Original Paper

Educational Potential of Three-Dimensional Volumes Based on Seriate Histological Slices of First Trimester Fetal Hearts

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ABSTRACT: The advantages of earlier diagnosis give the family more time to adjust to the fetal cardiac and related extracardiac diagnoses and to make informed pregnancy decisions. If a severe fetal CHD is detected in the first trimester and pregnancy termination is selected, the intervention may have a lower risk for the mother's physical and mental health. Training medical staff is a crucial part of implementing obstetric ultrasonography services well, since effective patient care depends on their ability to use the equipment skillfully and interpret results properly. In many low- and middle-income nations, there is a scarcity of healthcare professionals trained to offer ultrasound services and one of the reasons for this issue is the lack of available lectures, simulations and instruments to explain how ultrasound sections are acquired. We propose an alternative method of visualizing the ultrasound planes of interest using three-dimensional volumes of fetal hearts reconstructed from seriate histological slices. This method may aid trainees in understanding echocardiography.

KEYWORDS: *Three-dimensional histology, virtual autopsy, fetal echocardiography.*

Introduction

The main and most common method for assessing for fetal anatomy is ultrasonography.

Its non-invasiveness, quick results, and many other benefits have made it the method of choice.

It is a secure diagnostic instrument that can spot a variety of significant structural problems [1,2].

With high-frequency, high-resolution transducers for transvaginal and transabdominal imaging, first-trimester FE enables examination of the fetal heart, with a majority of cases having a nearly full anatomic assessment after 11+0 weeks.

The use of color Doppler flow mapping improves study of the heart's structure, especially early in pregnancy [3].

However, the operator heavy reliance is its primary drawback, among other factors such as the small heart size, dynamic movement of the heart, frequent fetal movements, suboptimal fetal position, or well-represented fatty panicle tissue in obese people.

According to Tegnander et al. [4], sonographers who have performed more than 2,000 fetal echocardiograms had a greater detection rate of CHD (52% vs. 32.5%) than those who had performed less than 2,000.

Another issue is that only 0.8% to 1.2% of live births present a congenital heart defect [5].

Taken this into consideration, an individual abnormality is highly unusual to be detected under routine screening circumstances and might only be encountered once or not at all in a doctor's lifetime, despite the comparatively high overall rates.

Prenatal ultrasound examinations have a significant false-positive rate, which results in psychological stress for the parents and unnecessary treatment of the mother and child.

Debost-Legrand et al. [6] noted that the largest diagnostic misclassification rates were observed for cerebral and cardiac abnormalities.

Currently, education is delivered using the traditional two-stage model: theoretical information, which is acquired via the use of the leading textbooks in the field, and practical knowledge (experience) which is only acquired through the performance of ultrasound tests on as many patients as feasible.

This however, may be insufficient in nowadays settings of increased depth of knowledge.

Supplementary materials are required to improve the diagnostic skills of a beginner trainee, starting with the recognition and understanding of normal ultrasound aspects.

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The aim of this study is to determine if 3D volumes reconstructed from seriate histological slices can be used as learning material for ultrasound evaluation.

Materials and Method

Fetal hearts from normal fetuses in the first trimester were evaluated sonographically and after on demand termination of pregnancy, the hearts were removed and processed histologically.

The slides were digitalized and the resulting images were imported in Amira Avizo.

After alignment and segmentation of each individual anatomic element, the 3D volume was analyzed by a multidisciplinary team composed of a materno-fetal specialist and pathologist.

The full protocol is described in our initial study [7].

The slice function was used to recreate the standard plane used for the ultrasound examination.

The orientation of the slice was easily set using the orientation buttons at the proprieties panel of the module.

Using the "translate" slider we moved the slice to the area of interest.

Positioning of the slice plane can also be performed in the 3D viewer when the "interact" button is used.

Click and hold the plane while dragging it to the desired section is a much more fluid method of exploring the volume.

To simulate the Doppler function of the ultrasound machine, we needed to extract the interior of the cavities: the atriums, ventricles as well as the great vessels and their ramifications.

This can be performed by creating a second label field for segmentation which contains only the interior of the elements mentioned above.

Another method for extracting the cavity volumes is by using the „compute ambient occlusion" function.

Overlapping of the visual representation of the cavities and the rest of the volume was performed by "volume rendering" of the two separate label fields and reducing the opacity of the heart volume render.

Results

The general aspect of the 3D volumes obtained after alignment and segmentation of seriate histological slides can be seen in Figure 1.

Furthermore, we extracted the cavities and interior of vessels to simulate the Doppler function of the ultrasound machine.

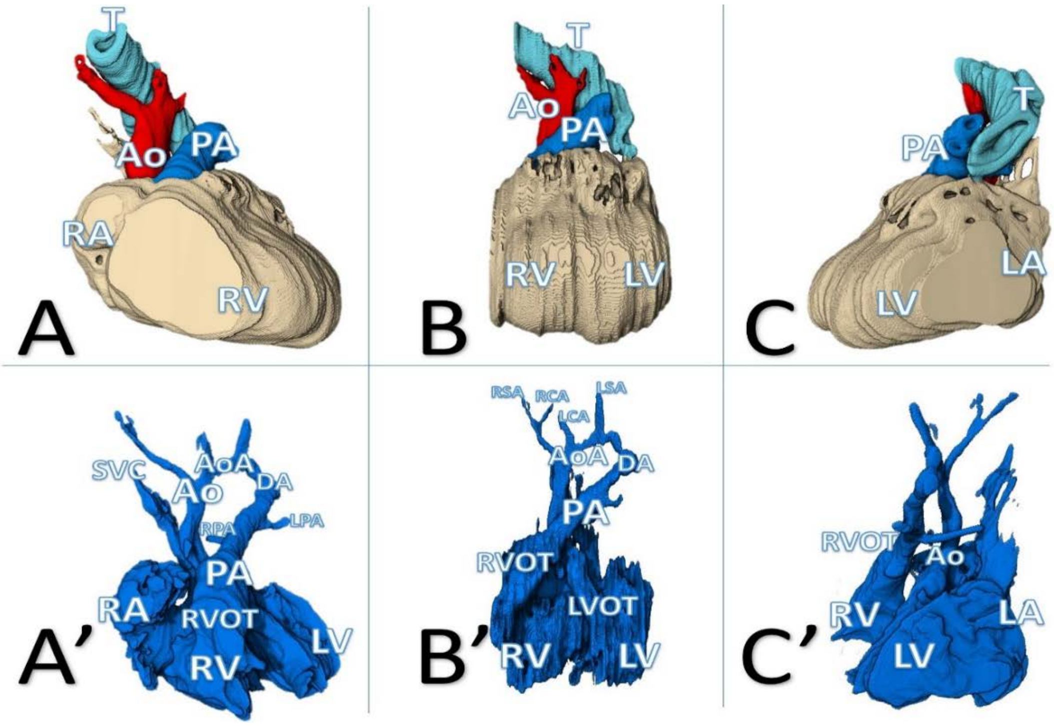

Figure 1. General aspect of the rendered volume of the heart (A; B; C) and the aspect of the extracted cavities and arteries volumes (A'; B'; C'). A, A'. view from the right ventricle; B, B'. view from the apex; C, C'. view from the left ventricle. LV: left ventricle; LA: left atrium; RV: right ventricle; RA: right atrium; PA: pulmonary artery; Ao: Aorta; T: Trachea; LPA: left pulmonary artery; RPA: right pulmonary artery; SVC: superior vena cava; RSA: right subclavian artery; LSA: left subclavian artery; LCA: left carotid artery; RCA: right carotid artery; AoA: aortic arch; DA: ductus arteriosus.

After evaluating the fetal lie, heart axis and position within the thoracic cavity, the first plane of interest in establishing the normalcy of the fetal heart is represented by the four-chamber view.

All of the elements need to accomplish this objective can be identified in our 3D models as show in Figure 2.

During the ultrasound examination of the fetal heart in the first trimester, the grey scale 2D image is often accompanied by Doppler color examination to further improve the diagnosis.

In the four-chamber view, the atrioventricular fluxes are evaluated and compared with each other.

The normalcy is represented by 2 parallel fluxes, equal in size and with no in-between connection.

This can also be represented and seen in our model (Figure 3).

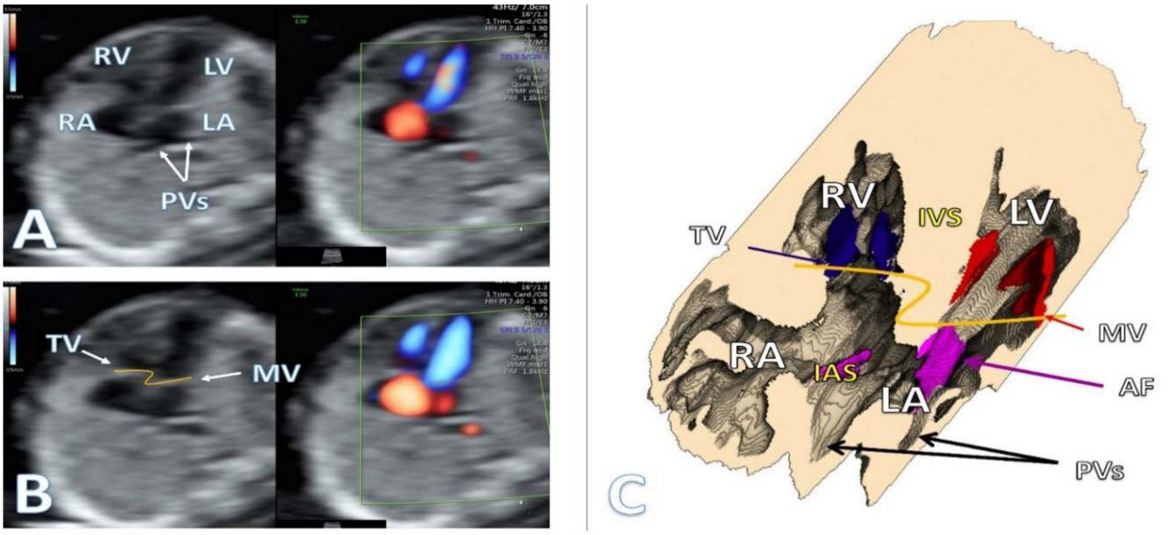

Figure 2. Four-chamber view comparison. A. Ultrasound four chamber plane showing the pulmonary veins entering the left atrium; B. Ultrasound image of the four-chamber view with closed atrioventricular valves-normal offset of the valves, with the tricuspid valve inserted higher than the mitral valve; C. Three-dimensional volume slice similar to the four-chamber view revealing the offset of the atrioventricular valves and the pulmonary veins drainage into the left atrium.
LV: left ventricle; LA: left atrium; RV: right ventricle; RA: right atrium; PVs: pulmonary veins; TV: tricuspid valve; MV: mitral valve; IVS: interventricular septum; IAS: inteatrial septul; AF: atrial flap.

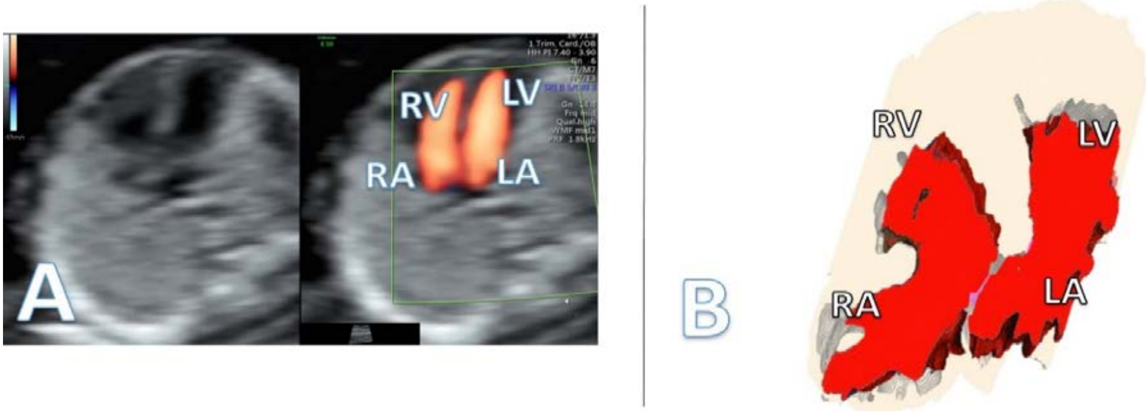

Figure 3. Evaluation of the atrio-ventricular fluxes. A. Ultrasound duplex mode revealing two parallel, individual and equal atrioventricular flows; B. Three-dimensional visualisation of the atrio-ventricular flows represented by the heart cavities volumes extracted separately.
LV: left ventricle; LA: left atrium; RV: right ventricle; RA: right atrium

The next planes of interest are represented by the outflow tracts: left ventricle outflow tract in Figure 4 and right ventricular outflow tract in Figure 5.

During the left ventricular outflow tract, the septum aortic continuity is and important element (Figure 4).

This element was easily seen in our model.

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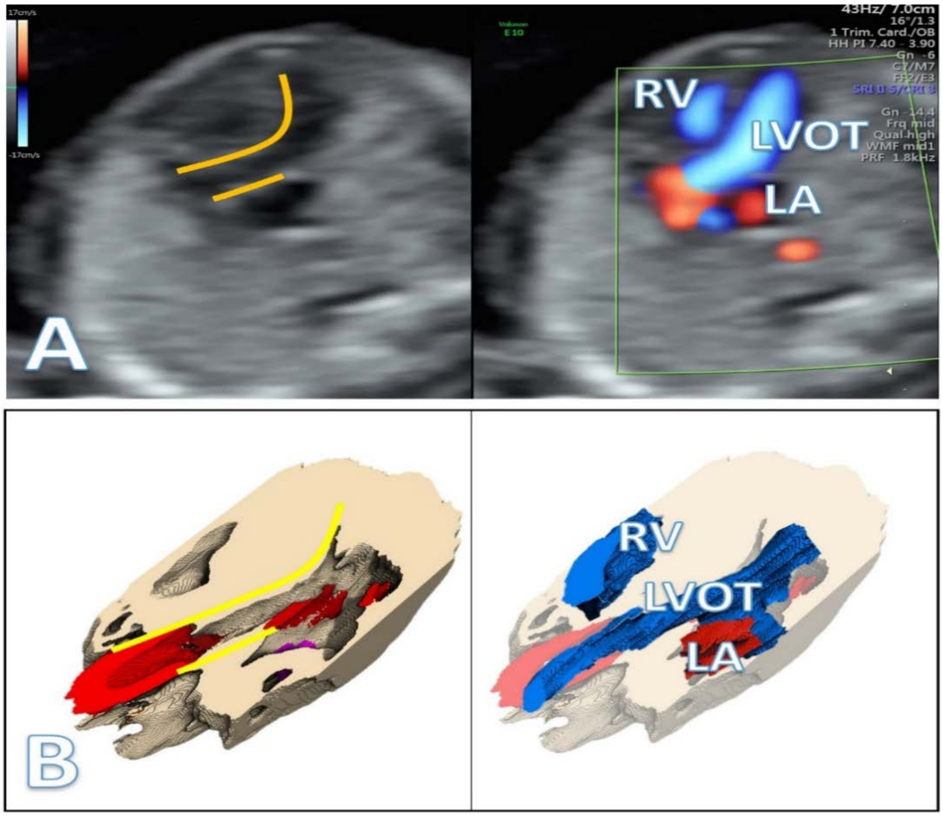

Figure 4. Evaluation of the left ventricular outflow tract. A. Ultrasound duplex mode showing the septoaortic continuity in grey mode (left, marked by yellow lines) and normal left ventricular outflow tract. B. Three-dimensional representation identifying the septoaortic continuity (left, marked by yellow lines) and visual representation of the cavities and vessels volume resembling the Doppler examination (right) RV: right ventricle; LVOT: left ventricle outflow tract; LA: left atrium

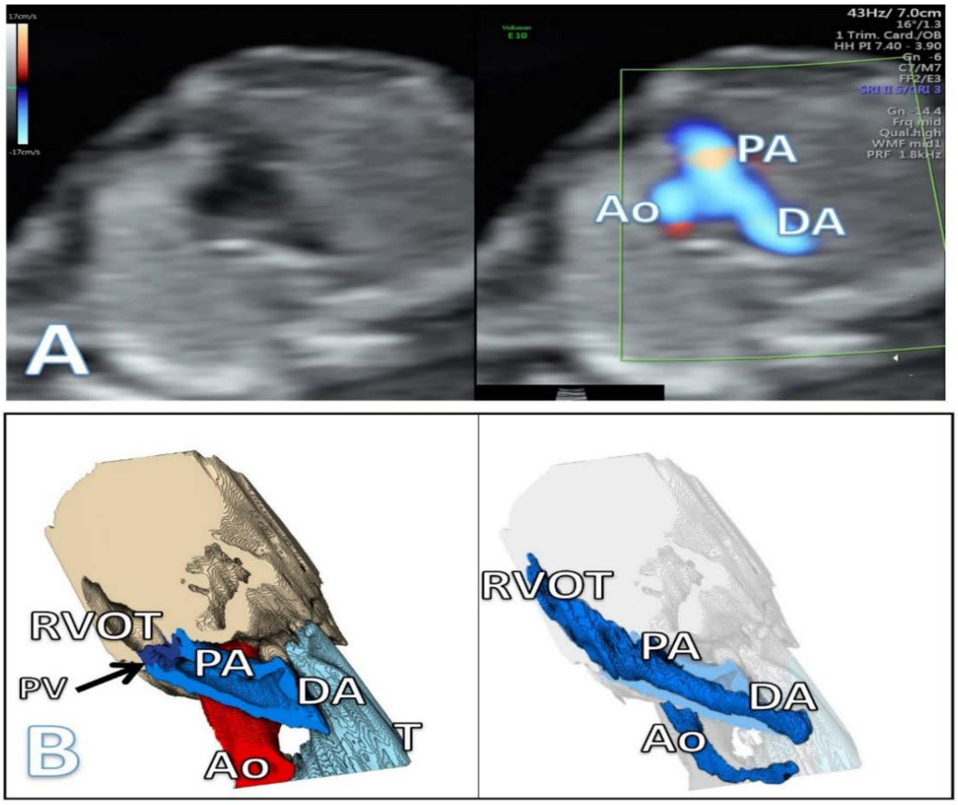

Figure 5. Evaluation of the right ventricular outflow tract. A. Ultrasound duplex mode showing normal right ventricular outflow tract. B. Three-dimensional representation identifying the right ventricular outflow tract and nearby elements (left) and visual representation of the cavities and vessels volume resembling the Doppler examination (right). RVOT: right ventricle outflow tract; PV: pulmonary valve; PA: pulmonary artery; DA: ductus arteriosus; Ao: aorta; T: trachea

The cardiac sweep ends with the “V-sign” formed by the pulmonary and aortic arches.

An important aspect is represented by its position.

In normal fetuses, this arch is formed on the left of the spine.

Unfortunately, our models do not include the spine however, this aspect can be overcome by its relationship to the trachea.

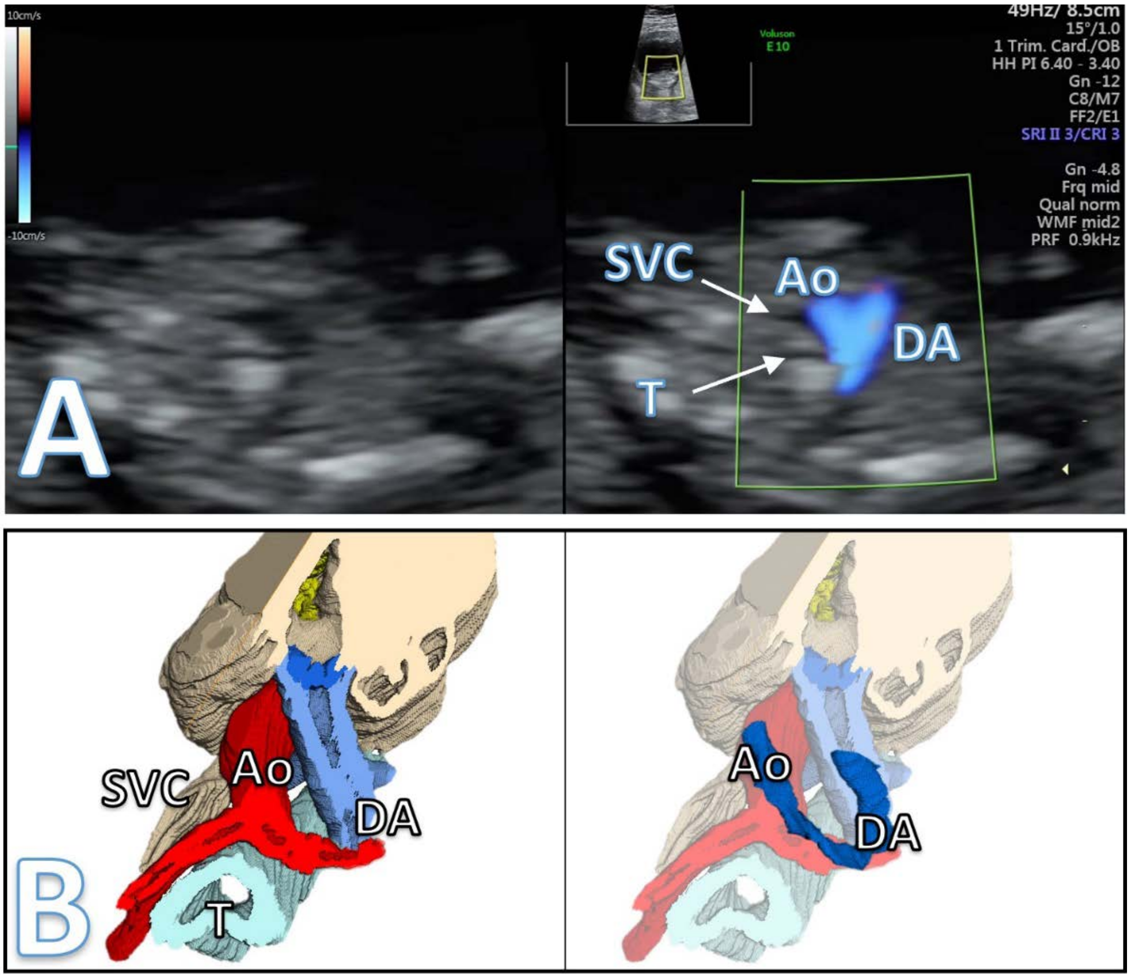

Figure 6. Evaluation of the arterial arches, the three-vessel trachea plane. A. Ultrasound duplex mode showing the classic “v-sign” formed by the aorta and ductus arteriosus. B. Three-dimension volume illustrating the anatomical elements which form the 3VT plane.
SVC: superior vena cava; Ao: aorta; DA: ductus arteriosus; T: trachea

Discussions

Pregnancy outcome and management relies on early detection of a fetal malformation.

Patient counselling is better performed and it offers the family time to make an informed decision.

Early termination of pregnancy is favored as it has a lower risk for the mother's physical and mental health [8,9].

Since proper patient treatment depends on the capacity of health workers to use the machine competently and interpret findings appropriately, training of health personnel is a key component of excellent implementation of obstetric ultrasound services [10,11].

There is a shortage of healthcare workers qualified to provide ultrasound services in many low to medium income countries [12,13].

Additionally, the majority of fetal defects that need to be detected during pregnancy are quite uncommon.

Supplementary materials used as a complementary method of learning and understanding the acquired ultrasound images can increase the number of specialist able to perform ultrasound examinations [14,15] and refer patients when deviations from normal anatomy are detected.

Our models can be used as an additional material of learning or improving fetal echocardiography skills, especially for young specialist at the start of their career.

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Histological analyses remain the cornerstone of pathological diagnosis and research.

Presently, classical microscopy is progressively being replaced by digital pathology, which photographs tissue sections to create digital, high-resolution entire slide pictures (WSI) [16].

Due to the fact that our protocol involved the entire fetal heart to be sectioned, stained and scanned to create the 3D volumes, the histological images are retained and digitalized in the process.

This presents an opportunity to study the histological samples.

The need of a method for study of the ultrasound acquired images can be seen in the literature, where studies have compared sonography with pathological sections [17,18].

The usefulness of these studies is indisputable; however, the lack of 3-dimensional exploration can be seen as a drawback as only one plane can be explored and compared with the ultrasound examination.

Hazell et al. [19] investigated how simulation-based training might help radiography students become more clinically ready.

Their meta-synthesis showed that using simulations that are authentic, realistic, and pertinent to a professional's growth within the framework of that field best prepares students for clinical practice.

This can also be applied to any imagistic speciality profession.

There is a lot of data to support the idea that active student learning is better for learning quality and learning experience than passive learning [20-22].

By exploring a 3D model, trainees can see all of the structures, their relationship to each other and not only can the key ultrasound planes be recreated using sections of the volumes, but the entire volume can be explored in any desired section plane.

We acknowledge that this study is limited to the normal aspects of the fetal heart echography.

Further studies are required to include models of possible fetal hearts defects which can be detected in the first trimester.

However, the first step into fetal anatomy scan is represented by the establishment of normal structures.

If deviations from normality are seen, the patient can be referred to an experience sonographer for further investigations.

Another limitation is represented by the static aspect of the 3D volume.

The heart is in a continuous motion due to the contractility function which induces motion to the ventricular cavities, the atrioventricular valves and the great vessels valves as well as the interatrial flap.

These aspects can be overcome in a future study where animation is added to these volumes to better simulate the live examination.

Conclusions

Exploring the three-dimensional volume of the fetal heart can yield the ultrasound planes of interest used to determine the normalcy of the cardiac sweep used in the first trimester pregnancy.

Sonography education may benefit from the use of 3D volumes for trainees, but more studies are needed to identify the best ways to incorporate this technique in the learning process.

Furthermore, pathological 3D volumes are needed in order to create a complete method of understanding ultrasonography and why different anatomical elements are seen.

Conflict of interests

None to declare.

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