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Fetal echocardiography at 11 + 0 to 13 + 6 weeks using four-dimensional spatiotemporal image correlation telemedicine via an Internet link: a pilot study

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KEYWORDS: cardiac defects; congenital heart disease; fetal echocardiography; first trimester; nuchal translucency; spatiotemporal image correlation; STIC; telemedicine

ABSTRACT

Objectives *To assess whether spatiotemporal image correlation (STIC) volumes from fetuses at 11 + 0 to 13 + 6 weeks' gestation can be obtained by a non-expert and whether fetal echocardiography can be performed via a telemedicine link, providing a remote and reproducible diagnosis of the fetal heart condition.*

Methods *STIC volume datasets from 35 fetuses at 11 + 0 to 13 + 6 weeks were obtained prospectively by a general obstetrician, transmitted via the Internet and subsequently analyzed systematically by two different reviewers. Forty-nine pregnancies were initially enrolled into the study, but adequate volumes were not obtained for 14. Thirty-four datasets were obtained on transabdominal and one on transvaginal ultrasound examination. A checklist was used that included 18 structures and views relating to the fetal heart evaluation, and each reviewer assigned the variables as normal, abnormal or unsure. Cohen's kappa analysis was used to evaluate the agreement between reviewers and the reported findings were compared with the outcome where available.*

Results *The mean gestational age was 12 + 3 weeks and the mean (range) crown–rump length was 68 (47–84) mm. The mean maternal age was 33 (range, 26–41) years; 12/35 (34%) were older than 35 years. The four-chamber view obtained was apical in 22/35 (63%) cases and lateral in 13 (37%). Volume datasets were obtained after 12 weeks' gestation in 30/35 fetuses. Three cases had nuchal translucency thickness above the 99th percentile, and two of these had an abnormal heart. Five cases had abnormal outcomes. A mean of 3 (range, 1–6) STIC datasets per patient were acquired. The kappa index obtained confirmed interobserver reliability, with good or very good concordance (kappa > 0.6) in 14/18 structures and views related to the heart.*

Conclusions *STIC volumes acquired between 11 + 0 and 13 + 6 weeks' gestation could be sent over the Internet and their analysis enabled recognition of most of the structures and views necessary to assess the small fetal cardiac anatomy, with a high degree of interobserver concordance. Copyright © 2008 ISUOG. Published by John Wiley & Sons, Ltd.*

INTRODUCTION

Nuchal translucency (NT) measurement is well established as a method of first-trimester ultrasound screening for chromosomal abnormality, and increased NT is a recognized indication of a need for more detailed fetal cardiac assessment[1–3]. The first line of management of these pregnancies should be to offer the parents the option of fetal karyotyping by chorionic villus sampling. If the karyotype is normal, a detailed scan including fetal echocardiography should be carried out[4]. It has been reported recently that a wide range of cardiac defects can be identified by targeting particular high-risk groups for early specialist echocardiography, such as those with significantly increased NT or those with appearances indicating possible abnormality[5,6]. Within this high-risk group, early fetal echocardiography is effective in identifying major abnormalities, thus avoiding false-positive diagnoses[7–10]. However, specialist fetal echocardiography can only be offered in these cases if such services are available. In many countries, access to this examination would clearly

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be limited by the small number of fetal echocardiographers and pediatric cardiologists with expertise to interpret the small fetal cardiac structures. Major changes would be needed in the way specialist fetal echocardiography services are provided if all euploid fetuses with increased NT were to have access to fetal echocardiography[4].

Telemedicine could offer a solution to the shortage of specialists in fetal heart diagnosis. Recently, our group reported how spatiotemporal image correlation (STIC) volumes from mid- and third-trimester fetuses can be acquired by operators inexperienced in fetal echocardiography, and transmitted via the Internet to a specialist who can then examine most of the structures and views necessary to assess the fetal cardiac anatomy[11]. The objective of this study was to assess whether STIC volume datasets from fetuses at 11 + 0 to 13 + 6 weeks' gestation could be obtained by a non-expert and if fetal echocardiography could be performed via a telemedicine link (TELE-STIC), providing a remote and reproducible diagnosis of the fetal heart condition.

METHODS

STIC volume datasets from fetuses at 11 + 0 to 13 + 6 weeks were obtained by a general obstetrician (R.A.) performing routine ultrasound imaging in a private practice in Lima, Peru, and subsequently analyzed systematically by two different reviewers (F.V. and I.H.) located remotely in Concepción, Chile, and London, UK. The operator had certification for NT assessment, training in the interpretation of cardiac images from STIC volume datasets and 4 years' experience in the use of a STIC-capable Voluson 730 ultrasound scanner (730 Expert version 3.1.174 2004, GE Medical Systems, Zipf, Austria), equipped with a 4–8-MHz transabdominal and a 5–9-MHz transvaginal transducer. Offline analysis was performed using Voluson 4DView software.

Forty-nine singleton pregnancies at 11 + 0 to 13 + 6 weeks' gestation were prospectively evaluated over a 2-month period. The primary reason for the scan was NT measurement. In each case, the operator attempted to obtain a STIC volume of the fetal heart within a period of 20 min. Patients gave oral informed consent for storage of volumes and for offline evaluation. None of the patients had any previous family history of heart defect or maternal diabetes mellitus.

The operator attempted to obtain a four-chamber view as a starting point, both in gray scale and using color Doppler. The following color Doppler settings were used: frequency low, color flow map 1, flow resolution low, artifact off, smoothing 4/4, line filter 2, ensemble 14, line density 7 and balance > 200. The methodology of STIC acquisition has been reported previously[11]. A standard 7.5-s acquisition time and 15° angle of acquisition were used. Before transmission for offline analysis, the STIC volumes were reduced in size using a standard compression included in the 4DView software (wavelet compression 'lossy' and quality 90). Volumes were uploaded from Lima, Peru, to a web disk on a private server and then downloaded to be analyzed by the two reviewers independently.

A checklist was used that included 18 structures and views relating to the fetal heart evaluation (Table 1). Each reviewer assigned the variables as normal, abnormal or unsure. Cohen's kappa analysis was used to evaluate concordance between reviewers. Neonatal condition was assessed up to 28 days after birth when possible and compared with the reviewers' results.

RESULTS

An appropriate apical or lateral four-chamber view acquisition was obtained successfully in 35/49 (71%) consecutively examined fetuses over a 2-month period. In 14 cases the fetal position or fetal movements were such that it was not possible to image the fetal heart and obtain the appropriate STIC volume within the allocated

Table 1 Concordance of visualizing different structures and views of the fetal heart using spatiotemporal image correlation telemedicine by two reviewers

Variable	*Kappa*	P
Stomach on the left	1	< 0.001
IVC and abdominal aorta arrangement	0.397	0.003
Normal heart size	1	< 0.001
Cardiac apex on same side as stomach	0.639	< 0.001
Cardiac axis 45°	1	< 0.001
Two equal-sized atria	1	< 0.001
Two equal-sized ventricles	0.82	< 0.001
Two opening atrioventricular valves	1	< 0.001
Intact ventricular septum in 4CV	0.82	< 0.001
Intact crux	0.895	< 0.001
At least one pulmonary vein to left atrium	0.536	< 0.001
Intact ventricular septum in LV outflow tract	0.666	< 0.001
Two great arteries identified	0.657	< 0.001
Great arteries crossing	0.478	0.001
Great arteries equal in size	0.558	< 0.001
Arch and duct similar in size in transverse view	0.721	< 0.001
Forward flow in both arches	0.611	< 0.001
Left aortic arch	0.624	< 0.001

4CV, four-chamber view; IVC, inferior vena cava; LV, left ventricle.

Table 2 Characteristics of patients and spatiotemporal image correlation volume datasets transmitted

Variable	*Mean (range)*	*Comments*
Maternal age (years)	33 (26–41)	12/35 (34%) older than 35 years
Crown–rump length (mm)	68 (47–84)	30/35 CRL > 59 mm
Nuchal translucency (mm)	2.4 (1–10)	3/35 NT > 99th percentile
Volumes sent per patient (*n*)	3 (1–6)	2 cases with 1 gray-scale VD
Size per volume transmitted (MB)	5.9 (1.6–13.0)	Size postcompression
Birth weight (g)	3269 (2820–4000)	—

MB, megabytes; VD, volume dataset.

Table 3 Summary of cases with abnormal findings or suspected abnormal findings in the spatiotemporal image correlation telemedicine (TELE-STIC) evaluation of the fetal heart and fetuses with abnormal outcome

MA (years)	*CRL (mm)*	*NT (mm)*	*Findings on TELE-STIC evaluation*	*Outcome*
38	69	1.4	Normal fetal heart	IUFD, autopsy declined
41	60	10.0	Crux, interventricular septum and PV drainage of uncertain evaluation (both reviewers)	TOP, autopsy declined
27	58	2.0	Ventricular disproportion, small LV, VSD or AVSD, single great artery with thick valve, PLSVC	Trisomy 13, miscarriage
39	83	3.0	Normal fetal heart	Miscarriage, 46,XY
27	47	8.0	AVSD, ventricular disproportion, stomach not seen, right aortic arch?	Miscarriage, 46,XY
37	84	2.4	Ventricular disproportion	No abnormalities identified postpartum
36	66	3.5	Tricuspid regurgitation (color flow)	No abnormalities identified postpartum
34	64	1.3	Tricuspid regurgitation (color flow)	No abnormalities identified postpartum

AVSD, atrioventricular septal defect; CRL, crown–rump length; IUFD, intrauterine fetal death; LV, left ventricle; MA, maternal age; NT, nuchal translucency; PLSVC, persistent left superior vena cava; PV, pulmonary vein; TOP, termination of pregnancy; VSD, ventricular septal defect.

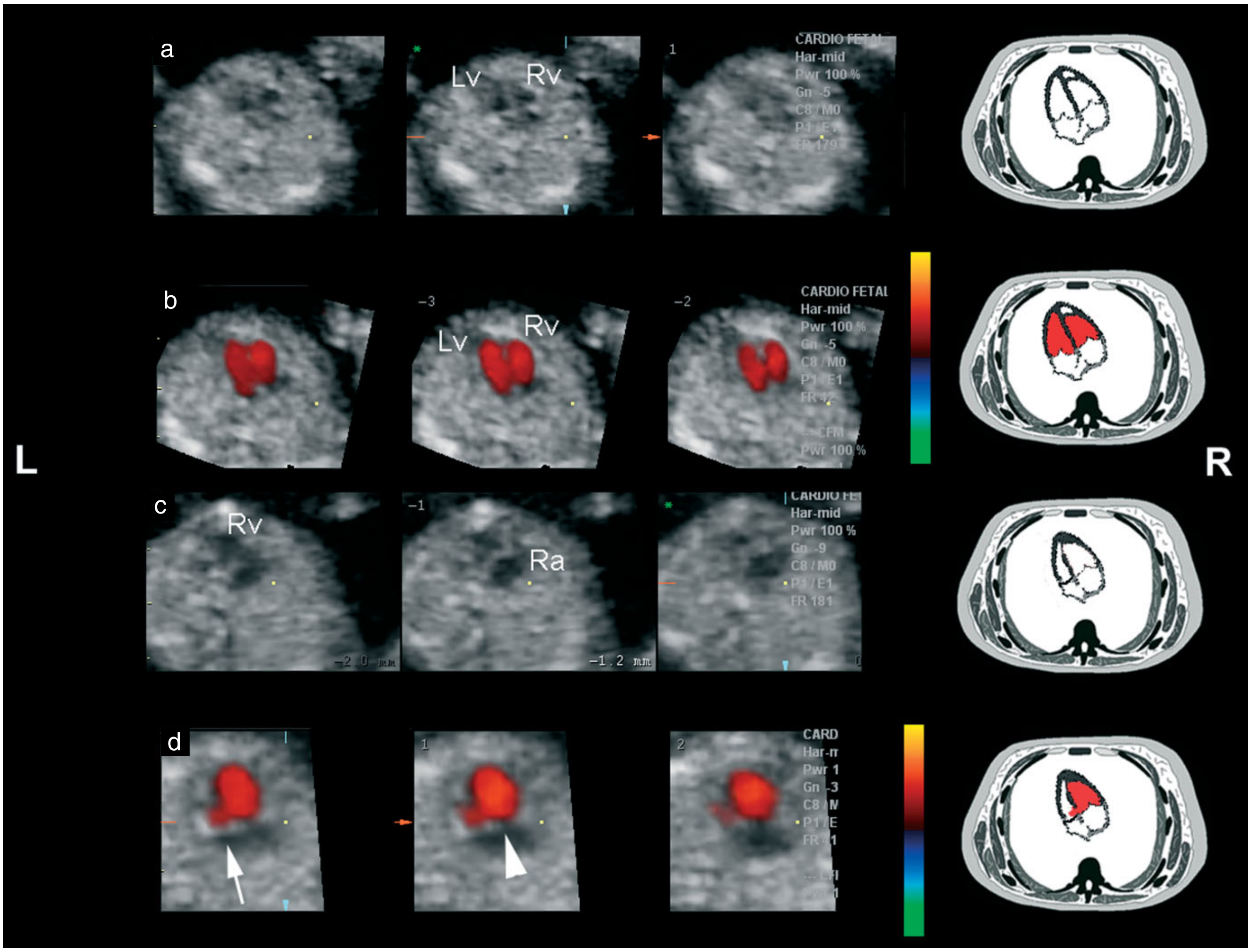

Figure 1 Tomographic ultrasound imaging sections analyzed offline by a fetal echocardiographer from STIC volumes obtained by a non-expert. Gray-scale (a and c) and color Doppler (b and d) images of the four-chamber view of fetuses with a normal (a and b) and abnormal (c and d) heart at 12 + 6 weeks' gestation are displayed. Note the disproportionately small left ventricle and absence of flow across the thick left atrioventicular (AV) valve (arrow) in (c) and (d). Flow across the right AV valve is shown (arrowhead). L, left; Lv, left ventricle; R, right; Ra, right atrium; Rv, right ventricle.

20-min period. Nine of these cases had a crown–rump length (CRL) between 45 mm and 58 mm, and in two cases maternal habitus could also have affected the image resolution.

The study population consisted of 35 singleton fetuses with a mean gestational age of 12 + 3 weeks, for each of which between one and six separate volumes were acquired. Volumes of 34 fetuses were obtained transabdominally and one was obtained transvaginally in a patient with retroverted uterus. The characteristics of patients and STIC volume datasets transmitted are shown in Table 2. Acquisition was performed after 12 weeks' gestation in 30/35 fetuses. In 22 cases (63%) an apical four-chamber volume was acquired and in 13/35 a lateral four-chamber volume. The distribution of cases according to CRL were as follows: five cases between 45 mm and 58 mm (11 + 0 to 11 + 6 weeks), 22 cases between 59 mm and 72 mm (12 + 0 to 12 + 6 weeks), and eight cases between 73 mm and 84 mm (13 + 0 to 13 + 6 weeks). Three cases had increased NT with a measurement above the 99th percentile for the normal range, according to the reference curves of The Fetal Medicine Foundation (http://www.fetalmedicine.com). Three other cases had NT measurements between the 95th and 99th percentiles, but normal heart anatomy and normal outcome.

The kappa index obtained in the comparison between analyses of the two reviewers confirmed interobserver reliability, with good and very good concordance (kappa > 0.6) in 14/18 structures and views related to the heart (Table 2). Only in the evaluation of the inferior vena cava and abdominal aorta arrangement was low concordance found (kappa < 0.4).

The five cases with abnormal outcomes are described in Table 3. Cardiac abnormality was suspected by both reviewers in three of these cases. The two cases without abnormal cardiac findings on STIC evaluation but with an abnormal outcome both ended in spontaneous intrauterine death (at 14 weeks and 27 weeks) without autopsy. There was one false-positive case in which ventricular disproportion was suspected but the outcome was normal. Two other cases showed tricuspid regurgitation on color Doppler analysis, but normal fetal heart structure and normal outcome. Details and outcome of the eight cases with abnormal or suspected abnormal findings are shown in Table 3.

DISCUSSION

Measurement of first-trimester NT is increasingly being included in routine clinical practice as an established method of screening for chromosomal abnormalities. The method for measurement is well described and a standardized approach ensures a high level of reliability. The measurement is easily acquired by skilled operators and demonstrates a high degree of reproducibility. Moreover, the transabdominal scan is acceptable to patients[1,12,13]. NT screening can also be used to identify fetuses at increased risk of other major anomalies, including cardiac defects[14–18]. In a meta-analysis of studies examining the relevance of NT thickness measurement in the detection of cardiac defects in fetuses with normal karyotype, detection rates were about 37% and 31% for NT cut-offs at the 95th and 99th centiles respectively[19]. In comparison, confining specialist fetal echocardiography to pregnancies

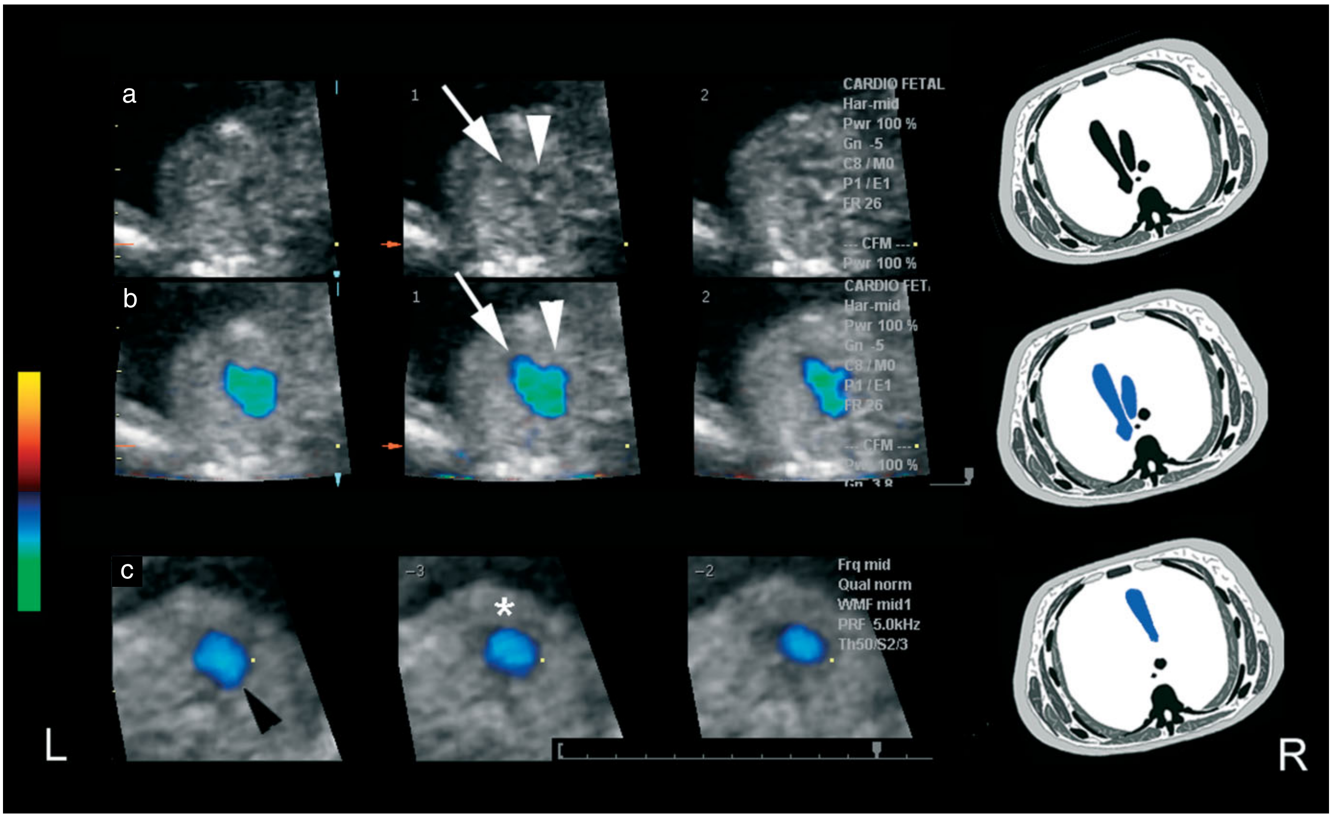

Figure 2 Tomographic ultrasound imaging sections analyzed offline by a fetal echocardiographer from STIC volumes obtained by a non-expert. Gray-scale (a) and color Doppler (b) images at the level of the three-vessel view from a 12 + 6-week fetus with a normal heart showing the pulmonary artery (arrows) and transverse aortic arch (arrowheads). In (c), the equivalent sections from a fetus with an abnormal heart (the same one as in Figure 1) reveal a single great artery (black arrowhead and asterisk).

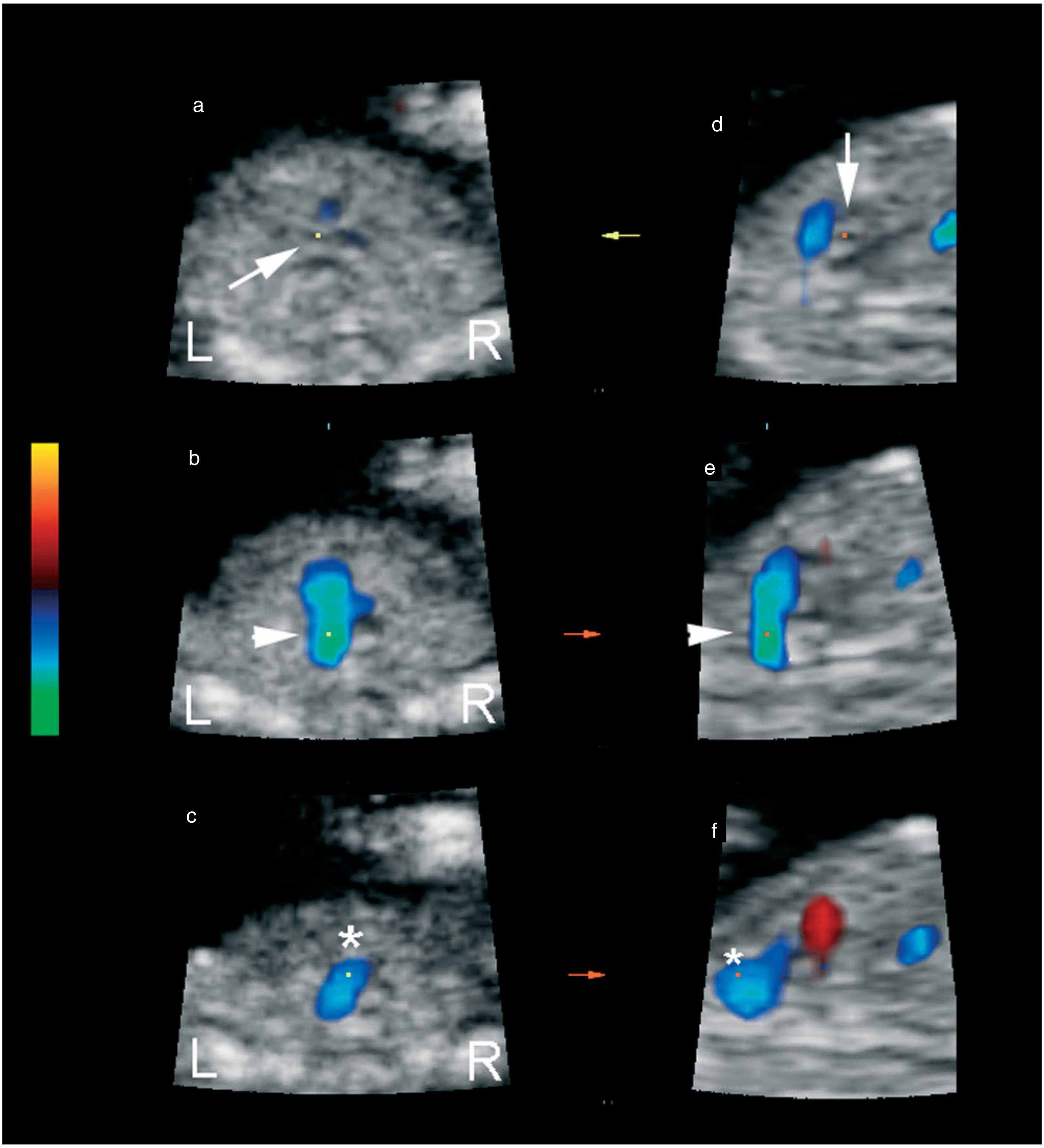

Figure 3 Color Doppler spatiotemporal image correlation of a normal fetal heart at 13 weeks. The original transverse plane of acquisition (a–c) and the sagittal plane (d–f) are displayed. The reference dot is positioned at the level of the ascending aorta (arrow) in the five-chamber view (a) and the corresponding sagittal plane displays the short-axis view (d). The reference dot is positioned at the level of the ductus arteriosus in the three-vessel and trachea view (b) and the corresponding sagittal view displays the ductal arch (arrowhead) (e). The reference dot (asterisk) is located at the transverse aortic arch, displayed in the transverse (c) and sagittal (f) planes. L, left; R, right.

with a maternal history of diabetes mellitus or exposure to teratogens and family history of cardiac defects offers only a 10% detection rate[20].

An NT-based screening program could thus identify a group of fetuses at risk of major cardiac defect[21]. It has been stated recently that first-trimester fetal echocardiography should be considered as an option for high-risk patients desiring information regarding the presence of detectable severe cardiac abnormalities[10]. The examination is feasible for accurately detecting major cardiac defects[22]. However, such screening is hindered by the shortage of fetal echocardiographers with the skills to assess small cardiac structures, while adequate image resolution and transducer frequency are necessary to assess the fetal heart in early pregnancy[10]. This situation limits access to specialist and secondopinion appointments, so telemedicine becomes an attractive option for diagnosis. Moreover, infrequent exposure of operators to abnormalities has been postulated as an important reason for disappointing results of screening of low-risk populations by early fetal echocardiography[23].

Our study demonstrates that volume datasets of the small fetal heart could be obtained by a properly trained non-expert operator and then transmitted for specialist analysis. By acquiring a mean of three volume datasets in a standardized format, most of them including at least one color Doppler acquisition, subsequent concordance is possible between two experts assessing the different structures and views of the fetal heart (Figures 1 and 2). Offline analysis provides the freedom to virtually re-scan the fetus, performing a new fetal echocardiogram, navigating and utilizing virtually all planes contained in the acquired volume (Figure 3). The use of a 15° rotation step for volume acquisition is sufficient for the fetal heart, but the acquisition needs to be centered slightly above the four-chamber view to acquire the stomach and the full aortic arch. The image resolution obtained was mainly good from 12 weeks' gestation onwards, enabling the experts to examine the images more thoroughly than with video or live scanning. Detection of subtle abnormalities, such as ventricular disproportion and isolated tricuspid regurgitation, was possible. Both findings are recognized as compatible with a normal outcome at later gestations[7].

The main limitation of the study was the incomplete verification of some of the cases with abnormal outcome. Pathological and postnatal correlation of fetal echocardiographic findings has been an essential part of the advancement of fetal cardiology[7,8]. However, in many Latin American countries there is a lack of specialists able to perform an adequate morphological analysis of small specimens of fetal hearts following intrauterine fetal death or termination of pregnancy.

Using a telemedicine link via the Internet is technically feasible. The STIC volumes acquired between 11 + 0 and 13 + 6 weeks' gestation could be sent over the Internet and their analysis enabled recognition of most of the structures and views necessary to assess the small fetal cardiac anatomy, with a high degree of interobserver concordance. The success of telemedicine based on STIC depends mainly on the quality of the acquired volume datasets.

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