Three Dimensional Reconstruction and Modeling of Complex Pelvic Anatomical Structures by Using Plastinated Cross Sections

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Computerized reconstruction of anatomical structures is becoming very useful for developing anatomical teaching modules and animations. The first computer-aided 3D reconstruction was achieved in 1965 by Glaser and Van der Loos. With the improvements in computer hardware and software tools, computerized modeling of anatomical structures has become very useful for visualizing complex 3D forms. Three-dimensional visualization of various microanatomic structures using special preparation and staining methods is important. Although databases exist consisting of serial sections derived from frozen cadaver material, plastination represents an alternate method for developing anatomical data useful for computerized reconstruction. Plastination is used as an excellent tool for studying different anatomical and clinical questions. The sheet plastination technique is unique because it offers the possibility to produce transparent slices series, which can easily be processed morphometrically. A female pelvis was obtained, plastinated, sectioned and subject to 3D computerized reconstruction using WinSURF modeling system (SURFdriver Software). Qualitative observations revealed that the morphological features of the model were consistent with those displayed by typical cadaveric specimens. Morphometric analysis indicated that the model did not significantly differ from a sample of cadaveric specimens. This data supports the use of plastinates for generating tissues sections useful for 3D computerized modeling.

Keywords: plastination, 3D reconstruction, anatomy, female pelvis, urinary bladder, uterus.

Since its development 30 years ago, plastination is the best method for the preservation of human tissue. In recent years, plastination has been applied as excellent method for studying different anatomical-clinical questions. By using the E12 technique, we obtained transparent slices that show different structures in their initial position, especially regarding the muscular, vascular and interstitial tissue [1-3]. With many of the modern diagnostic techniques, including corrosion casts [4], radiographic imaging such as computed tomography [5-8], magnetic resonance imaging [9], and ultrasound [10, 11], the importance for understanding serial sectioned anatomy of the human body cannot be overlooked. The E12 plastination method allows accurate, precise and transparent sectional preparations offering accurate visual clarity of gross structures down to a submacroscopic level viewable with the naked eye [12-15].

The main steps for the E12 plastination method are: cold dehydration, degreasing, impregnation and finally curing [13, 16, 17]. There are two methods for obtaining E12 slices, namely the classical E12 method for 3mm thick slices and the ultra-thin E12 plastination method for slices between 0.3 - 1mm [12-14, 18-20]. Anatomical structures of the desired region are then 3D reconstructed. Three dimensional reconstruction computer models made from scanned plastinated models may have benefits in terms of representing real tissue and in case of 3D-IT reconstructions. This offers the opportunity to compare the use of identical physical and virtual models for the development of a 3D anatomical computer models basic system and its interactive manipulation.

The pelvic floor has a complex spatial structure, whose knowledge is a condition for assessing pathologies in this area [20, 21]. Women, for the most part, undergo pelvic floor examinations for urinary incontinence or prolapse of the internal genitalia or of the urinary bladder [20, 22, 23]. Pelvic floor dysfunction, which includes urinary and fecal incontinence as well as pelvic organ prolapsed, is a highly prevalent disease in women. Ten percent of all women undergo at least one operation to treat pelvic floor dysfunction during their lifetime [20]. Up to day, little is known about specific pelvic floor pathomorphology and even less about pathophysiology as it relates to pelvic floor dysfunction. DeLancey et al. [24] used Magnetic Resonance Imaging (MRI) to investigate levator ani muscle damages, Lien et al. [25] constructed a computerized model in order to determine the stretch forces that exceed the forces which muscle tissue can usually sustain. In our study, a three-dimensional (3D) model of the pelvis was built based on thin slice plastination cross-sections of the

adult female pelvis and 3D reconstruction technology. In order to investigate biomechanical the Petros and Ulmsten theory, the key structures of the pelvic floor had to be defined and reconstructed [26]. The key ligaments, such as the pubourethral ligament, the cardinal ligament, the uterosacral ligament and the pubovesical ligaments were first detected on plastinated slices and then reconstructed.

Experimental part

The 3D model was reconstructed from a 70 year old female cadaver specimen. The specimen was a part of the human donation program of the Medical University of Vienna. The female pelvis was frozen at –80°C for one week and afterwards it was plastinated according to the standard ultra-thin E12 slice plastination method [14]. Freeze substitution is the standard dehydration procedure for plastination. Shrinkage is minimized when cold acetone is used. The tissue block was submerged in cold (-25 °C) acetone (high purity) for dehydration. Degreasing was performed by using methylene chloride (high purity). Impregnation was performed using the following epoxy Biodur (Rathausstr.18, 69126 Heidelberg, Germany) mixture: E12 (resin)/ E6 (hardener)/ E600 (accelerator) (Sora et al., 2007). When impregnation was completed, the tissue block was removed from the vacuum chamber. A mold was constructed of styrofoam and lined with polyethylene foil and the tissue block inserted. The mold containing the impregnated specimen and resin-mix was placed in a 65°C oven for four days to harden the resin-mix. The tissue/resin block was cooled to room temperature and the mold removed. A contact point diamond blade saw, Exact 310 CP (Exact Apparatebau GmbH, Norderstedt, Germany) was used for cutting the block. The hardened E12 block was cut into 1.6 ± 0.26 mm. Finally, the caudal surfaces of the plastinated slices were scanned into a computer using an EPSON GT-10000+ Color Image Scanner. In every scan, a ruler as a calibration marker was included. For morphological measurements, the UTHSCSA IMAGE TOOL v.2.0 for Windows software (The University of Texas Health Science Center in San Antonio) was used. The objects which had to be reconstructed were traced manually by using a graphic table (Wacom Cintiq 24HD). Each object was traced and numbered accordingly on every BMP file. After that, the reconstruction was rendered, visualized and qualitatively checked for surface discontinuities by rotating the model. The following features, defined as objects, were used in the reconstruction: pelvic girdle, levator ani, obturator internus, coccygeus, piriformis muscles, rectum, uterus, uterosacral ligaments, cardinal ligament, ureter, urinary bladder, pubovesical ligament, urethra, pubourethral ligament, vagina, lumbosacral plexus, internal and external iliac arteries, sciatic nerve, lumbar plexus, obturator nerve and pudendal nerve.

Results and discussions

The transparency and color of the plastinated slices were perfect and of high quality (fig. 1A, 1B, 2A, 2B). Sectional plastination showed the structures of the pelvic floor muscles and their relationship to adjacent structures with a resolution down to the microscopic level (fig. 1B, 2B). This method allowed assessment of the course of muscle fibers and ligaments.

Once scanned and loaded into WinSURF, automatic edge detection was used to quickly collect tissue borders or contours. These contours were visualized on the tissue borders and showed close continuity with the edges of the objects. The pelvis model was rendered and rotated in real
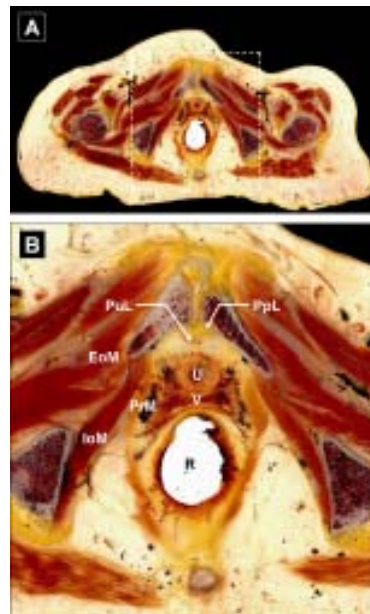

Fig.1. Plastinated transverse section of the female pelvis below the pubic symphysis. A - Whole image; slice thickness 1.6 mm. B - Detail of a plastinated cross section of the marked area on figure 1A. EoM - External obturator muscle; IoM - Internal obturator muscle; PpL – Posterior pubic ligament; PrM – Puborectalis muscle; PuL – Pubouretral ligament; R – Rectum; U – Urethra; V - Vagina. [Color figure can be viewed in the online issue, which is available at www.revmaterialeplastice.ro]
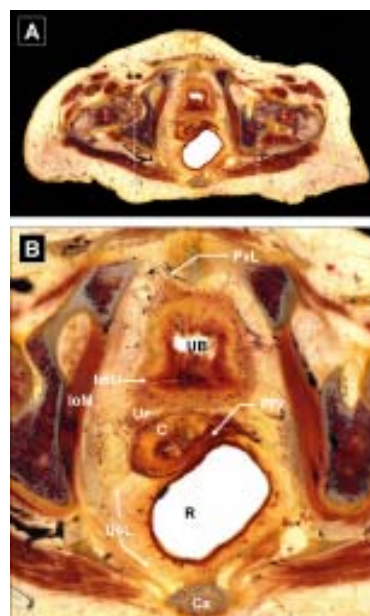

Fig.2. Plastinated transverse section of the female pelvis at the level the femoral head. A - Whole image; slice thickness 1.6 mm. B - Detail of a plastinated cross section of the marked area on figure 2A.. C – Cervix; Cx – Coccygis; ImU – Intramural part of ureter;IoM - Internal obturator muscle; PfV – Posterior fornix of the vagina; PvL – Pubovesical ligament; R – Rectum; UB – Urinary bladder; Ur – Ureter; UsL – Uterosacral ligament. [Color figure can be viewed in the online issue, which is available at www.revmaterialeplastice.ro]

time and it resembled well with a representative cadaveric pelvis. The quality of the reconstructed images appeared distinct, especially the spatial positions and complicated relationships of contiguous structures of the female pelvis. All reconstructed structures can be displayed in groups or as a whole and interactively rotated in 3D space. Various features, such as transparency control, individual object selection, animation and a variety of manipulation modes facilitate visualization of the complex pelvic anatomy (fig. 3-5).

Quantitative measurements showed that the overall morphology was retained. Coefficients of variation for the six variables ranged from a low of 11.3% to 19.5%. None of the variables recorded from the model were significantly different from the corresponding values measured from the cadaveric specimens at the $p < 0.05$ level.

The pelvic floor extends between pubis and sacrum and consists of the urogenital and the pelvic diaphragm. The pelvic diaphragm consists of the levator ani, the coccygeus and the sphincter ani muscles. The levator ani muscle has three parts: pubococcygeus, iliococcygeus and puborectalis muscles. It is perforated by the rectum [27]. The urogenital diaphragm consists of the transversus perinei, sphincter urethrae externus, the bulbospongiosus and the ischiocavernosus muscles [27]. The pelvic floor
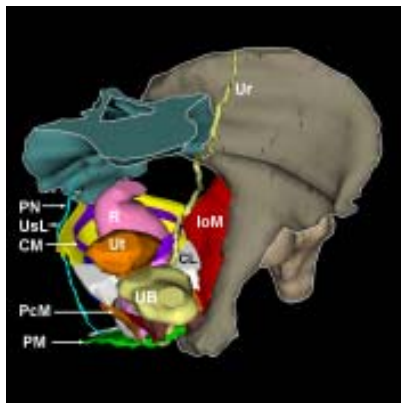
Fig.3. Cranial view of the 3D reconstruction of the female pelvis. CL – Cardinal ligament; CM – Coccygeus muscle; IoM - Internal obturator muscle; PcM – Pubococcygeus muscle; PM – Perineal membrane; PN – Pudendal nerve; R – Rectum; UB – Urinary bladder; Ur – Ureter; UsL – Uterosacral ligament; Ut – Uterus. [Color figure can be viewed in the online issue, which is available at www.revmaterialeplastice.ro]
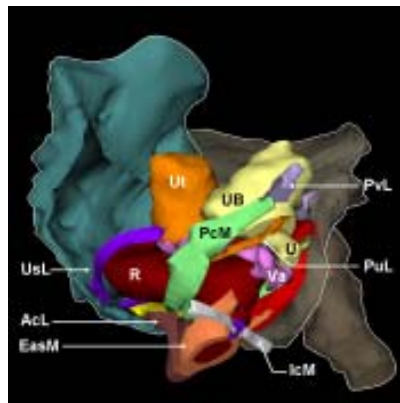

Fig.4. Lateral view of the 3D reconstruction of the female pelvis. CL – Cardinal ligament; EasM – External anal sphincter muscle; IcM – Iliococcygeus muscle; PcM – Pubococcygeus muscle; PrM – Puborectalis muscle; PvL – Pubovesical ligament; R – Rectum; U – Urethra; UB – Urinary bladder; UsL – Uterosacral ligament; Ut – Uterus. [Color figure can be viewed in the online issue, which is available at www.revmaterialeplastice.ro]
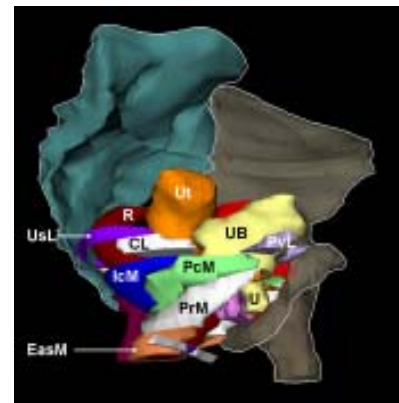

Fig.5. Inferior view of the 3D reconstruction of the female perineum. AcL – Anococcygeal ligament; EasM – External anal sphincter muscle; IcM – Ischiocavernosus muscle; PcM – Pubococcygeus muscle; PuL – Pubourethral ligament; PvL – Pubovesical ligament; R – Rectum; U – Urethra; UB – Urinary bladder; UsL – Uterosacral ligament; Ut – Uterus; Va - Vagina. [Color figure can be viewed in the online issue, which is available at www.revmaterialeplastice.ro]

contains only striated muscles. Its purpose is to hold the pelvic organs and to occlude the urethra and the rectum [28, 29]. The pudendal nerve (S2-S4) passes through the pudendal canal (Alcock-canal) and innervates motoric the pelvic floor and the genitalia and the anus sensitive [27, 28]. The physiological tasks of the female pelvic floor are to provide the correct sequences of events during miction, defecation and giving birth. Damage in the pelvic floor can cause malfunction of these sequences. Malfunctions are urinary incontinence, stool incontinence, uterine descensus, uterine prolapse, cystocele, rectocele, douglasocele and enterocele [29].

Miction, defecation and giving birth can only run correctly if the pelvic floor is fully functional. The integral theory leads incontinence back to a weakness of the vaginal wall. The inserting muscles and ligaments are responsible for the physiological processes. Following a weakness in the vaginal wall leads to malfunction [26]. Re-establishing the physiological structures shall lead to a restitution [30]. The four pairs of muscles (three parts of the levator ani and the coccygeus muscles) contract in different directions. This causes a tension in the vaginal wall [31]. The fascia and ligaments support this process significantly [30].

The pelvic floor has a complex spatial structure, of which only parts are visualized on sectional images [32-34]. It is, however, necessary for proper assessment of pathologies to correctly relate the visualized part to the entire structure. A 3D model in which the positions of the imaging plane of interest are shown improves the vividness of depiction. With recourse to the plastinated sections it was possible to derive additional information, such as the course of muscle fibers or connections of the muscles with each other for a given imaging plane. In contrast to anatomic preparation, the structures and spatial relationships of the tissues were not altered by plastination. Although muscular tonicity is not present in cadaveric material, a study [34] about the postmortem changes of the levator ani muscle showed that there are only little changes in its architecture after death. This study used MRT and CT of living subjects and compared those with plastinated slices to point out

those morphologic studies done on plastinated slices of the pelvis floor can be assign to living humans.

Thin plastinated slices of 1.6 mm are essential if 3D reconstruction is desired [13, 20, 35, 36]. Due to the high transparency of the slices, also fine ligaments could be identified: pubourethral ligament, the cardinal ligament, the uterosacral ligament and the pubovesical ligaments. These ligaments take a key role in suspending the organs, like urinary bladder, urethra, vagina and the uterus, in preventing their prolapse. Although the process of plastination extends the time and effort required to generate images for analysis, considerable detail is provided and the reconstructed pelvic model exhibits the bones and surrounding soft tissue. The thin slices used in this study offer numerous advantages over other gross anatomical preparation methods currently utilized to generate images for computer reconstruction. The reconstruction of these anatomical structures is only possible due to the transparency of plastinated slices. A major problem that occurs with existing anatomical databases is the low resolution for smaller anatomical structures. Plastination provides a useful alternative for generating anatomical databases. Plastinates are significantly easier to cut, stain, and handle compared to fresh frozen tissue since they are significantly more durable owing due to the epoxy infiltrate. Although the female pelvis reconstruction presented here did not appear to be affected by a loss of this information (tissue loss between slices), further testing will be required to examine this issue. The capability of reconstructing individual and combined images of the pelvic structures, viewing them from all surgical angles, and allowing for accurate measurement of their spatial relationships enables important guidance for surgeons. The reconstructed model can also be used for residency education, testing an unusual surgery and for the development of new surgical approaches. The 3D model of the female pelvis presented in this paper provides a stereoscopic view to study the adjacent relationship and arrangement of respective pelvis sections.

Conclusions

The utilization of plastinated slices for generating tissues sections is useful for 3D computerized modeling. The 3D model of the female pelvis presented in this paper provides a stereoscopic view to study the adjacent relationship and arrangement of respective pelvis sections. Our model could lead to a better understanding of the pelvic floor anatomy and serve as a realistic model in the generation of a Finite Elements model, which will undergo biomechanical stress investigations.

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