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Dynamic sequential cross-sectional scanning increases detection rate of congenital heart disease in sonographers: a prenatal ultrasound training program

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Abstract

Background Prenatal ultrasound is the preferred modality for diagnosing fetal congenital heart disease. Given issues of physician proficiency and hospital distribution, we propose a dynamic sequential cross-sectional scanning (SCS) to explore the feasibility of cardiac screening by sonographers with less than 5 years of experience in ultrasound.

Materials and methods Twenty residents were randomly divided into two groups, receiving training in the American Institute of Ultrasound in Medicine (AIUM) fetal echocardiography and the SCS method. According to the needs of training, the professional staff developed the theoretical knowledge question bank, the CHD ultrasonic video disease bank, and the assessment scale. Trainees completed the pre-training examination, theory and skill operation training, and post-training assessment. For the two groups, the theoretical knowledge, skill operation and disease diagnosis were analyzed statistically before and after training.

Results After training, the trainees in both groups had significantly improved knowledge and diagnostic abilities, their diagnostic thinking about CHD was clear, and they could identify major or even all structural abnormalities and make a definite diagnosis. In terms of skill operation, both groups could complete all required scanning within the specified time. The scanning time of the SCS group was significantly lower than that of the AIUM group, and the effect of the receptor site in the AIUM group was significantly higher than that in the SCS group.

Conclusion SCS can be used as a new rapid fetal cardiac scanning method and try to popularize among echocardiographer.

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Keywords Fetal echocardiography, Congenital heart disease (CHD), Sequential cross-sectional scanning, Training program.

Introduction

Congenital heart disease (CHD) is a leading cause of infant morbidity and mortality from birth defects [1–3]. Fetal echocardiography is the best method for prenatal examination of the fetal heart [4–6]. Although this has been recognized, the rates of missed diagnosis, misdiagnosis, and infant mortality are still very high [4]. Due to economic factors, medical resources, examination time and many other factors, fetal echocardiography is difficult to popularize, and regular follow-up is even more difficult. PubMed searches for existing country guidelines indicate [2, 7, 8] that fetal echocardiography must be performed for a valid medical reason, such as a paternal or maternal diagnosis of CHD, high-risk factors in the fetus or mother, and the indication of CHD by other routine prenatal screening required by guidelines. However, most cases of CHD occur in fetuses at low risk, which is consistent with literature reports [2, 9].

Prenatal ultrasound guidelines formulated by the Chinese Medical Doctor Association Ultrasound Branch classify fetal echocardiography as a targeted examination and a Grade IV prenatal ultrasound examination, which is the highest level. The methods and requirements of the examination refer to the American Institute of Ultrasound in Medicine (AIUM) fetal echocardiography guideline [10]. Level 3 examinations involve the systematic examination of the anatomical structure. The heart is evaluated using the International Society of Ultrasound in Obstetrics and Gynecology (ISUOG) five section method to rule out major structural abnormalities. Level I tests are only basic biological measurements. Level II tests require the exclusion of only six major malformations specified by the Ministry of Health, including anencephaly, severe encephalocele, severe open spina bifida, severe sterno-abdominal wall defects with visceral eversion, a single-chamber heart, and fatal chondrodysplasia. For the heart, only a four-chamber view is needed. A referral for a Level IV test is made only if an anomaly is found in a level I-III test. In addition, China's relevant laws strictly stipulate the qualification requirements for doctors and hospitals to perform Grade III and IV examinations. In China, the educational pathway for sonographers is under the category of clinicians and also requires residency training. Sonographers who have been practicing obstetrics and gynecology (OBGYN) ultrasound for at least five years are qualified to perform prenatal diagnostic screenings [10]. As the level increases, the requirements increase. In the province where our center is located, only 43 hospitals, or less than 10%, are currently able to perform level III tests; even fewer (only 14 hospitals) are able to perform level IV tests, and any prenatal tests must follow the principle of informed choice and volunteerism. Therefore, according to China's national conditions, medical resources, low pregnancy screening awareness among pregnant women and many other factors, most pregnant women receive only one level III test from 18 to 24 weeks gestation, and some pregnant women are unable to complete any level III tests within the prescribed time and receive only level I or II tests.

Combined with China's national conditions, a cardiac examination method that can be popularized among non-fetal echocardiographer, especially for residents with less than 5 years of experience in ultrasound, is urgently needed; this method should be convenient, quick and easy for examiners to accept and understand, so that every pregnant woman can undergo the examination to the maximum extent, CHD can be diagnosed as early as possible and the rate of missed diagnosis and misdiagnosis of CHD can be reduced.

The ISUOG notes that the examination of the fetal heart is still based on the transverse section. According to our clinical experience and based on the principle of fetal heart anatomy and MR imaging, to popularize a comprehensive evaluation of the fetal heart among non-fetal echocardiographer, we proposed dynamic sequential cross-sectional scanning (SCS) based on the ISUOG five section method [11]. From the standard section of abdominal circumference, the probe followed the great vascular structure of the heart in a continuous cross-section until it disappeared to the mediastinum. Fetal cardiac development was evaluated by continuous cross-sectional tracking of the connections of the great vessels of the heart, walking and spatial structure. If the fetus was in an unfavorable position and/or with substantial shadowing from skeletal structures, the imaging beam was adjusted to the opposite side of the spine to complete the examination. The difference from the ISUOG scanning method is that the SCS method is more extensive and can assess the complete structure of the heart, including the ductus venosus and aortic branches. Continuous dynamic tracking is more conducive to finding the structural abnormalities of the great vessels of the heart and accurately diagnosing CHD. The suspected cardiac condition is determined by observing the relationship between the abnormal structure and peripheral anatomy. In our examination, there was no significant difference between the SCS detection rate and fetal echocardiography. The examination time of the SCS method was shorter, approximately 3 min, and that with the AIUM method was 5 min. SCS sections are easier to obtain, are less affected by the fetal position, gestational age, and examiner's manipulation, and are more conducive to the examiner's understanding and diagnosis [11]. This current study was conducted to explore the feasibility of promoting the SCS among performing fetal examinations.

Materials and methods

Materials

Trainees

A total of 20 OBGYN sonographers in our center with less than 5 years of experience in ultrasound were included. None of them had been exposed to Level III and IV examinations. They were randomly divided into two groups, one group was taught the AIUM fetal echocardiography method and the second group, SCS method (AIUM group/SCS group).

Training teachers

Two senior physicians in our center who had more than 10 years of experience in fetal echocardiography and able to conduct both methods of examination (AIUM and SCS) provided the training.

Pregnant women in the normal group

Pregnant women at 20–28 weeks of gestation with a BMI<30 kg/m^2 and without other known abnormality fetuses were screened by the training teachers, and all pregnant women signed informed consent forms.

Theoretical question bank of two groups

The two training teachers provide 400 single-choice questions and 100 multiple-choice questions to form the input software system of the theoretical question bank and assigned the difficulty coefficient value. The content covered cardiac anatomy, fetal hemodynamics, fetal echocardiography guidelines and disease diagnosis.

CHD gallery

In the early stage, the center established the two groups of CHD ultrasonic video disease bank for the same cases according to the AIUM/SCS scanning methods. A total of 43 cases of CHD were submitted by the training teachers. The training teachers retained images and videos according to the requirements of the AIUM and SCS methods to form the AIUM and SCS galleries. Good image quality and a clear structure display were required. The content covered fetal echocardiography to assess congenital heart disease, including duplicate diseases. The training teacher assigned different difficulty coefficients to each disease according to the type of CHD and the difficulty of diagnosis and input them into the software system.

Methods (Fig. 1)

Pre-training assessment

This assessment included theoretical knowledge, film reading, and skill operation.

Theoretical knowledge During the exam, questions were randomly selected by the software to form theoretical papers with similar difficulty coefficients. Each paper included 40 single-choice questions, accounting for 80% of the exam, and 10 multiple-choice questions, accounting for 20% of the exam.

Film reading During the exam, dynamic and static images of ten types of CHD were randomly selected from the AIUM gallery, requiring similar difficulty coefficients and no duplication of disease species. Scores were given based on the number of abnormal structures identified and the accuracy of diagnosis (supplementary Table 1).

Skill operation All structural scans were performed by using the fetal echocardiography guidelines within the prescribed time (15 min) according to the present level. If the heart structure could not be observed due to fetal position, a second examination could be performed after changing the position, with no more than two scans per fetus (note that only the scanning time was recorded, and the total time should not exceed 15 min). The time that the pregnant women were standing and performing activities was not included in the scanning time. Each trainee completed 5 fetal examinations on different patients, and the average examination time was taken.

All assessments were supervised and graded by the training teacher. The grading table is shown in supplementary Tables 1 and Table 2. The assessment results and answers will not be published, and there will be no guidance, communication or explanation.

Training process

Theoretical training Intensive theoretical training covering cardiac anatomy, fetal hemodynamics, fetal echocardiography guidelines and disease diagnosis was provided.

Operation training The AIUM group: According to the AIUM guidelines, this group obtained the four-chamber view of the heart, the section of the left and right ventricular outflow tracts, the section of the three-vessel trachea, the short-axis view of the great artery, the short-axis view of the heart, the long-axis view of the aortic arch, the long-axis view of the ductus arteriosus, and the section of the superior and inferior vena cava (Fig. 2).All sections should be scanned with gray scale combined color Doppler scan.

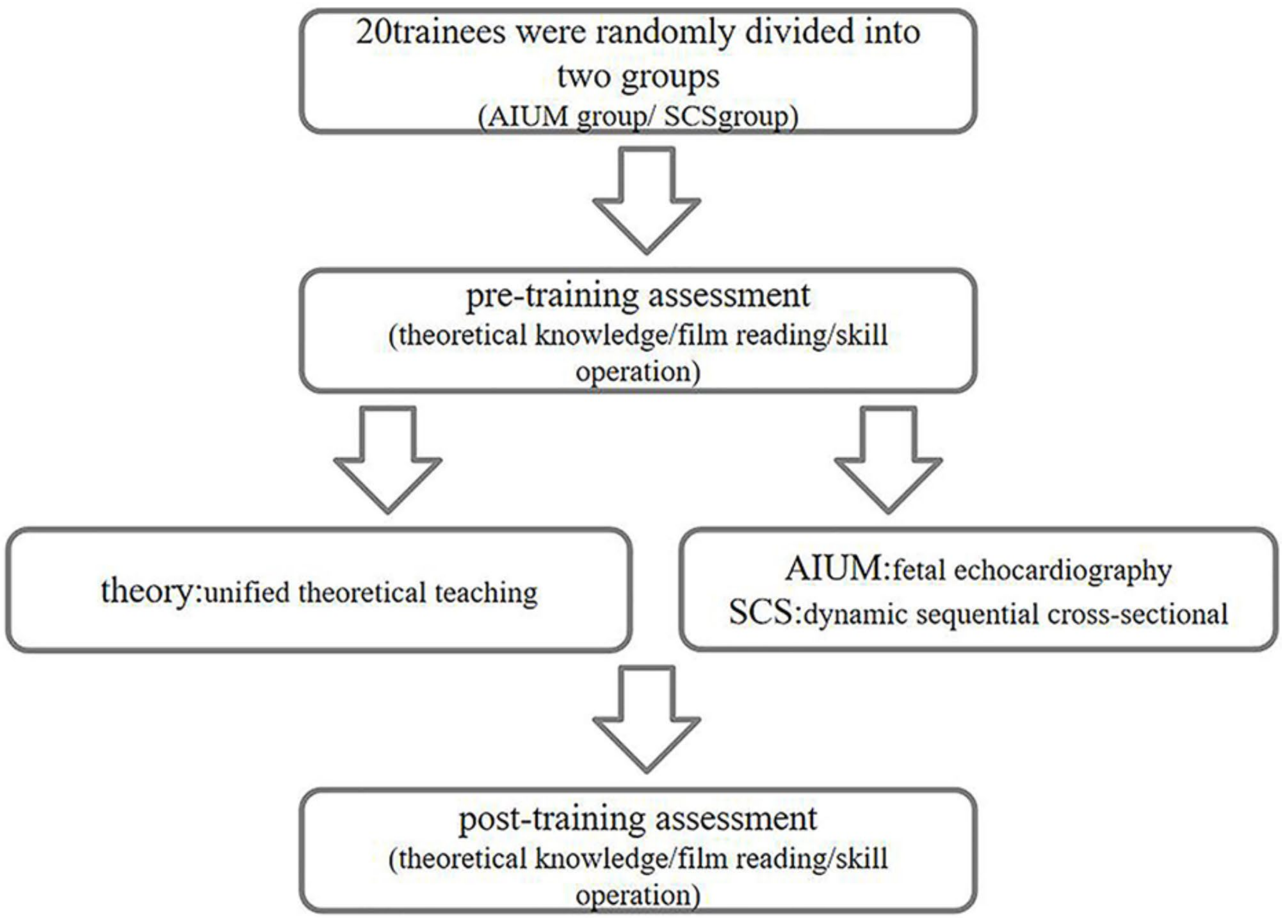

Fig. 1 Training program flow chart

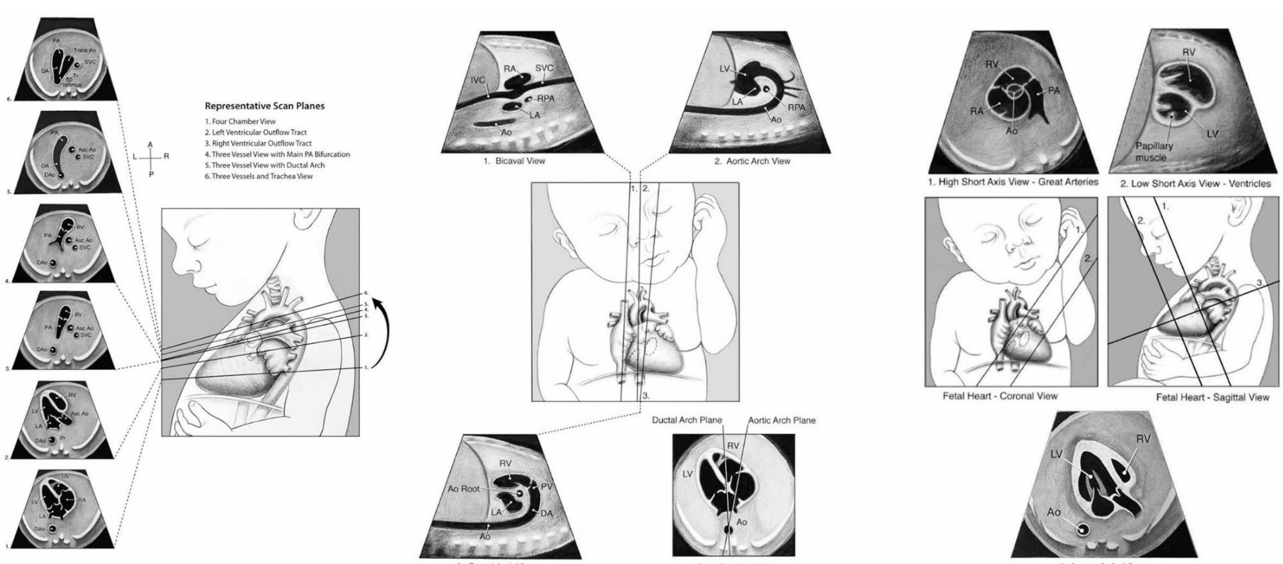

Fig. 2 AIUM guidelines for fetal echocardiography for cardiac evaluation Section[2]

The SCS group: Following to the anatomy of the heart and the connection of the great vessels, starting from the standard section of the abdominal circumference, the probe moved cephalically along the long axis of the body until the superior mediastinum disappeared, following the anatomical structure in successive cross-sections. During the scanning process, the probe moved appropriately according to preserve continuity of the cross-section and image quality of the structure to be observed (Fig. 3). The beam could be repositioned to the opposite side of the spine if skeletal shadowing was present. (Supplementary video file 1–3). The whole dynamic scanning process should be combined with gray scale and color Doppler scanning.

The training teacher first gave a teaching demonstration, explained the skills and requirements of scanning sections, observed the key points, and then let the students perform the scan, correcting and guiding the students in real time. The total heart examination time for each normal fetus was no more than 15 min, and each trainee practiced 30 times in total.

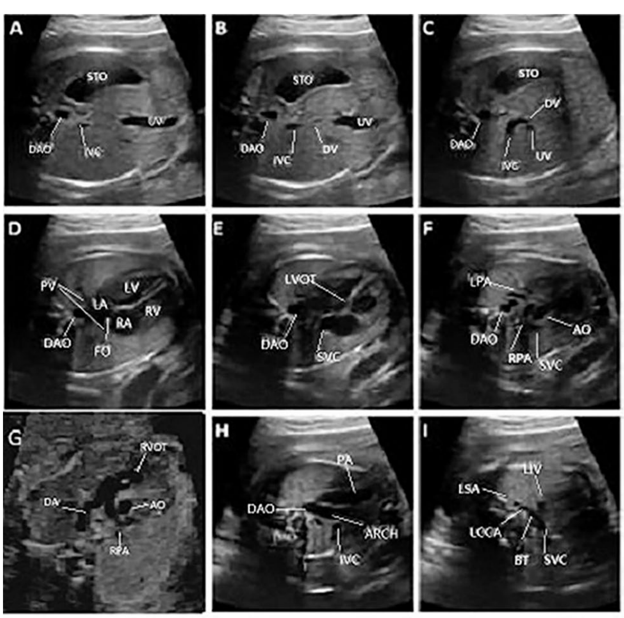

Fig. 3 (**A-I**)The SCS videos were decomposed into pictures, and the contents were observed in sequence according to the scanning sequence[12]: Stomach (STO), descending aorta (DAO), inferior vena cava (IVC), umbilical vein (UV), ductus venosus (DV), hepatic vein (HV), left ventricular (LV), left atrium (LA), right ventricular(RV), right atrium (RA), foramen ovale (FO), pulmonary vein (PV), left ventricular outflow tract (LVOT), superior vena cava (SVC), left pulmonary artery (LPA), right pulmonary artery (RPA), aorta (AO), pulmonary artery (PA), arterial duct (DA), aortic arch (ARCH), trachea (T), left innominate vein (LIV), left subclavian artery (LSA), left common carotid artery (LCCA), brachiocephalic trunk (BT)

Post-training assessment

Theoretical knowledge The examination form and method were the same as those used before training.

Film reading The AIUM gallery was used in the AIUM group, and the SCS gallery was used in the SCS group to complete the diagnosis of CHD in 10 cases from the previously established CHD gallery. The examination form and method were the same as those used in the pretraining period.

Skill operation According to different operation methods, each group scanned the structure to be observed in the guide within the specified time and retained the images and videos. Incomplete scanning over 15 min was recorded as 15 min, while the actual recording time was less than 15 min. Each trainee completed 5 fetal examinations, and the average examination time was taken.

Statistical analysis

The rank sum test was used to analyze the theoretical examination, film reading and skill operation before and after training, and the time for the two groups to complete the scan was analyzed.

Results

Grasp of theoretical knowledge before and after training

Before the training, participants had little knowledge of the fetal heart. After the unified theoretical training, the trainees' knowledge had significantly improved and they had a certain understanding of the latest guidelines. The average score of the AIUM group increased from 48.5 to 94 points and that of the SCS group increased from 46.5 to 94 points, and there was no significant difference between the AIUM group and SCS group (Tables 1 and 2).

CHD diagnosis after training

Before training, the radiographic diagnosis within the CDH gallery of the AIUM group and SCS group was poor; the AIUM group scored only 33.2, and the SCS scored only 35.6 (Table 1). The trainees could only find a few structural cardiac abnormalities, which made it difficult to make a clear diagnosis, and the diagnostic ability for CHD was poor. After training, the AIUM group scored 89 points, and the SCS group scored 90 points. Referring to diagnoses made by two senior physicians, the diagnostic ability of both groups was significantly improved, the diagnostic ability for CHD were clear, and the trainees could identify major or even all structural cardiac abnormalities and make definite diagnoses (Tables 1 and 2).

Table 1 Assessment score before and after training

Items	AIUM group	Z	*p*	SCS group	Z	*p*
Theory Pre-training	47.5(40.0,56.3)	-3.803	0.000	45.0(40.0,52.5)	-3.805	0.000
Theory Post-training	95.0(90.0,100.0)			95.0(90.0,100.0)		
Radiographic diagnosis pre-training	31.0(27.0,40.5)	-3.785	0.000	37.0(29.5,42.0)	-3.813	0.000
Radiographic diagnosis post-training	89.0(85.5,92.5)			90.0(88.0,90.5)		
Skill operation Pre-training	33.0(29.0,40.0)	-3.797	0.000	34.0(27.5,36.5)	-3.792	0.000
Skill operation post-training	88.0(85.5,90.0)			90.0(88.0,95.0)		
Scanning time	10'16''(5'6'',12'50'')	-	-	4'37''(3'55'',5'19'')	-	-

Table 2 Original score before and after training

Group		Theory	Radiographic diagnosis	Skill operation	Scanning time
		Pre-training/Post-training	Pre-training/Post-training	Pre-training/Post-training	
AIUM group	Trainee1	45/90	40/92	44/90	4'27''
	Trainee2	40/95	28/82	30/84	11'32''
	Trainee3	55/100	30/84	30/86	12'42''
	Trainee4	60/100	46/96	40/90	6'45''
	Trainee5	35/85	24/86	26/82	14'32''
	Trainee6	40/90	32/90	30/88	11'15''
	Trainee7	50/95	20/88	26/86	13'17''
	Trainee8	60/100	42/94	40/92	4'19''
	Trainee9	45/90	30/90	36/88	9'17''
	Trainee10	55/95	40/88	38/90	5'20''
Average		48.5/94.0	33.0/88.6	34.2/87.2	9'20''
SCS group	Trainee1	50/95	42/90	38/94	4'11''
	Trainee2	60/100	46/96	40/98	3'17''
	Trainee3	45/95	40/90	34/90	4'20''
	Trainee4	40/90	38/88	36/92	4'55''
	Trainee5	30/90	24/88	24/88	5'17''
	Trainee6	65/100	42/90	34/100	3'25''
	Trainee7	40/90	30/92	34/88	5'14''
	Trainee8	45/100	30/90	28/86	7'19''
	Trainee9	40/85	28/86	26/90	4'05''
	Trainee10	50/95	36/90	30/88	5'27''
Average		47.0/95.0	36.0/90.0	32.0/91.2	4'45''

Skill operation before and after training

The rating scale in supplementary Table 2 was used to score each group. Before training, sonographers in both groups could only determine the standard section of the abdominal circumference and the four-chamber section of the heart to evaluate the position, size and direction of the heart axis, and their evaluation of the connection and direction of the atrioventricular and great vessels was poor. After training, the two groups were able to complete the fetal heart assessment within the prescribed time (Tables 1 and 2).

Comparison of the operation time between the SCS group and AIUM group

The average completion time of the AIUM group was approximately 9' 20'', and 17 of the 50 fetuses needed to be reexamined after changing positions for postural reasons. The average completion time of the SCS group was approximately 4'45'', and only four of the 50 fetuses needed to be repositioned. The time of fetal heart evaluation in the SCS group was significantly lower than that in the AIUM group (Table 2).

Discussion

Fetal echocardiography provides real-time images of multiple cardiac structures and is the preferred tool for prenatal cardiac screening [12]. However, due to a number of factors, such as the time and cost of testing, the difficulty of diagnosis and the lack of professional doctors, it should only be performed in high-risk groups or in cases of suspected heart abnormalities. Missed diagnosis and misdiagnosis of CHD still occur. Fetal echocardiography is not widely available, and most pregnant women can only receive examinations of the basic structure of the heart. In China, there are still some pregnant women who cannot undergo the systematic structure examination in a timely manner for various reasons. Therefore, there is an urgent need to popularize fetal heart screening by sonographers [13]. The idea is that a routine obstetric examination, even a level I-II ultrasound, in a pregnant woman can quickly assess the heart, maximize the screening for CHD, and assess prognosis.

At present, AIUM fetal echocardiography guidelines are adopted to evaluate the content and section requirements of fetal echocardiography in China, including the long axis and short axis: the four-chamber view of the heart, left and right ventricular outflow tract view, long-axis view of the aortic arch, long-axis view of the ductus arteriosus arch, three-vessel trachea view, long-axis view of the superior and inferior vena cava view, short-axis view of the great artery and short-axis view of the ventricle. This method is a comprehensive and systematic assessment of the structure, connection, and course of the great vessels of the heart. However, it is highly dependent on fetal position and gestational age, the operator's manipulative experience, fetal anatomy, and spatial imagination and requires a solid theoretical foundation and rich experience in the diagnosis, understanding, and scanning of CHD. It is very difficult to handle such a screening by teaching alone.

The ISUOG five-section method is used in the level III ultrasound examination of the fetal heart in China, including the section of abdominal circumference, the four-chamber section of the heart, the left and right ventricular outflow tract views, and the three-vessel trachea section. The method is convenient to use, easy to master, and beneficial to the evaluation of major structural abnormalities of the heart, but no obvious assessment requirements were made on structures such as the venous catheter and aortic arch brachial branch. For example, the right subclavian artery vagus, right arch with mirror branch, right arch with left subclavian artery vagus, and absence of the venous catheter are easily missed and misdiagnosed. The ISUOG notes that the examination of the fetal heart is still based on the transverse section. In China, the ISUOG method is classified as level III screening, which is restricted to sonographers with over five years of experience in OBGYN ultrasound and who have passed the examination. This has made it challenging to promote the method among sonographers. Sonographers who have not reached the age limit or who do not specialize in obstetrics and gynecology can only perform level I and II prenatal screening in their daily work. The SCS method is a convenient and fast method of fetal heart structure examination proposed based on the ISUOG method. The method is easy to operate and understand for sonographers, and enables detection of fetal cardiac structural abnormalities during level I and II prenatal ultrasound examinations for pregnant women.

Comparing the SCS method with fetal echocardiography assessed by AIUM guidelines, (1) there is no significant difference between the detection rate. (2) The scan of the long-axis section is avoided and lacks angle dependence, so the fetal position and gestational age have relatively little influence. 3)The whole examination is shorter and can be completed in the third trimester. 4) It is less affected by operator experience and proficiency. It starts from the standard section of abdominal circumference, which is a regular section that all sonographers must master. 5) Many cardiac anomalies cannot be visualized on standard views due to the frequent combination of specific structural abnormalities. This is difficult for young doctors and beginners. SCS can help trainees and early career to clarify their thinking, identify abnormalities and facilitate diagnosis through a cross-sectional tracking structure. Through continuous dynamic tracking, the condition can be better evaluated by observing the relationship between structural and space. Given the feasibility of SCS, we can try to popularize the SCS method among young doctors and beginners.

China's national conditions include a large population, birth policy liberalization, economic factors, a lack of trained doctors and other comprehensive factors. We are working to expand the SCS approach to more non-specialist prenatal sonographers. We carried out this training project, which consisted of a pre-training assessment, training process, and post-training assessment. According to the data of this project, before training, all the trainees had little knowledge about the fetal heart, and some of them did not even know about the special hemodynamics of the fetus and the latest guidelines. After unified theoretical training, the knowledge of the trainees was significantly improved after training, and they had a certain understanding of the latest guidelines. The average score increased from 48.5 to 94 points in the AIUM group and from 46.5 to 94 points in the SCS group. For the diagnosis of CHD, before training, only a few students could detect structural cardiac abnormalities in the four-chamber plane. They had difficulties in identifying structural abnormalities in other sections, and their diagnostic thinking was poor, which could not lead to a clear diagnosis. The most obvious disease is mainly vascular ring disease. Many students do not understand the composition of various vascular rings, the course of abnormal blood vessels, especially the diagnosis and differential diagnosis of right aortic arch with mirror branch and double aortic arch. After training, Students can easily understand the composition of the two blood vessels, branch walking, and can actively assess prognosis. Compare to the diagnosis result with two senior physicians, the diagnostic ability of both groups was significantly improved, and the diagnostic ideas of CHD were clear, and the trainees could identify major or even all structural abnormalities and make a definite diagnosis. For skill operation, after training, the SCS group was able to complete the fetal heart assessment within the prescribed time, and the position did not need to be changed in 92% of the fetuses. Trainees in the AIUM group were also able to complete the fetal heart assessment within the specified time, but due to the influence of fetal position, 33% of the fetuses needed to undergo a second scan after their position was changed. For the skill operation time, the time of fetal heart evaluation in the SCS group was significantly shorter than that in the AIUM group. Therefore, our data confirmed the feasibility of the integration of the SCS method especially among trainees and early learners of cardiac sonography.

Conclusion

SCS can be used as a method of rapid scanning of the fetal heart, worthy of promotion in sonographer education. It is suggested that sonographers can master the SCS operation method just as they master the abdominal section method so that every pregnant woman can undergo the maximum CHD screening and regular monitoring to assess prognosis.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12909-024-06154-y.

Supplementary Material 1: Supplementary Table 1 Review the diagnostic score sheet (There are 10 questions on a 10-point scale).

Supplementary Material 2: Supplementary Table 2 Skill operation rating scale (percentage scale).

Supplementary Material 3-4: Supplementary video 1–2: Fetal heart scan with SCS.avi.

Supplementary Material 5: Supplementary video 3: If the orientation of the probe is adjusted, the non-standard section of the fetal heart is changed to the standard section of the fetal heart.avi.

Supplementary Material 6: Supplementary video 4: Right aortic arch with mirror branch: SCS method of gray scale and color Doppler scanning video.

Supplementary Material 7: Supplementary video 5: Double Aortic arch: SCS method of gray scale scanning video.

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Author contributions

Y Z, CX Z: the conception of the study. J W, YY Z, YC X, M F: Data collection and analysis. Y Z: Manuscript writing. All authors reviewed the manuscript.

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Data availability

Data is provided within the manuscript or supplementary information files.

Declarations

Ethics approval and consent to participate

This study was performed in line with the principles of the Declaration of Helsinki. Approval was granted by the Ethics Committee of the First Affiliated Hospital of Anhui Medical University's Institutional Review Board (PJ2022-08-46). All pregnant women and their families understood the procedure of the experiment and signed informed consent.

Consent for publication

Every participant in the study agreed to publish the article.

Competing interests

The authors declare no competing interests.

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References

1. Donofrio MT, Moon-Grady AJ, Hornberger LK, et al. Diagnosis and treatment of fetal cardiac disease: a scientific statement from the American Heart Association. Circulation. 2014;129:2183–242.
2. AIUM Practice Parameter for the Performance of Fetal Echocardiography. J Ultrasound Med. 2020;39:E5–16.
3. Pekin AT, Kerimoğlu OS, Yilmaz SA, et al. Pentalogy of Cantrell accompanied by scoliosis and pes equinovarus deformity at 12 weeks gestation. Clin Exp Obstet Gynecol. 2015;42:392–4.
4. Behera SK, Ding VY, Chung S, et al. Impact of fetal echocardiography comprehensiveness on diagnostic accuracy. J Am Soc Echocardiogr. 2022;35:752–e76111.
5. Słodki M, Respondek-Liberska M. Fetal echocardiography: one of the most important tools in fetal diagnosis and assessing wellbeing. J Clin Ultrasound. 2022;50:636–8.
6. Shuping Ge MD, Dev Maulik MD, Introduction. From fetal echocardiography to fetal cardiology: a journal of over half a century. Echocardiography. 2017;34:1757–9.
7. International Society of Ultrasound in Obstetrics and Gynecology, Carvalho JS, Allan LD, et al. ISUOG Practice guidelines (updated): sonographic screening examination of the fetal heart. Ultrasound Obstet Gynecol. 2013;41:348–59.
8. Satomi G. Guidelines for fetal echocardiography. Pediatr Int. 2015;57:1–21.
9. Sun HY. Prenatal diagnosis of congenital heart defects: echocardiography. Transl Pediatr. 2021;10:2210–24.
10. Li, Shengli. Deng Xuedong. Guidelines for prenatal ultrasound (2012). Chinese Journal of Medical Ultrasound (Electronic Edition), 2012, 9: 574–580. [in Chinese].
11. Yi Zhou W, Qiu S, Jiang D, He C, Zhang. A rapid and convenient fetal heart screening proposal based on dynamic sequential cross-section. J Med Imaging Health Inf. 2019;9:1083–5.
12. Nakwan N. The practical challenges of diagnosis and treatment options in persistent pulmonary hypertension of the newborn: a developing country's perspective. Am J Perinatol. 2018;35:1366–75.
13. Sharland G. Fetal cardiac screening and variation in prenatal detection rates of congenital heart disease: why bother with screening at all? Future Cardiol. 2012;8(2):189–202.