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Newly developed three-dimensional animation of uterine closure according to the modified technique of cesarean section by Vejnović

Новоразвијена тродимензионална анимација затварања материце по модификованој техници царског реза по Вејновићу

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SUMMARY

Introduction/Objective Information provided as both visually and verbally is learned better than information received through either pathway alone. Animation ensures this dual coding. It gives us the possibility to display abstract details of operation that cannot be observed otherwise. This is especially important for an operation as common as cesarean section (CS). Although CS is the most common operation in women, animations of uterus suturing are very few. The aim was to develop a 3D-animation of uterus suturing in CS by Vejnovic modification.

Methods The project was done 2015-2018 as collaboration between the Faculty of Medicine and the Faculty of Technical Sciences at the University of Novi Sad. The development of the animation included following steps: filming simulation of uterus suturing on sponge model, interdisciplinary discussion, making storyboard, recording sound, animating using *Blender* software.

Results The animation lasts for 10 minutes 17 seconds. The film was designed to be self-explanatory. In the film uterus suturing technique was presented in detail. Important segments are additionally marked in the video and stressed in the background audio explanation. The educational 3D animation of uterus suturing in cesarean section – modification Vejnovic is available from: https://youtu.be/zY98Mzyupx8

Conclusion The animation shows advantages and benefits in surgery education, which might increase safety for the patient and the surgeon. The animation could help standardize the CS technique and disseminate precise surgical instructions, ensuring the same obstetrical outcomes.

Keywords: cesarean section; animation; uterus closure; suturing; technique; modification

САЖЕТАК

Увод/Циљ Информације представљене визуелно и вербално се боље усвајају од оних које су приказане само једним од два начина. Анимација пружа ово двоструко кодирање. Она нам даје могућност да прикажемо апстрактне детаље операције које се иначе не могу уочити. Ово је посебно важно за операцију учесталу као што је царски рез (ЦР). Иако је ЦР најчешћа операција код жена, постоји мали број анимација шивења материце. Циљ је био развити 3Д анимацију шивења материце током ЦР по модификацији Вејновић.

Методе Пројекат је реализован од 2015–2018. године у сарадњи Медицинског факултета и Факултета техничких наука Универзитета у Новом Саду. Развој анимације обухватао је следеће кораке: снимање симулације шивења материце на моделу од сунђера, интердисциплинарну дискусију, израду сценарија (сториборда), снимање звука, анимирање помоћу Блендер софтвера.

Резултати Анимација траје 10 минута и 17 секунди. Филм је дизајниран тако да се разуме без додатних објашњења. У филму је детаљно представљена техника шивења материце. Важни сегменти су додатно назначени у видеу и наглашени у позадинском гласовном објашњењу. Едукативна 3Д анимација шивења материце царским резом – Вејновићева модификација доступна је на: https://youtu.be/zY98Mzyupx8

Закључак Анимација пружа предности и користи у хируршкој обуци, што повећава безбедност пацијента и хирурга. Анимација би могла помоћи у стандардизацији технике царског реза и ширењу прецизних хируршких упутстава, обезбеђујући исте акушерске исходе.

Кључне речи: царски рез; анимација; затварање материце; шивење; техника; модификација

INTRODUCTION

Educational animations are animations produced for the specific purpose of fostering learning. The popularity of using animations to help learners understand and remember information has greatly increased since the advent of powerful graphics-oriented computers. However,

animations were used in early instructional medical films as early as 1920s. The animation enabled presentation of details and surgical sequences that were otherwise impossible to capture on film [1]. Quirino Cristiani was a pioneer of animated cinema. He directed the world's first feature-length animated film (El Apóstol, 1917). In 1925, he collaborated with two famous surgeons, Jose Arce and Oscar Ivanissevich, who wanted an animated film showing the technique of their work. They made two movies: Gastrotomia (1925) and Rinoplastia (1925), which Sorbonne University later bought for educational purposes. The films were praised for accuracy and realism [2]. In late 1920s, American College of Surgeons and Eastman Kodak made series of medical films and placed medical motion pictures at the center of surgical training [1]. *The Story of Menstruation* [3] is a 1946 10-minute American animated film produced by Walt Disney Productions. It was commissioned by the International Cellucotton Products Company and was shown in a non-theatrical release to approximately 100 million American students in health education classes [4]. Over time animation has become a powerful tool in education of both lay population and medical professionals. The reason for this is that animation combines two types of information that people receive and process via two distinct but interdependent pathways. The first pathway is for verbal inputs, whereas the second is for visual inputs. These pathways are additive, which means that the information provided as both images and words will be better learned than the information received through either pathway alone [5, 6].

There are over 200 video recordings and animated videos related to cesarean section available on YouTube platform [7]. However, there are only few computer animations explaining the surgical procedures in cesarean section. The great majority of them were made to provide a description for the patients rather than detailed information for medical professionals. Some of them are very sophisticated, others are simplified. Two interactive animations can be found on

the following links: http://www.surgerysquad.com/surgeries/virtual-c-section-cesarean-surgery/, https://www.touchsurgery.com/simulations/ain_csection.

Both of them show steps of cesarean section overall. The Surgery Squad aims to educate visitors through an interactive, personalized patient education experience. Patients can play a game about cesarean section. Through the game they get information about preoperative procedures, anesthesia, steps of operation and recovery. The presentation of operative steps is simple. The closure of the fascia layer is not included.

On Surgery Squad website visitors can also find FAQ about cesarean section and watch a live-surgery video.

The Touch Surgery platform is an interactive surgical simulator for healthcare professionals. It provides a realistic and detailed guide to the steps of different procedures. Users can quickly gain an insight into surgery watching an animation or a live surgery recording, and reading explanations written in the attachment. They can also test their knowledge and rehearse for surgery.

Animations of a new uterine suturing techniques with barbed monofilament suture were presented by Alessandri F. [8], and from the other side by Ischenko A.I, Murashko A.V. and Tarasenko Y.N. [9] at 3rd Regional Scientific Forum of Obstetricians and Gynecologists in 2019, but only the articles without videos have been published.

There are currently no available educational animations designed for medical professionals in order to elaborate on uterus suturing to the finest detail, so that it can be reproduced in clinical practice.

Cesarean section represents the most common operation in women. At the same time, it is probably an operation with the greatest performance variability, which is often overlooked.

The cesarean section technique, including uterus suturing, varies dramatically. Even within the same hospital, two surgeons perform different techniques. It was hypothesized by Vervoort [10] that one of the factors for developing cesarean scar defect (CSD) is the way the uterus was closed. And CSD is associated with complications in future pregnancies such as scar dehiscence, uterus rupture, placenta previa, placenta accreta spectrum (PAS), and scar pregnancy which can all contribute significantly to maternal morbidity and mortality [11]. There are plenty of scientific papers comparing the quality of the uterus incision site and complications depending on different uterus closure techniques.

Vejnovic modification of uterus suturing in cesarean section has been shown to preserve the thickness of the lower uterine segment measured intraoperatively in subsequent cesarean section, have less scar dehiscence and hysterectomies due to PAS [12] and make smaller and fewer CSD [13].

This is why the author of the modification decided to make an educational tool and provide a detailed explanation of his technique, not only to his trainees, but to all colleagues worldwide.

The aim is to standardize the technique of uterus closure in order to achieve reported outcomes in wider population. Increasing the patients' safety was the underlying incentive for creating an interdisciplinary team combining the expertise of obstetricians and professionals who deal with computer visualization, especially computer graphics.

The aim of this paper was to present a newly developed 3D animation of uterine closure by a modified technique of cesarean section - modification Vejnovic, and to discuss other available educational animations of uterus suturing.

METHODS

The development of the educational 3D animation lasted from 2015–2018 within the project "Interactive educational 3D simulation of uterus suturing during cesarean section – modification Vejnovic" granted by the Provincial Secretariat for Science and Technological Development of the Autonomous Province of Vojvodina. The project was done as collaboration between the Faculty of Medicine and the Faculty of Technical Sciences at the University of Novi Sad. The development of animation took several steps.

The first step was creating a storyboard. A storyboard is a graphic organizer in the form of illustrations or images displayed in sequence for the purpose of pre-visualizing a motion picture, animation, motion graphics or interactive media sequence. It constituted the pre-production phase of animation development.

The initial data were obtained by making a high-resolution film in which an obstetrician, instead of repairing the uterus, sutured a sponge model of the uterus that was made by the authors specifically for this purpose.

There were several reasons for this. First, when suturing the sponge model, the whole procedure was performed in a relaxed atmosphere. There was time to ask questions and discuss important aspects of the technique in order to familiarize the non-medical members of the team with the problem. In a real operation, the obstetrician must perform cesarean section in the shortest time, because of the bleeding and other risks for the patient.

The second reason was that in a real operation, the blood reduces visibility and transparency. Finally, in an operating theater the procedure is carried out by two surgeons, who stand on either side of the patient with other medical personnel (scrub-nurse, neonatologist,

anesthesiologist) also present, thus making a very crowded scene. The position of the camera in such a situation would be suboptimal and would, therefore, result in bad footage.

Once the sequence of the uterus suturing was captured, from a few iterations, the first version of the storyboard was drawn. It was reviewed by the medical members of the team. Several corrections were made to the storyboard prior to finalizing the version that was used for the animation.

The comments corresponding to individual drawings, which help every reader, regardless of whether they are a medical professional, understand the procedure of uterus closure in cesarean section – modification Vejnovic formed an integral part of the storyboard. These comments also formed the basis for the text that was prepared to be narrated in the background of the animation. In addition, the background text included important tips and observations that should help the learner to adopt the technique correctly. The text was recorded as an audio file.

The sound was recorded by a portable recorder ZOOM H6 that has six interchangeable input capsules, which makes the device the ultimate recorder for film, video, podcast and music. Raw sound processing was done in Izotope RX, which is the industry leader in audio repair and postproduction job. Sound and image compositing was done in Steinberg Cubase software.

For the realization of the project's graphical elements the Blender software was used [14]. The Blender is an open-source software and was used for modeling, animation, simulation, rendering, compositing and editing (Figure 1).

The results of the present paper were shown in the form of a storyboard and a 3D animation film.

Ethics: Ethical approval and informed consent were not needed for this research, as the entire process was performed using sponge models and computer programs, and did not involve patients.

RESULTS

According to Vejnovic modification of cesarean section, there are four steps in closing the uterus incision, resulting in a modified suture, which gradually compresses the incision of the uterus. In this manner the length of the incision already intraoperatively becomes about half the size it was. This helps not only to ensure good hemostasis and uterine closure at the moment of operation, but also to maintain satisfactory approximation of the whole thickness of the uterine wall in the first days of puerperium when the uterine involution is the most prominent and the healing process is at its most vulnerable stage. It is particularly important to preserve the thickness of the lower uterine segment and thus reduce the risk of complications in the subsequent pregnancies.

The storyboard of uterus suturing in cesarean section - modification Vejnovic is presented in Figures 2-12.

The 3D animation film lasts for 10 minutes 17 seconds. It took one month per minute on average to develop the animation. The film was designed to be self-explanatory. In the film uterus suturing technique was presented in detail. Important segments are additionally marked in the video and stressed in the background audio explanation. The voiceover in animation was recorded in three languages: Serbia, English and Russian. The English version of educational 3D animation of uterus suturing in cesarean section – modification Vejnovic is available from: https://youtu.be/zY98Mzyupx8

DISCUSSION

Studies have shown that using animated movies increases motivation for learning science [15, 16]. Animations are especially useful when complicated spatial structures and dynamic processes are involved [15], which can be found in surgical procedures.

Carole Yue et al. analyzed 430 instructional medical animations. They investigated degree to which these teaching tools followed empirically established learning principles outlined in the cognitive theory of multimedia learning (CTML). Meeting three main goals of CTML (managing essential processing, minimizing extraneous processing and facilitating generative processing) in development of the animation would enhance learning outcomes. There are several strategies to meet the CTML goals: words accompanying an animation should be presented aurally instead of visually; animation should contain only educationally relevant pictorial and verbal information; on-screen text should not duplicate narration [17].

Striving towards CTML goals, one of the main tasks in developing our animation was to make an optimal balance between video and audio elements in order to achieve the best learning effect in the adoption of the new technique. Simplifying the visual representation of the target structures is helping to better identify only the important elements of the technique. Audio comments provide another way to highlight crucial details and complement the explanation which would be unnecessarily complicated if shown visually.

The most important details of uterus suturing by Vejnović modification shown in animation could be summarized as following:

1. The entire thickness of myometrium should be included in suture to obtain better approximation of the layers. This is achieved by the needle entering at the junction of the serosa

and myometrium, richly biting the myometrial tissue, and exiting at the junction of the decidua and myometrium.

2. Decidual layer should not be included in suture (less than 5mm of decidua in not considered inclusion) to avoid edge eversion.

3. The length of sutured uterine incision should be approximately 50% smaller than initially and the level of sutured uterine incision should be in the level of surrounding uterine wall not above it.

The biggest challenge in the production of graphic elements for us was the animation of the ropes, because of the movement of the ropes through specific pathways in the tissue, a large number of stitches, and rope tightening and binding of complex knots.

The animation of the ropes could be performed by 3D animation, but such an animation involves setting a large number of key frames. It would require a rig with several hundred controls, which would be hard to use and the animation process would be extremely slow and impractical. For these reasons, instead of a complex animation, a computer ropes simulation was used. The rope is basically a long, curved line which is divided into several hundred segments. This line was applied with *Soft body physics* from Blender software, which is usually used to simulate soft tissue in character animation. So, the line becomes flexible and it is influenced by gravity and collision with surrounding elements, but also with itself. By using *Soft body physics*, a precise control of the movement of the rope was achieved.

The sutured tissue was animated by 3D (complex) animation using the rig, because it is a practical and reliable way to be animated in cases there is no requirement for realistic behavior of the tissue. New objects for collision in the form of tubes through which the rope passes

during sewing were added to the tissue and these tubes are not visible during the rendering process and final picture creating.

For rendering *Blender Internal renderer* was used. This was our choice because it was important to achieve transparency and clarity of the image instead of a photorealistic representation. This is an unrealistic type of renderer which makes it easy to achieve a stylized image look, resembling medical illustrations. Algorithm rendering takes place at a high speed and almost in real time.

Performing cesarean section is a skill every obstetrician must be familiar with. Surgery education is specific and training in the operating room on real patients cannot be fully replaced. Features and behavior of myometrial tissue while cutting and suturing can hardly be simulated. One can feel it only when operating on a real patient on their own. To prepare for this responsibility, it is important to adopt and understand as many details as possible before entering the operating theatre. Cesarean section training using videos, simulations on mannequins and computer-enhanced visual learning module improves knowledge and confidence levels among obstetrics residents [18, 19, 20]. However, even when assisting in cesarean section, or watching a live-surgery videos, one cannot gain a complete insight into the pathway of the needle through the tissue, the depth of the suture bites etc. Those shortages can be overcome using animation. This is the first animation explaining uterus suturing in cesarean section – modification Vejnović. It complements publications that have been published so far describing the modified technique [21, 22]. It is intended to be used as a part of the curriculum about cesarean section – modification Vejnović, which comprises lectures, animation, hand-on training on sponge models and live-surgery session.

CONCLUSION

We can conclude that, after extracting the newborn, suturing the uterus is the next most crucial step in the cesarean section. This is because it is important not only for the current pregnancy, but for the following pregnancies as well. From our point of view, the way of closing the uterus directly influences the healing process, and the incidence of acute and chronic complications. This is why the modification of uterine suturing represents the biggest value of Vejnovic modification.

Our animation has several advantages in medical education. Firstly, it does not take place in the operating theatre, where the benefit of the patient always stands before education. Secondly, it provides a young doctor with an opportunity to repeatedly see the procedure on the screen, while being able to enlarge or show in slow motion many segments of the operation. Finally, the whole procedure can be watched a countless number of times. This practically means that a young doctor will be present at the real operation only after familiarizing with almost the whole procedure in the virtual world. After that, during the actual operation, they will be able to elaborate on fine details together with a senior surgeon. On the other hand, the time an experienced surgeon spends on the education of young doctors is significantly reduced and the process of education significantly increases in efficiency, speed and quality.

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V.T, I.N. and V.J. revised paper critically for important intellectual content. All authors approved the final version of the manuscript.

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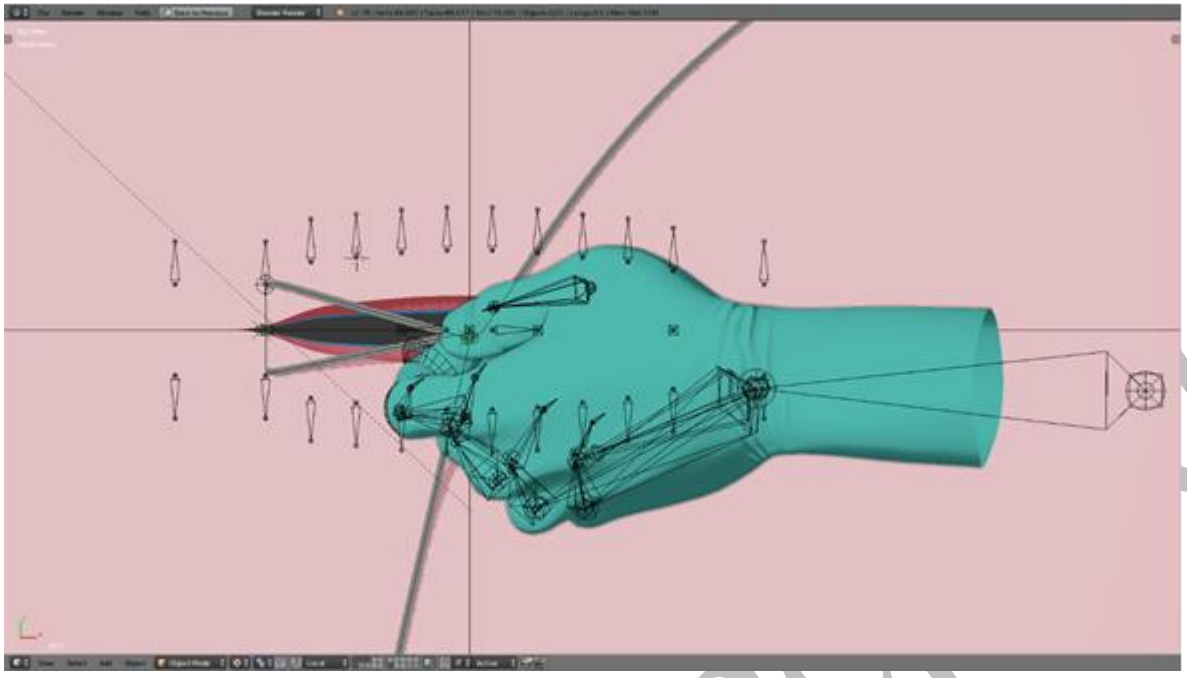

Figure 1. View of the working environment in the program Blender, in which the tissue is seen with the rig, a rope with control objects and a hand with its rig

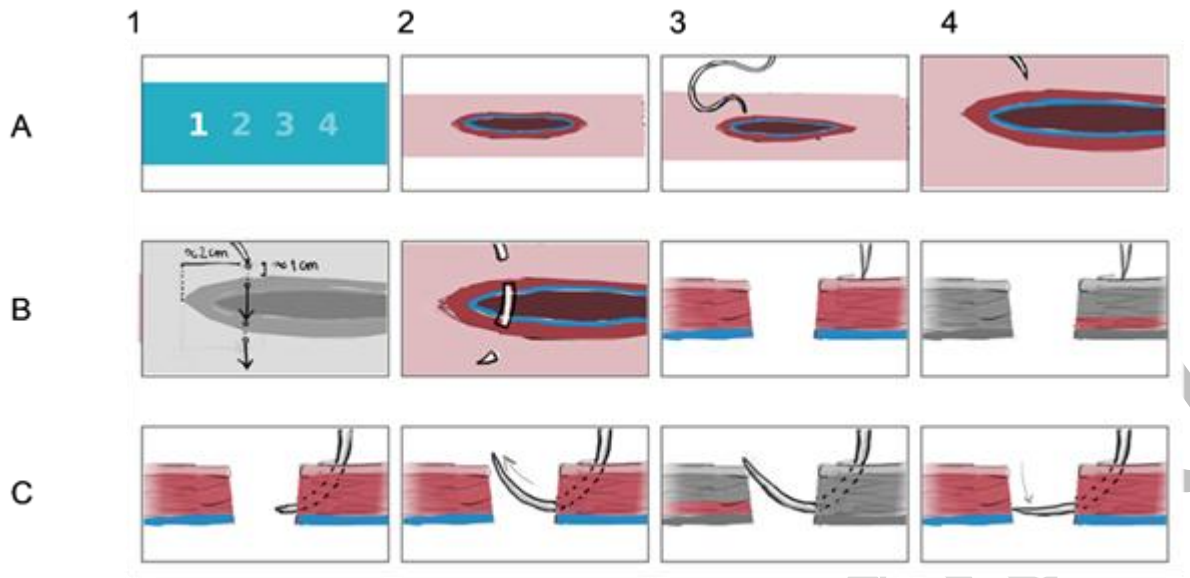

Figure 2. The first step of the repair of the uterus; important detail: the approximation of the uterine layers is better when whole thickness of the myometrium is involved into the stitch and when decidual layer is avoided; to achieve this needle should enter at the junction of serosa and myometrium, involve rich bite of myometrium and exit at the junction of myometrium and decidua from one side, then enter decidua-myometrium junction from the other side, take rich bite of myometrium and exit at the myometrium-serosa junction

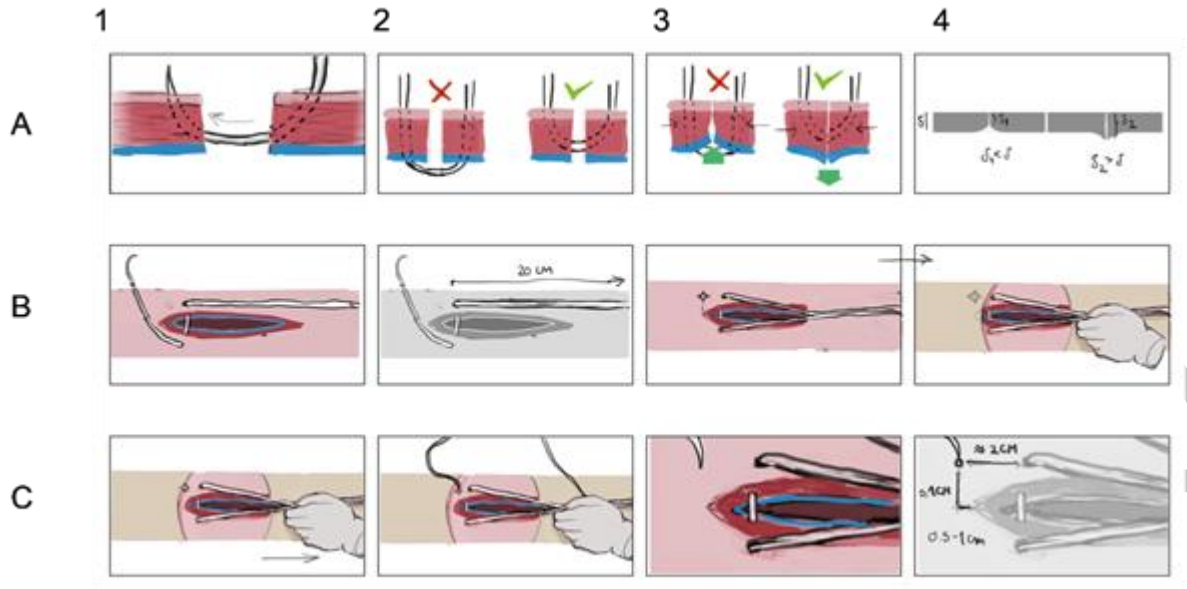

Figure 3. Creating initial suture; important detail: the first stitch is placed around 2 cm medial to the corner of the incision; thread is used as an instrument to visualize the corner of the incision and complete Z stitch safely placing the second stitch lateral to the corner in a healthy part of the wall

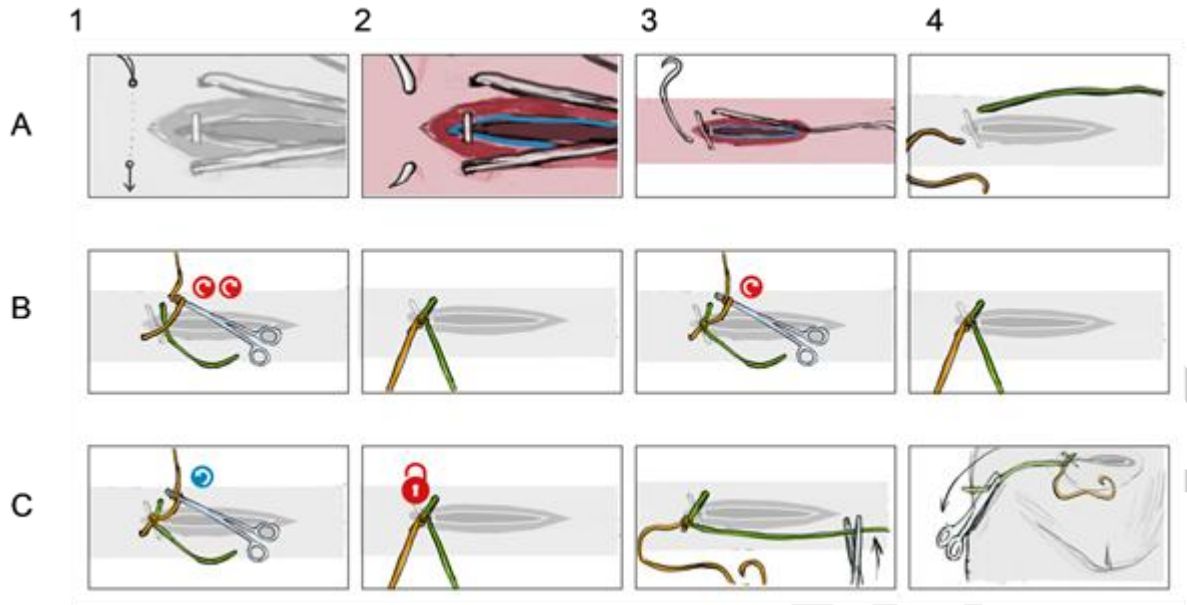

Figure 4. Creating the first knot; important detail: the knot of the first Z stitch should lie down at the cranial-medial point of the stitch if the operator works from the left side of the patient; around 10 cm of free end of the thread should be marked with Pean instrument in order to be used later

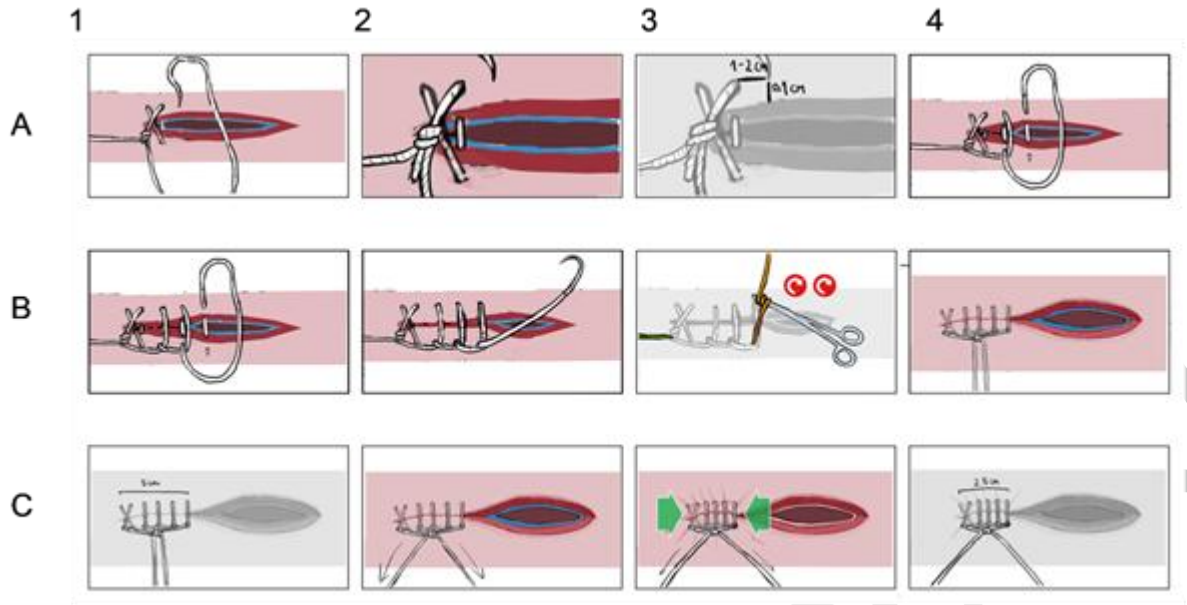

Figure 5. Making the first running-locked suture; important details: three running-locked sutures are placed towards the midline; the needle should exit from the opposite side of the incision compared to the knot of initial Z stitch; then the knot is tied using end of the thread with the needle and free end of the thread previously marked with Pean; by tightening the knot, the distance between the sutures is reduced

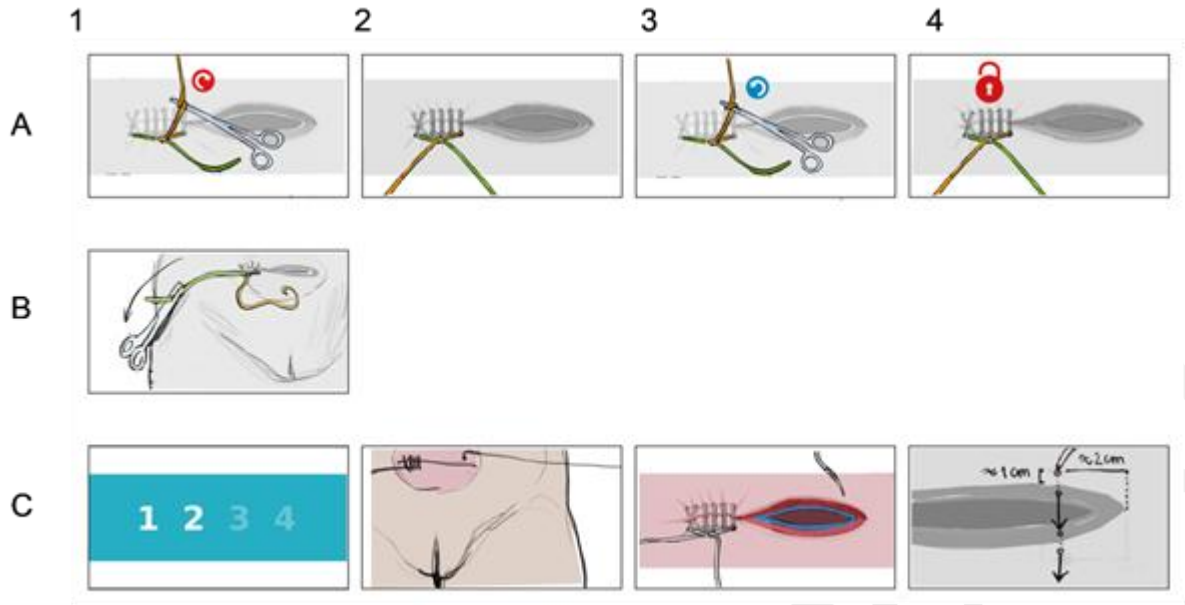

Figure 6. Finishing the first step and starting the second step of the repair of the uterus; important detail: the free end of the thread is marked with Pean; the end of the thread with the needle is left without cutting and it will be used in third step; the second step is started using a new thread

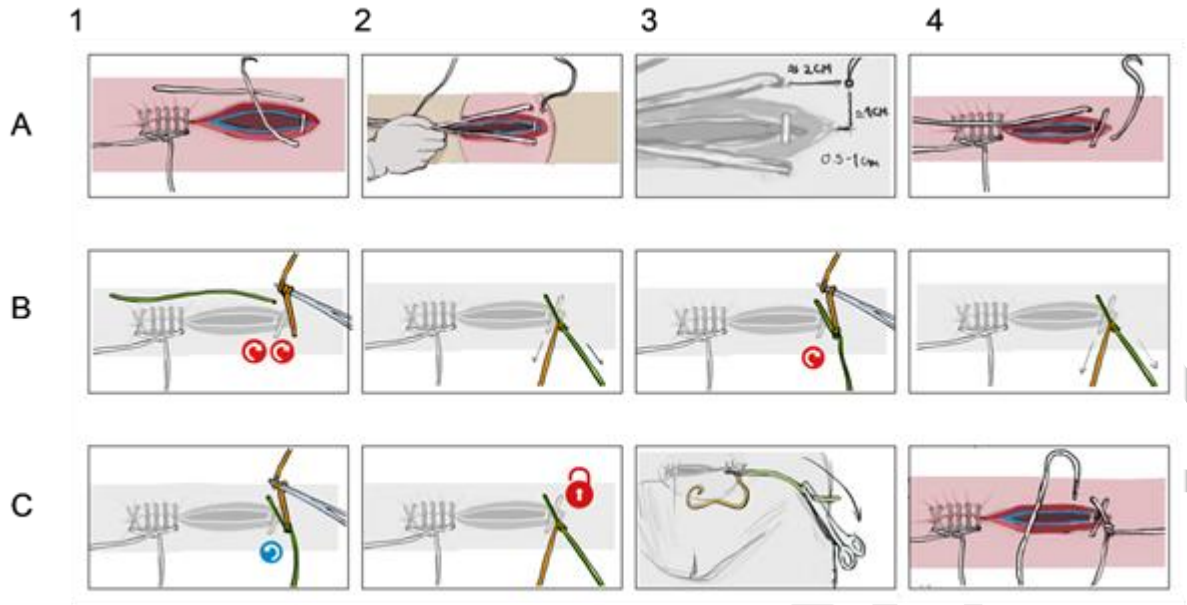

Figure 7. The second step – creating initial knot on the opposite angle of the incision; the whole procedure is the same as the first step of the repair of the uterus, except everything happens as a mirror image

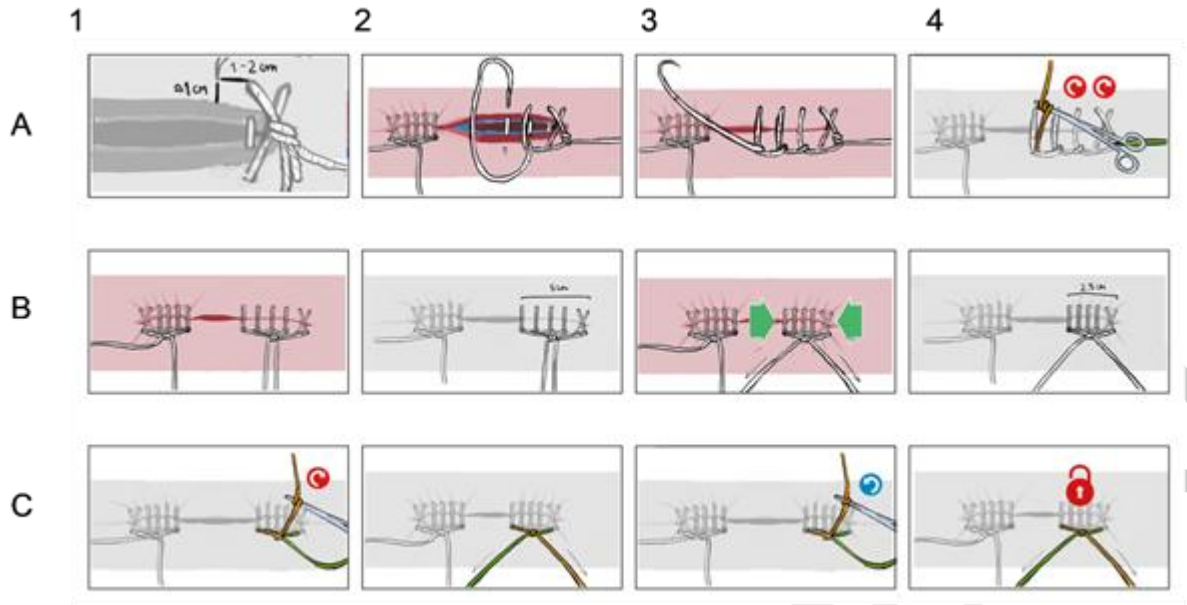

Figure 8. Making running-locked suture on the opposite angle of the uterine incision

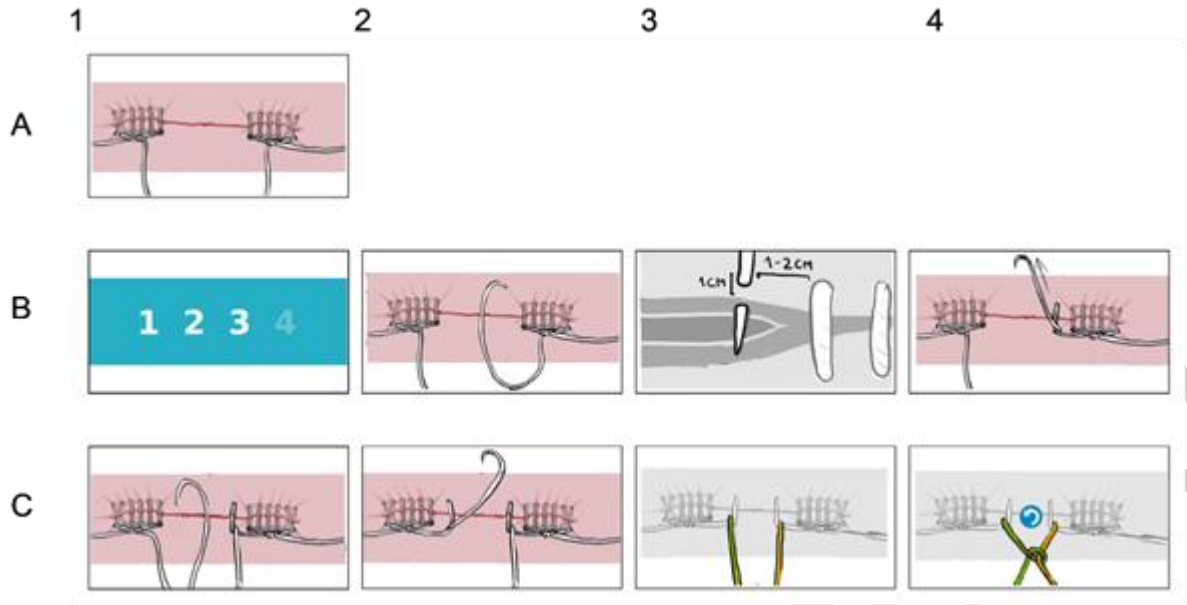

Figure 9. The third step of the repair of the uterus; the third step comprises the closure of the middle part of the incision using one to two running-locking sutures from each side

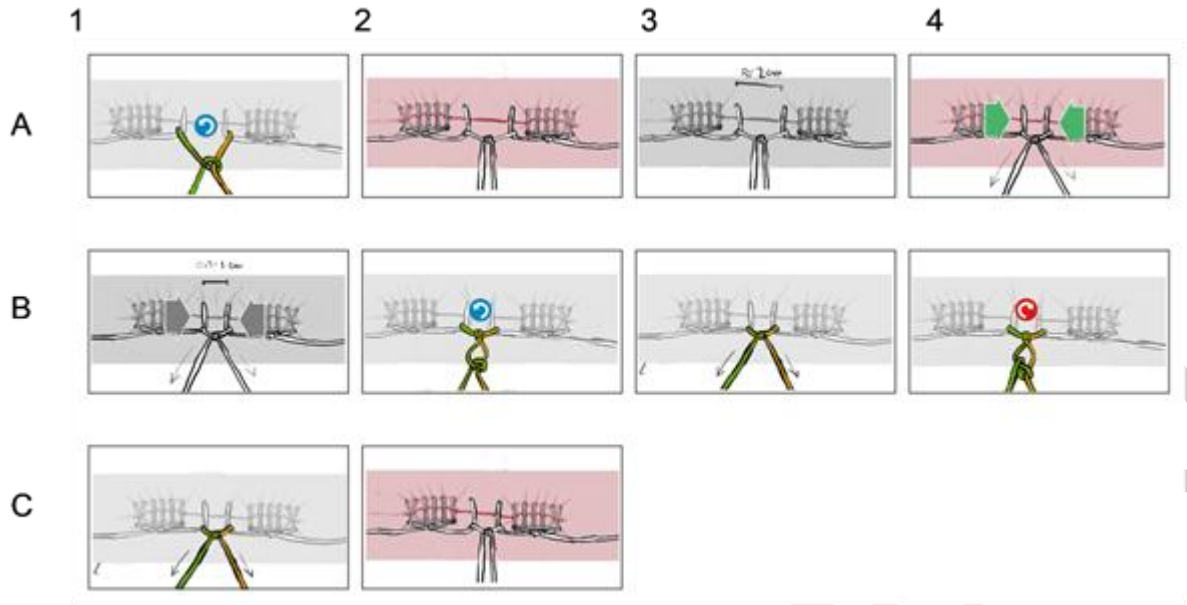

Figure 10. Making a knot in the central part of the incision; the central knot is tied using end with the needle of both threads

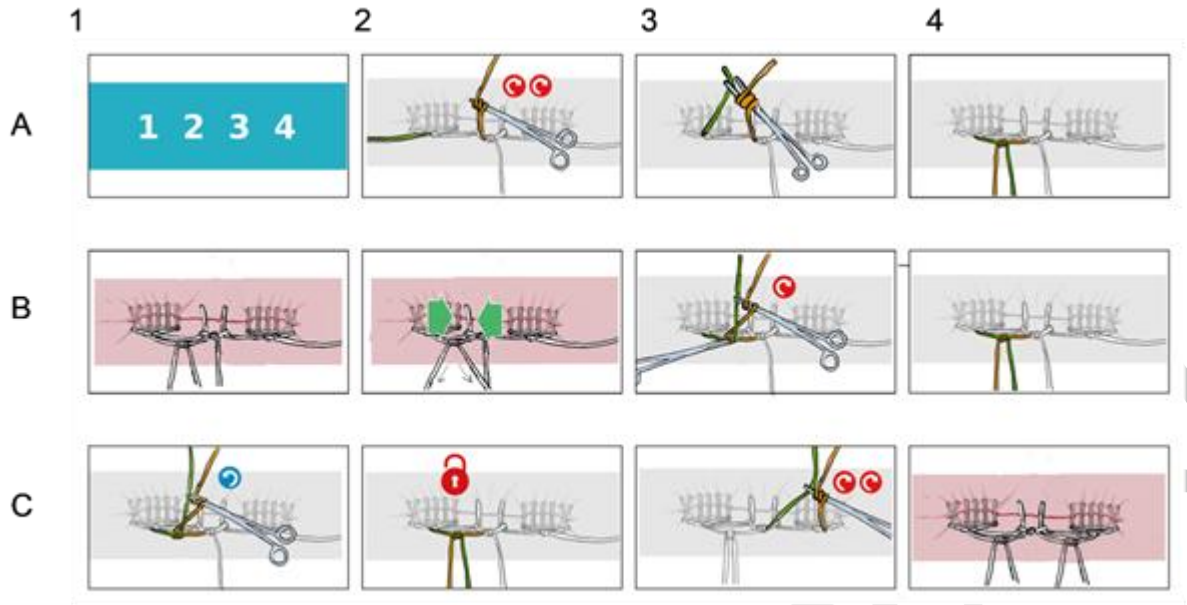

Figure 11. The fourth step of the repair of the uterus; important detail: during this step, the final shortening of the length of the sutured incision is achieved; this is done by tying one end of the thread with a needle from the middle to the free end of the thread in the corner of the incision; it is done from each side

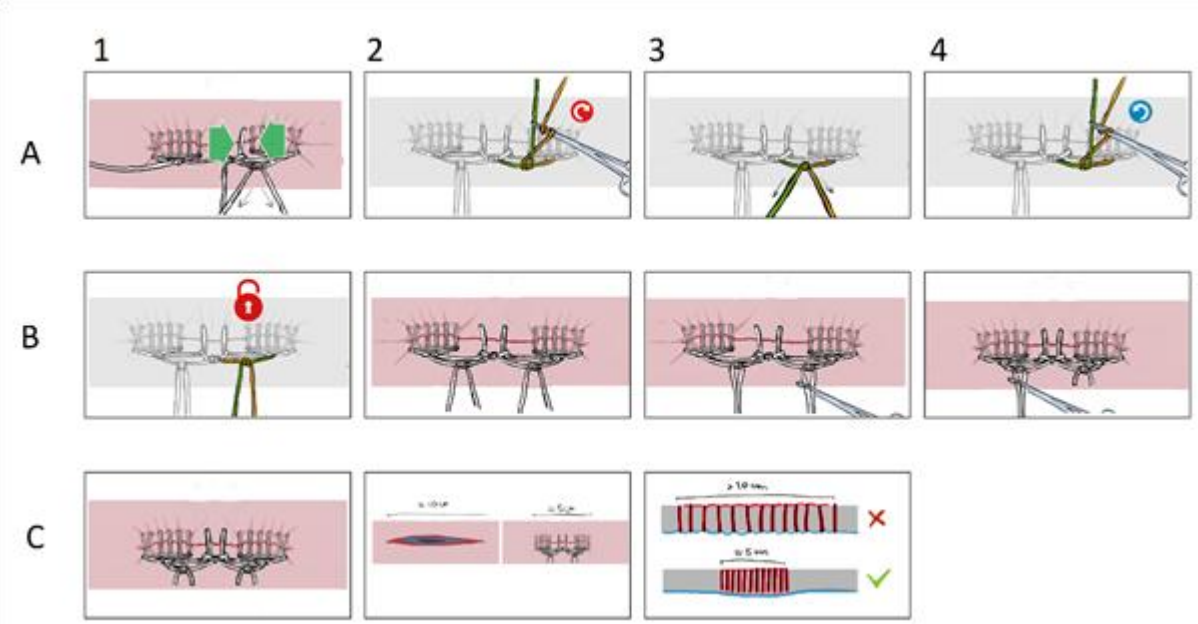

Figure 12. Finishing the repair of the uterus; this part of the storyboard shows final result of the uterus suturing according to Vejnović modification; important effects are that the uterine layers are well approximated and that length of the sutured incision is reduced by almost 50%; this will help to maintain the approximation of the uterine layers during the dynamic period of uterine involution and improve healing process

