Method for Creating Interactive Plastinated Models of the Male and Female Pelvis for Medical Anatomy Education

**ABSTRACT:**
The purpose of this study was to develop a plastinated model of a male and female pelvis that could be manipulated to allow students to remove organs, blood vessels and nerves from the pelvis. The pelvis of one male (70 years old) and one female (75 years old, para 2), with no known pelvic surgery or disease, were dissected by removing the organs, major arterial trunks and sacral nerves individually. All of the soft tissue was removed from the bony pelvis in each, except for the muscles of the pelvic floor, obturator membrane, sacrospinous ligaments and sacrotuberous ligaments. The erectile tissues were also dissected and removed en bloc. The pelvic components were then plastinated to replace the tissue fluids with silicone. The resulting plastinated pelvic models accurately represent the anatomy of the male and female pelvis, with removable parts. The dissection and plastination technique require a skilled dissector, a plastination lab, and can be repeated as necessary to represent desired pelvic anatomy variability. The plastinated pelvic models also resulted in excellent scanned images that were then used to print 3D models.

**KEY WORDS:** anatomy; education; model; pelvis; plastination

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Introduction

Understanding the three-dimensional (3D) anatomy of the human body is a critical component of first-year medical education. Many clinical tasks and procedures require a firm understanding of spatial relationships between closely associated structures (Cottam, 1999; Garg et al., 2001). This is especially true for one of the more complex areas of the body, the pelvis. Pelvic issues, in general, make up a significant percentage of patients scheduling visits with their physicians. This is true in both males and females. It is estimated that 25% of women in the United States are affected by urinary incontinence, fecal incontinence and pelvic organ prolapse (Nygaard et al., 2008). In men, prostate cancer is the second most common cause of death (Halpern et al., 2003). It is important for medical students to acquire a very good understanding of pelvic anatomy to effectively treat pelvic conditions in their future patients with minimal disruption to nearby unaffected structures. Understanding the 3D anatomy of the pelvis is also essential for interpreting medical imaging.

Cadaveric dissection is a key teaching component in the anatomy laboratory at the University of Minnesota. This is where students have the opportunity to not only learn anatomy, but understand it through discovery. Dissection has withstood the test of time as an effective teaching tool because it allows students to discover the 3D relationships of the structures of the body through the use of multiple senses (Sugand et al., 2010; DeHoff et al., 2011). Dissection also exposes the wide variety of anatomical variation seen in the general (donor) population. However, when it comes to the pelvis, students are often frustrated with the dissection process because of the layering of structures and organizational complexity in this region. It is notoriously one of the most challenging dissections students face. In order to alleviate some of the pressures during the pelvic dissection laboratory, prosections performed by the anatomy faculty have become important teaching aids that students depend on for understanding this region of the body. However, the time-consuming dissections required to meet the demands of a 175-student class are short-lived, being removed from the laboratory and cremated at the end of each semester. Silicone
plastination, in which tissue fluid is replaced with a curable polymer (von Hagens, 1979a; 1979b; 1986), was considered as an option for preserving the carefully dissected pelvic specimens. However, the resulting plastinated model would significantly reduce the ability of students to mobilize structures to inspect surrounding anatomy. This dilemma led to the development of the dissection and plastination method described in this current report. The method described here allows for the creation of plastinated pelvic dissections that allow students to remove organs, blood vessels and nerves individually. Taking advantage of the flexibility of the model described here, it is also possible for students to approach pelvic anatomy through “syncretion,” a term coined by Miller (2000) for anatomical discovery by “putting things back together again.” To our knowledge, this is the first description of the development of a male and female plastinated pelvis model that allows students to “build a pelvis” by inserting organs, blood vessels and nerves into the pelvic cavity with the pelvic floor muscles intact.

Materials and Methods

Pelvic dissections were performed on one male and one female human cadaver. The cadavers were gratefully donated to the Anatomy Bequest Program, at the University of Minnesota. The cadavers were first embalmed with a solution of 70% isopropyl alcohol, 13.25% phenol, 8% sorbitol, 7.5% formaldehyde and 1.25% barquat MB-50 diluted in water (50:50). The female cadaver was 75 years old with a history of two live births. No pelvic surgeries or anomalies were noted. The body was prepared for dissection by isolating the pelvis. A horizontal cut was made through the body at the L3 vertebral level. The lower extremities were then sectioned horizontally through the upper thighs. The pelvic viscera were then dissected, with the urinary bladder, rectum, pelvic nerves and major arterial trunks removed separately. Finally, the bony pelvis was cleaned of all soft tissues except for the pelvic floor muscles and major ligaments. The pelvic components were then plastinated.

The plastination process employed is referred to as “room temperature plastination.” In contrast to the basic cold process, which combines a silicone polymer with a catalyst and chain extender to serve as the impregnation mixture (von Hagens, 1986), the room temperature method combines the silicone polymer with a cross-linker (Glover et al., 1998). This method produces a more stable impregnation-mix at room temperature compared to the cold method. The specific materials and methods used to prepare the plastinated pelvis models in our study are comparable to techniques previously described (Henry, 2007; Raoof, 2007). However, North Carolina products were used based solely on familiarity and availability.

Plastination Process

1. The male and female pelvic components were submerged in a water bath to remove excess preservative chemicals and lipids. The water bath was allowed to overrun with fresh water at a rate of roughly two liters per hour. The specimen was bathed for five days, with gentle agitation once per day to encourage thorough rinsing.

2. The parts were then submerged in a series of cold (-23°C) acetone baths to displace all cellular fluids, beginning with five baths of 98% acetone and ending with one final 100% acetone bath. Cold temperatures decrease tissue shrinkage during dehydration (DeJong and Henry, 2007). The specimen soaked for one week in each bath with gentle agitation every day to encourage fluid displacement. The fourth and fifth acetone baths were allowed to come to room temperature after five days to encourage defatting of adipose tissue, as adipose tissue does not properly plastinate. Acetone displacement is considered complete when acetone purity measured after one week of tissue soaking is ≥99% (measured by specific gravity acetonometer calibrated for 15°C).
3. The structures were then submerged in a silicone polymer bath (Silicones, Inc. NC-PR12), inside a stainless-steel vacuum chamber, and allowed to settle for 24 hours before placed in vacuum. The vacuum pressure was slowly decreased over five days until a gentle boil of solvent from the tissues was maintained. Rapid boiling of solvent results in poor silicone displacement and incomplete plastination (DeJong and Henry, 2007). Solvent boil continued for two weeks until pressure in the vacuum reached roughly <5 mmHG (measured by standard digital manometer). When silicone displacement was complete, a trickle valve was opened, and atmosphere slowly returned to the vacuum chamber over the course of 24 hours. Forced impregnation took place at room temperature (~23°C).

4. The specimens were then placed over a drip pan and allowed to drain excess silicone polymer for three days with moderate exposure to a heat lamp.

5. Catalyst curing chemical (Silicones, Inc. NC-t32) was applied to the dissections via spray bottle and gently brushed into the tissue surface with a common paint brush. The structures were then moved into a desiccant chamber to cure for one week. Excess silicone polymer was manicured from the specimens daily. Polymer curing occurred at room temperature (~23°C).

6. Cross-linker curing chemical (Silicones, Inc. NC-r22) was applied to the tissues via gas aerosolization inside of the desiccant chamber over a period of eight hours. The specimens were then allowed to settle in the desiccant chamber for three weeks without additional chemical application. Excess silicone polymer was manicured from the structures daily for the first additional week and every three days thereafter. Specimens were dry to the touch after two weeks, but remained in the desiccant chamber for two more weeks to avoid chemical precipitate from forming on the tissues.

Results

The resulting pelvic plastinate models included parts that could be placed within, or removed from, the pelvic cavity.

Eight Parts of Female Pelvic Model:

1. Bony pelvis along with the pelvic diaphragm (levator ani and coccygeus muscles), obturator membrane, sacrotuberous ligaments and sacrospinous ligaments (Fig. 1).

2. Erectile tissues of the external genitalia (Fig. 2).
3. Urinary bladder, urethra and distal ends of the ureters (Fig. 3a).

4. Uterus, vagina and adnexal structures (Fig. 3b).

5. Rectum and anus (Fig. 3c).

6. Distal aorta, common iliac arteries and main trunks of the internal and external iliac arteries (Fig. 4a).

7&8. Left and right sacral nerves (Fig. 4b).

Figure 5 shows the fully assembled female plastinated pelvis.

Seven Parts of Male Pelvic Model:

1. Bony pelvis along with the pelvic diaphragm (levator ani and coccygeus muscles), obturator membrane, sacrotuberous ligaments and sacrospinous ligaments (Fig. 6).

2. Erectile tissues of the penis (Fig. 7).
3. Urinary bladder, ureters (distal ends), prostate gland, seminal vesicles and testes connected by vas deferens (Fig. 8a).

4. Rectum and anus (Fig. 8b).

5. Distal aorta, common iliac arteries and the main trunks of the internal and external iliac arteries (Fig. 9a).

6&7. Left and right sacral nerves (Fig. 9b).

Figure 10 shows the fully assembled male plastinated pelvis.

In order to maintain the natural shape and position of the various pelvic components during plastination, the various pelvic structures were pinned into position or suspended by wires at the start of plastination (Fig. 11) but were removed from the pelvic cavity after impregnation.

Although a formal experience survey was not administered, students have commented that the pelvic plastinate models “really helped” with the understanding of pelvic anatomy, was “a fun way to learn pelvic anatomy,” and provided for “immediate comprehension” of the organization of pelvic contents.
Discussion

To our knowledge, this is the first description of a process by which the male and female pelvis can be dissected and plastinated to allow organs, blood vessels and nerves to be removed individually, or placed into the pelvis to “build a pelvis.” Other types of models can be used to help teach pelvic anatomy. Plastic models have been used in anatomy courses for decades to help students understand the structure of the body. They may be sufficient for an introductory anatomy course, but tend to lack the detail, accuracy and interactive qualities that are desirable for more advanced courses such as medical anatomy. This is especially true for the pelvis. For example, the robustness of the levator ani muscle (the main muscle of the pelvic floor) is overly represented in most plastic models. In reality, the muscle is usually very thin and disrupted with regions of the connective tissue. In addition, plastic models lack the interactive nature desired by students. Many times, several organs are represented in a single mass, limiting a student’s spatial understanding. It is clear that a student’s spatial ability is an important predictor of success in learning anatomy (Garg et al., 2001).

There has also been a rise in the popularity of computer-generated 3D models of the pelvis. Computer models and animations of anatomical features are becoming increasingly attractive as a means to communicate complex spatial relationships effectively (Dev et al., 2002). Virtual models of the pelvis are typically produced from cross-sectional images (Bajka et al., 2004; Holubar et al., 2009; Sergovich et al., 2010; Wu et al., 2010; Sora et al., 2012; Kraima et al., 2013; Sora and Jilavu, 2013). Earlier studies questioned the efficacy of such models with helping students perform better on exams (Garg et al., 2002; Hariri et al., 2004) and suggested that they may actually handicap those students with poor spatial ability (Garg et al., 1999). However, more recent studies have shown that they are beneficial to anatomy students (Qayumi et al., 2004; Nicholson et al., 2006; Brown et al., 2012; Cui et al., 2017), which may be due to the much-improved quality of computer-generated modeling.

These virtual models, however, require a great amount of time and expertise to create. They must have the boundaries of each structure rendered slice by slice by an expert in anatomy and with proficiency using the software. The process, called “segmentation,” is the digital identification and labeling of structures of interest on individual two-dimensional (2D) slices. This process...
must be completed in several planes for tortuous structures such as blood vessels. A major problem for segmentation arises from the separation of ligaments and connective tissue from bones and muscles, because structures merge directly into one another (Bajka et al., 2004). The definition of the borders of individual structures is left to the discretion of the software user. The resulting model is an interpretation of 2D sectional anatomy. Secondly, the final 3D model lacks realistic tissue texture. This is because the rough form of the digital model usually undergoes further processing, such as "smoothing" to become more presentable and portable (Sergovich et al., 2010). The smoothing process results in the loss of detail and surface texture.

The process described in our current report does not require expensive, high-tech equipment or software. The plastination process cost approximately $1400 to perform for both pelves. It does, however, require the skill of dissection and plastination capabilities. There is no "guess-work" or "interpretation" involved, but simply revealing the structures in their true form. All of the detail and surface textures of the structures are retained. The technique can be used to preserve unlimited variations of pelvic anatomy with the level of detailed limited only by the person performing the dissections. They can be left natural in color or painted to make structure identification easier. The plastinated models described in this report also work very well for creating 3D printed models, of which the plastination process is a critical step. Once plastinated, the pelvic models' components hold their shape when being scanned and can be placed directly on the scanning table without special containment or ventilation. Once scanned, the image files are converted to a compatible format for 3D printing. The various components of the models can also be printed in different colors and planes for ease of identification (Fig. 12). If developing colored 3D prints is not feasible, the plastinates can be painted for easier identification.

While the development of innovative learning resources should be actively encouraged, their incorporation into medical education should include quantitative evidence supporting their efficacy at improving students’ knowledge and understanding. We plan on moving forward by determining the utility of our plastinated pelvic models by evaluating student performance in a measurable way.

Conclusions

The pelvis is a challenging region of the human body to conceptualize yet very important for medical students to understand. It is important for interpreting diagnostic imaging as well as for treating the myriad dysfunctions and diseases in the pelvis. The interactive pelvic plastinate models described in this report, with removable organs, blood vessels and nerves, should prove to be of great usefulness in this effort. Interaction with, and manipulation of, the model should improve students’ understanding of the spatial relationships in the male and female pelvis. This approach to producing interactive physical models of the pelvis are also ideal for scanning and 3D printing. The principles of the technique can be applied to virtually any region in the body when physical 3D models are desired.

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References


