study are to:

1- Present the development of a V2 female and male 3D pelvic prototypes based on the feedback collected from 13 education and health professionals exposed to our V1 models, using available anatomical cadaveric data of the selected reproductive/sexual pelvic organs.
2- Pilot our new V2 3D female and male pelvis models in the anatomy practicals of Geneva University School of medicine and in the osteopathy program of the *Haute école de santé* of Fribourg.
3- Collect 2nd year medical and 3rd year osteopathy students' perceived usefulness and satisfaction on the use of the V2 pelvic models in their curricula.

2. Materials and Methods

2.1 - Development of 3D V2 male and female 3D pelvic models

In-vivo-based 3D female and male pelvic model prototypes (named thereafter models V1, shown in Figure 1) were generated by our team and evaluated by medical and education specialists (39). Their pedagogic and technical feedback (Table 1) collected in our previous study informed the development of the new female and male pelvic 3D prototypes (named thereafter models V2) we present in this manuscript.

Figure 1: Version 1 of female (right) and male (left) 3D pelvic model assembled.

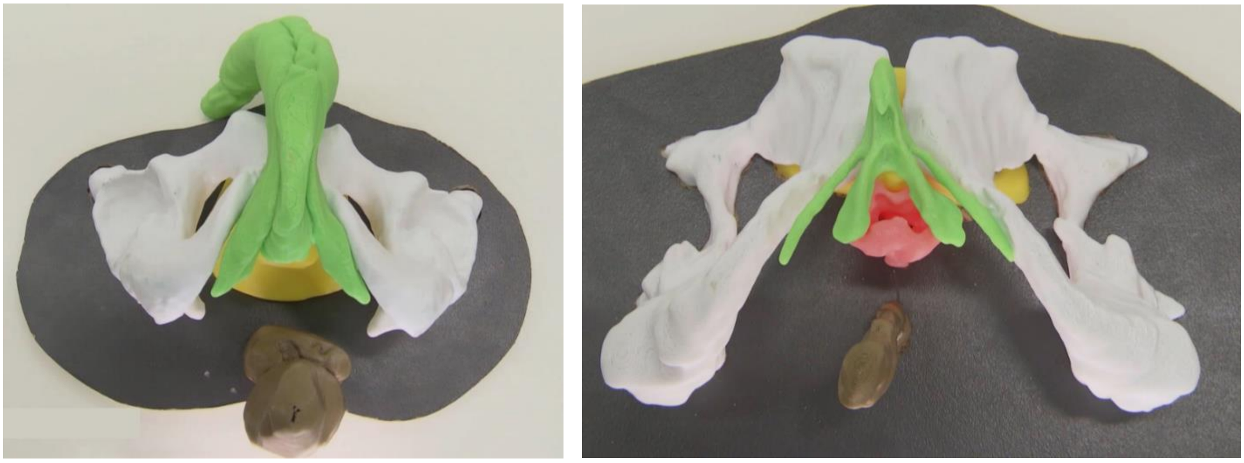

Table 1: Suggestions integrated in the V2 3D kit based on feedbacks collected with V1.

Beta-tester(s) of the V1 prototype	Comments on V1 prototype and/or suggestions for V2	Suggestion integrated in the V2 prototype
All professionals	Very useful in clinical or educational practice	N/A
	Keep 1:1 size	Done
	Use elastic (silicone-like) material for the soft tissues, especially the vagina and rectum	To be used in version 3 (V3) for costs reasons
	Use same color for spongious and cavernous tissues of common embryological origin	Done
	Prostate should be represented with a different color than the bladder/urethra	Done
	Keep the possibility to assemble and disassemble the kit	Done
All except anatomist	Include all the reproductive and sexual organs (ducts and gonads)	Done
	Include the skin	Not done

Anatomist- pathologist and Pediatric surgeon	Include urogenital triangle and the sexual glands (Bartholin and Seminal glands).	Done
	Include Skene and Cowper glands	Not done
Pediatric surgeon	Include the embryological remnants of the Müllerian/Wolffian ducts (eg, Gartner's duct, the paradidymis and the vas aberrans of Haller).	Not done
One sex educator	Bladder/urethra and rectum should be in a different color to that of urine and feces.	Not done

If V1 were based on our own (39,40) *in vivo* imaging, V2 were based on cadaveric anatomical data from Wu et al. (41). The latter publication reports on the development of an interactive multi-layered pdf document of 3D female and male pelvic floor models for anatomy education, using anatomical data from the Chinese human visible body project (CVH/CVH5) of female and male cadavers. Our 3D printed V2 prototypes are based on modified data from Wu et al., with permission from the authors.

The 3D pelvic data from Wu et al. was imported into Blender software (https://www.blender.org). The organs of interest were selected for further processing and 3D printing. They included for both sexes: pelvic bones, erectile structures (corpus cavernosum and spongiosum of clitoris and penis), bladder and urethra. In addition, ovaries, uterine tubes, uterus, cervix, vagina and greater vestibular glands (Bartholin) were imported for the female model, as well as testicles, vas deferens, seminal glands, prostate and bulbourethral glands (Cowper) for the male model. The bulbourethral glands in the male looked perfectly round and symmetrical; this triggered doubts in our team on the anatomical accuracy of the available 3D tracing by Wu et al; they were thus excluded from the data for 3D printing. Minor vestibular glands (Skene) were also excluded from the 3D printing data because they were too small to be represented. Comments proposing to add Gartner's duct, the paradidymis, the vas aberrans of Haller or to represent the bladder and rectum with different color to that of urine and feces were not retained for the V2 version because they were proposed by only one person each time. The skin was not added on this version for practical and technical reasons.

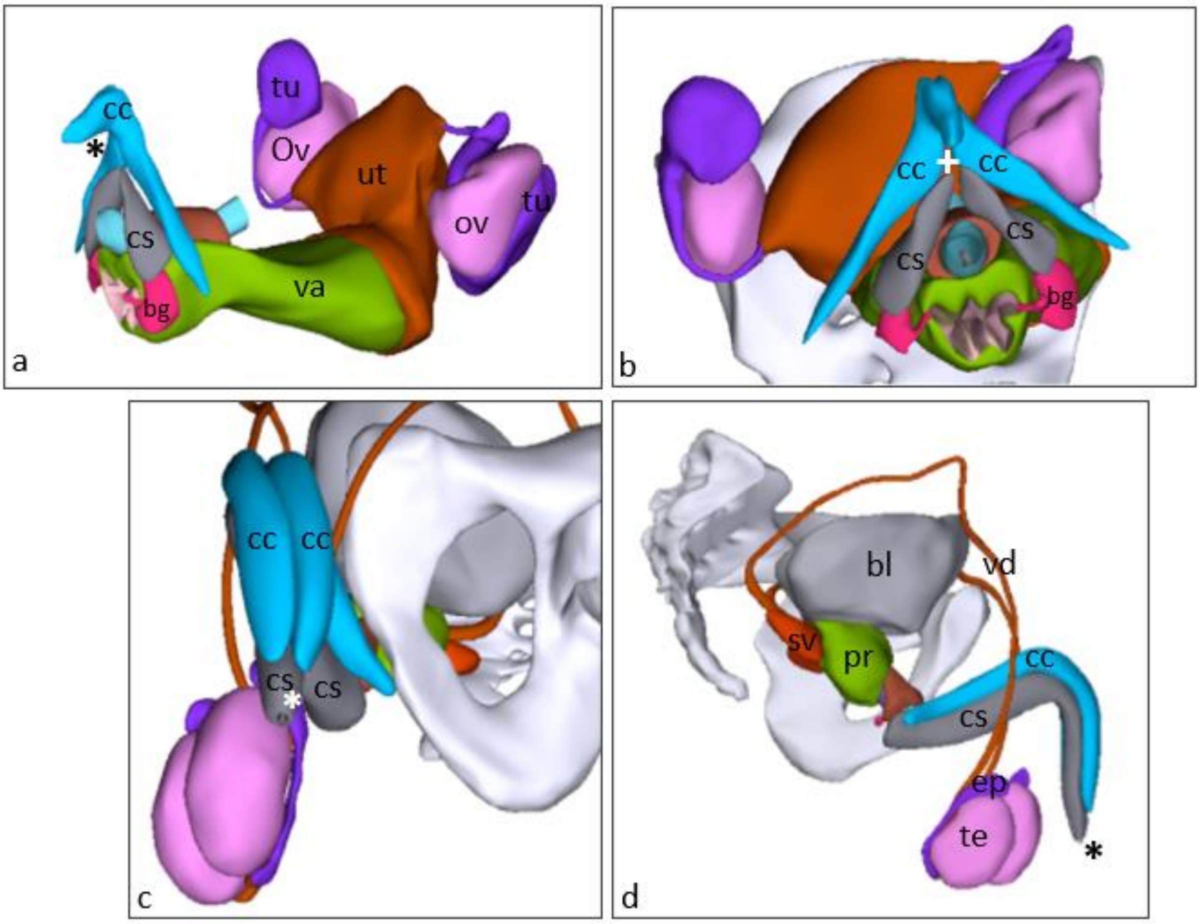

Figure 2: Selected organs for 3D printing from the 3D data of the digital female (a,b) and male (c,d) pelvic models developed by Wu *et al.* : vagina (va), uterus (ut), ovaries (ov), corpus cavernosum (cc) and spongiosum (cs) of the clitoris, fallopian tubes (tu), bladder (bl), epididymis (ep), prostate (pr) , seminal vesicle (sv), vas deferens (vd) and Bartholin's glands (bg). Note there were missing parts of the organs from the data of Wu *et al.*:the *pars intermedia* of the clitoris connecting the descending body and the bulbar commissure (a, *) and the medium septum of the corpus cavernosum of the clitoris (b,+) , as well as the glans of the penis (d, *).

The glans penis, the *pars intermedia* of the clitoris, the bulbar commissure and medium septum of the corpus cavernosum, were not included in the digital model of Wu *et al.* Additional data from the CVHB dataset was thus traced and imported into Amira softwareTM (ThermoFisher Scientific) in order to make new 3D objects from missing parts of organs (Figure 2 and 3). The complete penis and clitoris were then imported from Amira to Blender for further processing and 3D printing.

The *pars intermedia* of the clitoris has been neglected in 3D models and 2D representation. The fine anatomical structure and putative function for the coordinated neuro-vascular response of the female erectile/tumescent organ was described in detailed by Kobelt in 1851 (42) (Figure 3, a). The *pars intermedia* and its connection to the bulbar commissure was thus traced by a radiology technician (JR) from the original cadaveric images of the CVHB, with input of an interdisciplinary scientific team with expertise in clitoral anatomy: a gynaecological radiologist, a gynaecologist surgeon with expertise in clitoral reconstruction after female genital mutilation and two biologists. In the clitoris traced by Wu *et al* an empty space can be observed between the 2 adjacent corpora cavernosa (Fig 3b, +). This space is where resides the well-described thick collagenous medium septum, which was clearly visible on the original CVHB dataset (Figure 3c, +), and thus traced by our team to complete the 3D clitoris structure.

Similar additional tracing was done for the penis and data were included in the final 3D model. The original CVHB dataset and the 3D models from Wu *et al.* were thus submitted to a surgeon urologist in order to increase accuracy of our tracing of the missing parts of the organ in Wu *et al.*'s male pelvic model: the glans penis, the smooth muscle sphincter of the urethra (the connection between the bladder and the prostate) as well as the seminal vesicle. In addition, a thick empty space between the penis corpus cavernosum and the penile skin was observed on Wu's models and was judged too large as per common anatomical knowledge to correspond to a real anatomical structure, but rather an artefact or a consequence of *post-mortem* modification. The 3D model of the penis (CC and CS) was slightly increased in width in Blender, so as to fit in its skin. Once the whole organs and their missing parts were integrated into Blender, each organ could be printed individually.

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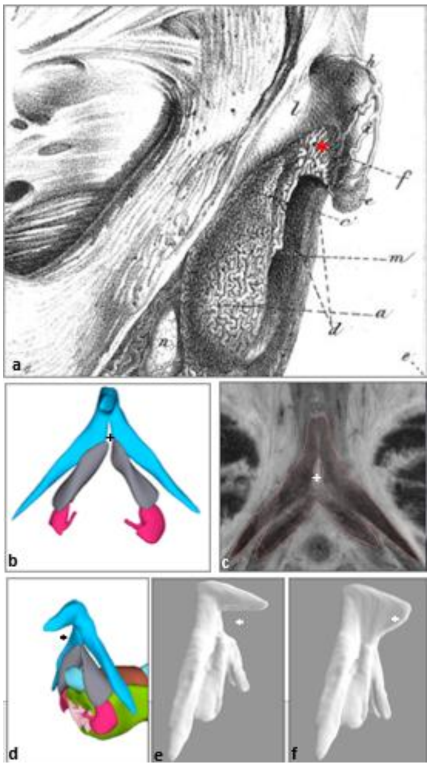

Figure 3: Tracing of the *pars intermedia* and medium septum of the clitoris from original CVHB dataset for production of a complete 3D clitoris. a. Illustration of the clitoris and its *pars intermedia* (*), Kobelt, 1851. b. Clitoris as traced by Wu *and al* . note lacking medium septum (+). c. CVHB photograph with visible collagenous medium septum (white, +). d. Clitoris as traced by Wu *et al* . note lacking *pars intermedia* (*). e.f. Clitoris 3D object in Amira before and after adding traced *pars intermedia* from the CVHB data.

2.2 - Piloting of the 3D models in medicine and osteopathy anatomy courses

We assessed the 3D V2 models with students from two different disciplines: medicine and osteopathy. The V2 models were first introduced in the reproductive/sexual system anatomy practicals in the second Bachelor year of medicine at the University of Geneva, along with a variety of 3D silicone moulded models of female and male external genitalia. The V2 models alone, were tested by third-year Bachelor students in osteopathy at Fribourg *Haute école de santé*.

2.2.1 - Evaluation of the 3D V2 models by medical students

2.2.1.a - Introduction of new learning objectives and 3D models in anatomy practicals

Geneva's anatomy practicals are organised as follows: students are divided into twenty-eight groups of five to six students with an “anatomy monitor” who is a 3rd or 6th year medical student, who was previously trained by the teachers of the reproduction and anatomy unit. Every group of students attend four successive 20 minute stations, during two 2-hour sessions, on separate days. Each station contains different anatomical modalities: cadaveric prosections, 3D models and various anatomical images such as 2D anatomical charts, medical imaging, etc presented on a wall computer screen. The monitors present each station in an interactive way to their assigned student groups and invite them to actively participate in the learning process. Each station is duplicated to accommodate more students per session.

Two new stations were added on 21-22.11.2022 (Figure 4 and Table 2) to the reproductive/sexual anatomy practicals, along with their associated new learning objectives. One on diversity of external genital anatomy, including silicone external genital molds (station 1) and one on 3D reproductive/sexual anatomy (station2) including the 3D printed V2 models. 177 second year medical students (human and dental medicine) of the University of Geneva were exposed to the two new stations.

Station 1 labelled "Anatomy and Diversity" included 18 models from Sex-Ed+ (https://positivesexed.org/boutique/) of diverse external genitalia (diverse vulvas, including with female genital mutilation/cutting, diverse penis/scrotum with or without circumcision; genitalia from transgender or gender diverse individuals with sex-reassignment surgery, and/or hormone treatment)

Station 2 called "Anatomy and Sexual Response" included the 3D V2 male and female pelvic models that are the object of the present study. This stations also included 3D *in vivo* imaging-based models of penises and clitorises of the V1 (39). In this station, the students were invited to assemble, disassemble the 3D V2 models, compare embryologically analogous organs and describe succinctly physiological events involved in the peripheral genital sexual response such as arousal (engorgement, erection, lubrication), and ejaculation.

Figure 4: Station 1 (left) and station 2 (right) during anatomy practicals at Geneva University.

Both stations were accompanied by a power point presentation displayed on a large neighbouring wall monitor, including visual schematics representations: 3D models, photographs, data from medical imaging (MRI, echography). Station 2, was also accompanied by a second monitor displaying a numerical 3D V2 male and female pelvic models in Sketchnote3D (a software developed at UNIGE's Faculty of Medicine: https://sn3d.unige.ch) which allows visualisation and annotation of 3D models for teaching purposes.

Table 2: Content and educational objective of the two added stations of anatomy class for medical students.

Number of the station	Models/specimens	Learning objective
Station 1: Anatomy and Diversity	**Anatomical models :** - Silicone moulds of female external genitalia (Sex-Ed+) of variable size and shape. - Silicone moulds of male externa genitalia, with/without circumcision. (Sex-Ed+) - Plastic moulds of external genitalia (Sex-Ed+) of AFAB/AMAB (Assigned female at birth/Assigned male at birth) transgender/gender diverse individuals after hormonal treatment and/or surgical sex reassignment surgery. - Silicone models of vulvas with female genital mutilation	**1. Identify the different parts of female and male external genitalia, their embryological analogies and their morphological diversity.** - Identify the different morphological features of the vulva (outer and inner labia, hood of the clitoris, descending body and glans of the clitoris, hymen, vestibule, vaginal orifice) - Identify different parts of the penis and scrotum and the morphological differences between casts (prepuce, glans, body, scrotum, penile/scrotal raphe). - Compare embryologically analogous structures in male and female genitalia (outer labia/scrotum and scrotal raphe; inner labia/inferior side of the penis and penis raphe; vestibule/penile urethra; prepuce,

	/cutting (available on request at this address: contact@bone3d.com) - One transparent mould of a vulva with an inserted 3D printed clitoris (Sex-Ed+). - Iconographic database on display on wall screen	descending body and glans of clitoris/prepuce, body and glans of the penis). **2. Understand how practices of genital modifications (surgical and/or hormonal, consented or not) can modify genital morphology.** - Observe the diversity of shape and size of male and female genital structures. - Observe the morphological diversity of the genitalia following surgical genital modification (consented (sexual reassignment surgery) or not. - Observe the morphological diversity of the genitalia following hormonal therapy. **3. Understand that transgender and/or gender diverse individual's gender identity is incongruent with their sex-assigned at birth.** **4. Understand that some (not all) TG/GD individuals chose to alter the morphology of their genitalia by taking hormones and/or undergoing sex reassignment surgery as part of a medical gender-affirming transition.**
Station 2: Anatomy and Sexual Response	**Anatomical models :** - 3D V2 kits of male and female sexual and reproductive organs. - 3D models of isolated female and male erectile structures (clitoris with/without MGF/C and penis) - Iconographic database on display on wall screen - Numerical 3D F/M V2 pelvic kits on display on wall screen in Sketchnote3D.	- **Identify the different internal sexual and reproductive female and male organs, their anatomical relationship and embryological analogies.** - Identify on the female 3D kit: the ovaries, uterine tubes, uterus, vagina, urethra, female prostate, clitoris (crura, ascending body, knee/elbow, descending body, glans) and greater vestibular glands). - Identify on the male 3D kit: the testicles, epididymis, vas deferens, seminal vesicle, prostate, bulbo-urethral glands, urethra, penis (crura, body, bulb, urethral spongious body and glans). - Note the similarities between the clitoris and the penis, in terms of structure and anatomical position in the pelvis.

2.2.1.b - Evaluation of second year medical students' satisfaction of station 1 and 2

The students were invited to fill a paper or digital survey at the end of the class to collect their feedback about station 1 and station 2 (Appendix 1). The digital format of the questionnaire was created with LimeSurvey software. The survey consisted in quantitative and qualitative questions to find out if the various 3D moulds and 3D models were useful for their learning and what were the students' feelings and reactions to the presentation of genital diversity. For station 2, we questioned the type of anatomical knowledge that the 3D models could bring (Table 3). We wanted to know if the V2 would help students better understand the key points of pelvic anatomy, such as the relationships between the organs, their physiology, as well as embryological analogies. The aim was also to determine whether the 3D V2 models were found useful by the students when combined with more traditional teaching methods such as anatomy plates or pictures.

The survey included quantitative questions with possible answers "not useful", "not very useful", "useful" and "very useful. Question number 1, 3, 4 and 5 we compulsory. Question number 2, 6 and 7 were open and optional. They enquired what students liked in the 3D models proposed and possible improvements they could suggest. Our study goal was to specifically pilot and assess the V2 pelvic 3D models which were only in station 2. All results were analysed with IBP SPSS Statistics software (https://www.ibm.com/fr-fr/products/spss-statistics).

Table 3: Questions of the survey gave to second year medical student about station 2.

1) As part of your practical anatomy work, do you think the 3D models of the clitoris and penis are useful and relevant to your learning? (1= not useful, 2= not very useful, 3= useful, 4= very useful)
2) The dismountable 3D kits in Station 2 "Anatomy and sexual response" were useful for: (1= not useful, 2= not very useful, 3= useful, 4= very useful) - Identifying the different organs and understanding their anatomical relationships. - Understand the embryological analogies between the female and male genitalia. - Understand the anatomical-physiology of the female and male sexual response.
3) Does the 3D pelvis kit, combined with conventional teaching aids (e.g. anatomical plates or pictures), increase understanding of the anatomy of the genital organs? (1= not useful, 2= not very useful, 3= useful, 4= very useful)
4) Generally speaking, what did you like about Station 2 - "Anatomy and sexual response"?
5) Regarding station 2 - "Anatomy and sexual response", do you have any comments on the way the kits have been designed, in particular on how they could be improved (e.g. materials, colors, etc) ?

2.2.2 - Evaluation of the 3D V2 models by osteopathy student in anatomy course

The two V2 models were introduced into the courses on semiology and management in gynaecology and obstetrics for 26 third year Bachelor osteopathy students of the *Haute Ecole de Santé* of Fribourg (07.06.2023). First, the students viewed a film (43) of the 3D anatomy of the pelvis. This was followed by their professor's presentation of both 3D V2 models. The models were then freely available for students to manipulate, even during breaks. A shorter version of the survey (Appendix 2) given to medical students (question 2 to 5 covering the V2 models) was administered to evaluate osteopathy students' satisfaction about 3D V2 models tested.

3. Results

3.1 - 3D V2 pelvic models

The 3D V2 models (Figure 5 and 6) were built with a base and magnets keeping together the various 3D organs so that they could be assembled and disassembled easily. The organs sharing a common embryological origin were displayed in the same colors: the clitoris and penis in green, the testicles and ovaries in purple, the rectum in brown, the bladder in yellow and the pubis in white. The rest of the organs shown are in different colors. Both 3D V2 kits are available for free on Sketchnote3D (Appendix 3).

Figure 5: Version 2 of 3D female pelvic model assembled and disassembled.

* : Urethra ; * : Rectum ; * : Bladder ; * : Vagina ; * : Pubis ; * : Fallopian tube ; * : Uterus ; * : Ovary ; * : Clitoris ; * : Greater vestibular gland.

Figure 6: Version 2 of 3D male model pelvic assembled and disassembled.

* : Prostate ; * : Testicle ; * : Penis ; * : Vas deferens + Epididymis ; * : Seminal vesicle ; * : Rectum ; * : Bladder ; * : Pubis.

3.2 - Results of the survey on the use of the 3D V2 pelvic models during anatomy practicals

114 of the 177 medical students and 19 of 26 osteopathy students completed the survey, 90.4% of the medical students and 100% of the osteopathy students found the models useful in identifying the different organs and understanding the anatomical relationships between them (Table 4). This is also what emerged in the qualitative answers (Table 5) with the perceived most frequent advantage being to have a better representation of the organs in 3D and in their actual size (39.4% of the qualitative answers). The use of 3D models was also considered an effective way of understanding anatomy, complementing more traditional learning tools, as stated by 93% of medical students and 100% of osteopathy students.

The 3D pelvic models were also found useful for understanding the anatomo-physiology of male and female sexual response by most of the respondents in both medicine and osteopathy classes, as well as for understanding the embryological analogies between male and female organs.

Table 4: Results from the survey administered to medical and osteopathy students.

		Studies of surveyed students	
		Medical students	Osteopathy students
		N (%)	N (%)
The dismountable 3D pelvic models were useful for: (not useful, not very useful, useful, very useful)		114 (100%)	19 (100%)
Identifying the various organs and understand their anatomical relationships	"not useful" or "not very useful"	11 (9,6%)	0 (0%)
	"useful" or "very useful"	103 (90,4%)	19 (100%)
Understanding the anatomo-physiology of the female and male sexual response	"not useful" or "not very useful"	16 (14%)	1 (5,3%)
	"useful" or "very useful"	98 (86%)	18 (94,7%)
Understanding the embryological analogies between female and male genital organs	"not useful" or "not very useful"	16 (14%)	4 (21,1%)
	"useful" or "very useful"	98 (86%)	15 (78,9%)
Combining these kits with conventional learning tools enhances understanding of genital organs anatomy	"not useful" or "not very useful"	8 (7%)	0 (0%)
	"useful" or "very useful"	106 (93%)	19 (100%)

Table 5: Additional answers of open-ended questions grouped by theme among medical and osteopathy students.

Benefits of using 3D kits to learn anatomy reported by medical and osteopathy students	**N (%)**
Better representation of organs in 3D and their actual size	28 (39,4%)
Playful assembly of 3D kits	16 (22,5%)
Better representation of male/female analogies with color representations	11 (15,5%)
Better representation of relationships between organs	8 (11,3%)
Increases clarity and intuitiveness of pelvic organ anatomy	6 (8,5%)
Better understanding of where pleasure comes from	1 (1,4%)
Better understanding of anatomical variability	1 (1,4%)
Total	71 (100%)

Feedbacks and ideas for improvement were collected from medical and osteopathy students. It was often suggested to have different textures more similar to the real ones of the organs. Many students also mentioned adding the main vascularisation and innervation of the various organs represented, as well as the main ligaments and tendons present in this region of the body. Finally, other feedbacks suggested creating a transparent pelvis to better see the organs inside the pelvis, or having a variant with an empty bladder or a nulliparous versus multiparous uterus.

4. Discussion

Our study presents the V2 of 3D pelvic models and their assessment during anatomy practicals among second-year bachelor students at the Faculty of medicine of the University of Geneva and the third-year bachelor osteopath students of the *Haute école de santé* of Fribourg.

Compared to our 2020 V1 pelvic 3D models, the V2 contains several new features. If for V1, the female model was based on the pelvic MRI images of 30 female volunteers, and the male one entirely on CT images of a single male (39), the V2 was based on a single cadaveric anatomical database from the Chinese human visible body project, containing one male and one female body (ref). The development of V2 from cadaveric specimens provided precise information on both male and female bodies, with identical acquisition techniques. Cadaveric specimens also offered a more detailed organ representation due to the absence of natural body movements and pre-existing data availability, saving acquisition time and allowing more organs to be included. Additionally, as Wu *et al.*'s digital models did not include the glans penis, *pars intermedia* of the clitoris, and bulbar commissure and medium septum of the corpus cavernosum, we added their tracing and represented of these organs.

The V2 3D models include nine organs for the female and eight for the male, all represented in seven printed pieces counting support (some organs are represented in one printed piece, for example, testicle, seminal vesicle and vas deferens are in a same 3D printed piece). They can being assembled using magnets. The uterus, fallopian tubes, ovary and greater vestibular glands were added to V2 of the female model and vas deferens linked to testicles, epididymis, and the seminal vesicles were added to V2 of the male model. Such addings together with the same color to represent female and male organs with the same embryological origin, were planned to improve understanding of pelvic and reproductive anatomy, while making learning more equalitarian. Addressing peripheric sexual genital response in both sexes opens the conversation on sexual response avoiding to focus on reproductive function only.

A recent Australian study found that taboos surrounding sexual organs and sexual health pose a significant barrier to teaching vulvar anatomy to students in Australian higher education (44). The study highlighted "personal reticence and student sensitivities" as major obstacles to teaching courses on vulvar anatomy. Additionally, it revealed that anatomy teachers often did not use inclusive language, primarily due to a lack of knowledge in this area. However, student response to the adoption of inclusive language was overwhelmingly positive, encouraging teachers to make this linguistic shift. Our 3D models not only reflect but also advance new learning objectives in anatomy practicals, addressing gender and anatomy diversity, and promoting sexual health education.

The 3D models were found very useful by the students for identifying the different organs of the pelvis and their anatomical relationships, as well as to understand the anatomy and physiology of the genital sexual response and the embryological analogies between the male and female genital organs. 90.4% of the medical students and 100% of the osteopathy students said that our 3D models were useful for identifying the different organs of the pelvis and the anatomical relationships between them. Furthermore, when asked in an open question about the contribution of these 3D models to learning, 11.3% and 8.5% of students respectively thought that using 3D models to learn anatomy provided a better representation of the relationships between organs and increased clarity and intuitiveness of pelvic organ anatomy. Our results are in agreement with previous literature. Undergraduate medical students having access to 3D models learned better about basic knowledge of the external cardiac anatomy, relations between structures of the heart and functions of the structures compared with those who had either cadaveric material alone or a combination of 3D prints and cadaveric material (45). The anatomical representation offered by 3D models may be clearer than traditional cadaveric specimens for students although these two learning tools are complementary for a complete understanding of anatomy, notably for the representation of vasularization, innervation or pelvic musculature, which is not represented on our 3D kits.

The use of 3D models when teaching respiratory pathologies resulted in increased student satisfaction compared to conventional methods. Self-assessment surveys revealed higher satisfaction among students using 3D models, correlating with a sense of better understanding (46). Although not quantitatively measured, 22.5% noted that assembling 3D pelvic models adds fun and interest to learning. Blakeley et al.'s 2009 study, after a systematic literature review, also supports the positive impact of games on learning (47).

A recent systematic review examined 68 PubMed articles focusing on the creation of 3D models for anatomy teaching (22). Among them, only 25% addressed the abdominopelvic region, with only one addressing sexual anatomy which is the study responsible for creating our 3D model V1. A PubMed search using "3D printing" and "Sexual anatomy" revealed studies mainly focused on the penis in the context of urological surgeries without exact anatomical representation or women's preferences for different penis sizes (48,49). A search on Google Chrome browser identified companies offering 3D models of pelvic and genital organs for anatomy learning, but the data on which these companies base the production of these models is not specified (50,51).

Strengths of our study include the use of models based on human cadaver anatomy (41), ensuring faithful representation of pelvic organs in terms of size and anatomical layout, which enhances spatial understanding of the organs and their relationships. The choice of colors for organs with common embryological origins is another positive aspect. Embryological knowledge is crucial for understanding anatomy, development, congenital defects, and gametogenesis (52). These knowledge promote an inclusive message by noting that around one child over ten born today with a urogenital malformation (53). Understanding the common origin of male and female urogenital embryology aids in comprehending these malformations (54). Teaching embryology also clarifies the shared development, anatomy and physiology during peripheral genital arousal of the penis and clitoris. 86% of medical students and 78.9% of osteopathy students found these 3D models helpful for understanding embryological analogies between sexes. Although we did not test the 3D models in clinical or surgical settings, the V2 models could be useful for discussing anatomy when preventing non-consensual genital mutilation, promoting self-knowledge, understanding treatments and anatomy for FGM/C, or sex-reassignment surgery and also in intersex patients (39).

Finally, this 3D model allows students to visualise the exact dimensions of the clitoris based on cadaveric data, as well as its actual position in the pelvis. Such faithful representation allows students to visualise it properly, which is a step forward in addressing knowledge gaps regarding the anatomy of the clitoris in the medical professions (31).

Strengths of our questionnaire include its easy format (paper and via QR code), which allowed us to collect numerous responses (114 medical students and 19 osteopaths). Having only seven questions encouraged students to complete the questionnaires immediately after class. Finally, the open-ended questions in the questionnaire will help identify potential improvements for future V3 models.

Limitations of the survey include the lack of information about the gender or age of the students surveyed, preventing correlation analysis between responses and these demographics. Additionally, we lack data on the religious or cultural backgrounds of respondents, which could influence their relationship with sexuality and their answers (55,56). We also did not gather information on prior sex education, which can improve students' knowledge of sexuality by over 20% compared to those without it (57). The culture and origins of respondents were not collected, limiting result interpretation since these factors significantly impact perceptions of sexuality and pleasure (58). Lastly, the anatomy instructors and teachers who presented the models might have influenced students' perceptions of the 3D models, as they provided varying information and explanations, potentially creating bias. We plan to repeat the questionnaire in the future and aim to collect more sociodemographic data from students.

Concerning limitations of the 3D models themselves, they represent genital organs without sexual arousal, lacking information on size and shape changes during arousal. Additionally, our 3D V2 models use only one texture material from the 3D printing process. Introducing variable textures for the vagina or vas deferens could enhance the learning experience.

It will be interesting to compare knowledge of pelvic and sexual anatomy in two student groups using pre- and post-use questionnaires: one group using 3D pelvic models, the other using traditional teaching methods. A future goal for these 3D pelvic models is to enhance anatomy education and benefit a larger proportion of the population. Testing these kits in schools or with patients during gynecology, physiotherapy, osteopathy, urology, pediatric, or obstetrics consultations would be valuable. They could also aid in understanding operative consent protocols for patients undergoing surgeries, such as those for FGM/C treatment, which involves re-exposing the clitoral body under the scar and sometimes re-innervating it (59–61). Pre-operative counselling has been found crucial for understanding surgery and clitoral anatomy (62) (63).

The 3D models accompanying information could be adapted to the target population, for example, by including representations of major vascular and nerve axes, as well as key pelvic ligaments. If the 3D model is intended for the general public or schools, it should be made of more robust materials to withstand handling, disassembly, and reassembly. These 3D pelvic models could thus play a crucial role in disseminating pelvic anatomical knowledge, with different versions adapted to target populations. This would allow for explanations of pelvic and clitoral anatomy, sexual response, sexual pleasure, and the representation of individual sexuality.

5. Conclusion

We have updated and tested our 3D V2 pelvic models for teaching pelvic and sexual anatomy. Medical and osteopathy students found the models useful for better understanding the actual size of the pelvic organs and the relationship between them. The same applies to understanding sexual response of penis and clitoris and the embryological similarities between them in an equalitarian and scientific way.

Personal Contributions

Conception, project design, data acquisition and analysis were led by Jasmine Abdulcadir, MD, PD, CC Diomidis Botsikas, MD, PD, Celine Brockman, PhD, Julien Da Costa, Romain Dewaele and Jorge Remuinan, RT.

Jasmine Abdulcadir, Maeva Badré, Céline Brockman and Victor Foubert were responsible for updating the anatomy practical exercises for second-year medical students at the University of Geneva.

I (Victor Foubert) took an active part in meetings with all the collaborators of this project concerning the realization of the 3D models as well as in discussing the organization of the evaluation the models during the anatomy practicals of the second year of medicine. I created the 3D model evaluation survey under supervision, collected the answers and analysed the data using different software such as LimeSurvey or SPSS Statistics. The results obtained were used to submit and present a poster for presentation at 2 congresses: the Swiss Society for Anatomy, Histology, and Embryology, the European society of sexual medicine. I was able to present the 3D models to second-year bachelor students at the University of Geneva during anatomy practicals, as I myself was one of the anatomy monitor in charge of teaching. I also reviewed the literature on 3D models and anatomy teaching used and drafted my master thesis under the supervision of Jasmine Abdulcadir. Once a first draft was finalised, I reviewed it according to the inputs of Jasmine Abdulcadir and Céline Brockman, both responsible of the V2 pelvic models' creation and piloting.

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Appendix

Appendix 1: Survey gave to second year medical students during anatomy practicals at university of Geneva.

Bioscope UNIGE UNIVERSITÉ DE GENÈVE

Questionnaire d'évaluation des kits d'anatomie 3D

Ce questionnaire est dédié à évaluer la pertinence et l'utilité pédagogique de deux nouvelles stations durant le TP d'anatomie de l'Unité Reproduction : **Station 1 « Anatomie et diversité »** et **Station 2 « Anatomie et réponse sexuelle »** ainsi que de **kits de visualisation 3D des organes génitaux** sur la station 2. Vos réponses sont anonymes et aideront grandement au développement et à l'amélioration de ces kits pour des utilisations futures.

Station 1 : Anatomie et diversité

1) Dans le cadre de vos travaux pratiques d'anatomie, pensez-vous que **les modèles d'organes génitaux externes portant sur la diversité génitale** soient utiles et pertinents à votre apprentissage ?

(1= pas utile, 2= peu utile, 3= utile, 4= très utile)

1 – 2 – 3 – 4

2) De manière générale qu'avez-vous apprécié sur **la station 1 – Anatomie et diversité** ?

Station 2 : Anatomie et réponse sexuelle

3) Dans le cadre de vos travaux pratiques d'anatomie, pensez-vous que **les modèles 3D** soient utiles et pertinents à votre apprentissage ?

(1= pas utile, 2= peu utile, 3= utile, 4= très utile)

1 – 2 – 3 – 4

4) **Les Kits 3D de la station 2** « Anatomie et réponse sexuelle » m'ont été utiles pour :

((1= pas utile, 2= peu utile, 3= utile, 4= très utile)

	1	2	3	4
Identifier les différents organes et comprendre leurs rapports anatomiques				
Comprendre les analogies embryologiques entre les organes génitaux femelles et mâles				
Comprendre l'anatomo-physiologie de la réponse sexuelle femelle et mâle				

5) Le kit 3D du bassin, associé aux outils pédagogiques classiques (exemple : planches anatomiques ou images), augmente la compréhension de l'anatomie des organes génitaux ?

(1= pas utile, 2= peu utile, 3= utile, 4= très utile)

1 – 2 – 3 – 4

6) De manière générale qu'avez-vous apprécié sur **cette station 2 – « Anatomie et réponse sexuelle »** ?

7) **A propos de la station 2 – « Anatomie et réponse sexuelle »** , avez-vous des commentaires sur la manière dont les kits ont été conçus, en particulier sur la manière dont ils pourraient être améliorés (e.g. matières, couleurs, etc) ?

Merci d'avoir répondu à ce questionnaire !

En cas de remarque ou de commentaires à propos de ce questionnaire, veuillez vous adresser à l'adresse
victor.foubert@etu.unige.ch

Appendix 2: Survey gave to second third year bachelor osteopathy students of the *Haute Ecole de santé* of Fribourg.

Questionnaire d'évaluation des kits d'anatomie 3D

Ce questionnaire est dédié à évaluer la pertinence et l'utilité pédagogique des kits de visualisation 3D des organes génitaux que vous avez à disposition. Vos réponses sont anonymes et aideront grandement au développement et à l'amélioration de ces kits pour des utilisations futures. Ce questionnaire est composé de quatre questions, pour une durée de 2 minutes.

1) **Les kits 3D démontables** m'ont été utiles pour :

(1= pas utile, 2= peu utile, 3= utile, 4= très utile)

	1	2	3	4
Identifier les différents organes et comprendre leurs rapports anatomiques				
Comprendre les analogies embryologiques entre les organes génitaux femelles et mâles				
Comprendre l'anatomo-physiologie de la réponse sexuelle femelle et mâle				

2) **Les kits 3D du bassin**, associé aux outils pédagogiques classiques (exemple : planches anatomiques ou images), augmente la compréhension de l'anatomie des organes génitaux ?

(1= pas utile, 2= peu utile, 3= utile, 4= très utile)

1 – 2 – 3 – 4

3) De manière générale qu'avez-vous apprécié sur **ces kits 3D** ?

4) Avez-vous des commentaires sur la manière dont les kits ont été conçus, en particulier sur la manière dont ils pourraient être améliorés (e.g. matières, couleurs, etc) ?

Merci d'avoir répondu à ce questionnaire !

En cas de remarque ou de commentaires à propos de ce questionnaire, veuillez vous adresser à l'adresse **victor.foubert@etu.unige.ch**

Appendix 3: Male and Female 3D V2 anatomy kits on Sketchnote3D software.

Female kit available following this link:
https://sn3d.unige.ch/instances/sn3d_v7/?biUzREtpdFYyX3Rlc3QlMjZpZCUzRGxlMmxoN3BwNjA5OGgwc2I1YTMlMjZ2JTNENzAx

Male kit available following this link:

https://sn3d.unige.ch/instances/sn3d_v7/?biUzREtpdF9tYWxlX3YyJTI2aWQlM0RsZTJsYmR2NWYzNm