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White paper

Value of 5D Heart Color™ Tool in Routine Use for Semiautomated Evaluation of Fetal Cardiac Structures

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Background

It has recently been shown that applying the Fetal Intelligent Navigation Echocardiography (FINE) method to spatiotemporal image correlation (STIC) volume data sets acquired with grayscale information in second- and third-trimester fetuses enables reconstruction of cardiac diagnostic planes of normal and abnormal hearts thereby allowing detection of congenital heart disease with a sensitivity up to 98 % [Garcia et al. 2016, Veronese et al. 2017, Yeo et al. 2018]. In 2017 Yeo & Romero published on additional color Doppler interrogation implemented in the FINE method investigated in a prospective cohort study [Yeo & Romero 2017]. They concluded that postprocessing STIC volumes of normal fetal hearts acquired with color or bidirectional power Doppler information can generate successfully eight to nine standard fetal echocardiography views. These features can readily be used in 5D Heart Color™ application integrated into the Samsung's high-end and premium ultrasound systems for comprehensive assessment of the fetal heart (Fig. 1 & 2).

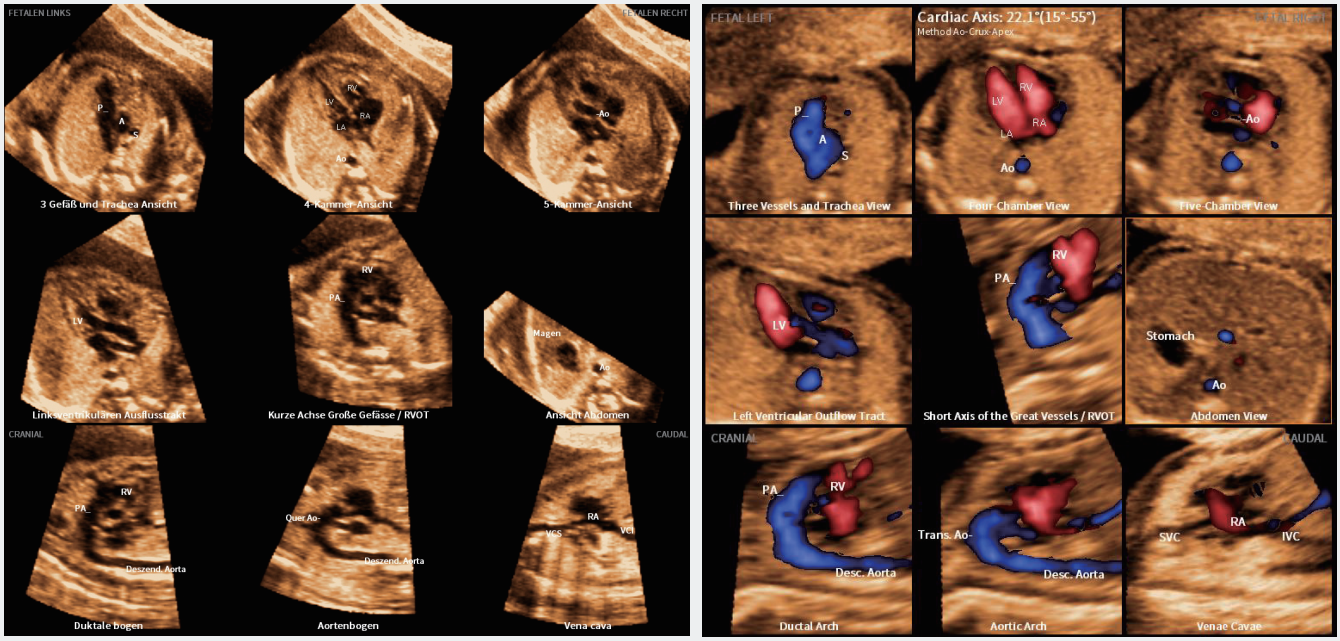

Fig. 1 Reconstruction of all diagnostic cardiac planes derived from a single STIC volume followed by application of 5D Heart Color™ (left panel), additional color Doppler information in 5D Heart Color™ (right panel).

Traditionally, during 2D scanning different maneuvers of the transducer are needed to complete an echocardiographic examination and to obtain all diagnostic planes either with or without color Doppler information [Chaoui&McEwing 2003, Huhta& Paul 2010]. As recently claimed by national and international guidelines, cardiac screening examination should include both the four-chamber view and outflow tract views [AIUM 2013, ISUOG 2013, Gerede et al. 2019]. Additional use of color flow Doppler is not considered mandatory in these guidelines, but is strongly encouraged by expert panels. In fact, color Doppler assessment constitutes an essential tool to the technique's ability to effectively evaluatei the fetal heart for both structural and functional diseases [Sklansky 2013].

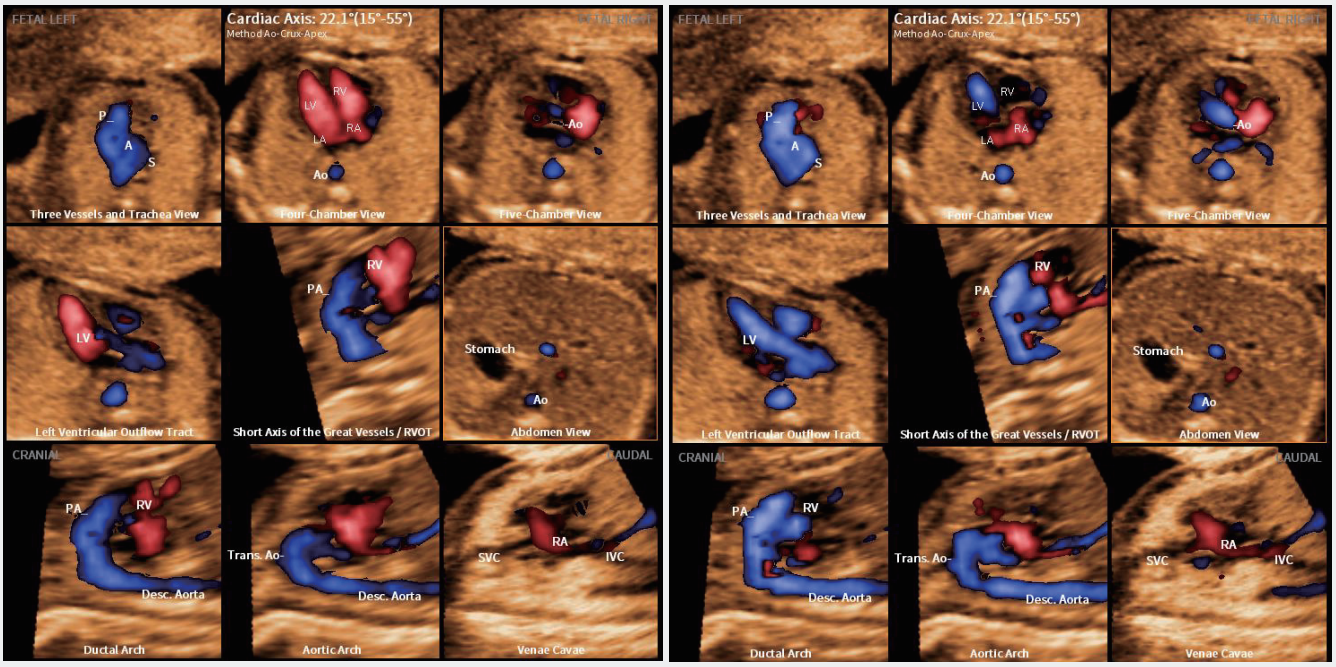

Fig. 2 Image display of 5D Heart Color™ during diastole (left panel) and during systole (right panel).

Echocardiographic examination of the outflow tracts and assessment of sagittal views

Beside the evaluation of four-chamber view, assessment of both ventricular outflow tracts and the course of the two great arteries increases the detection rate of serious fetal heart defects by 20 – 30 % [Berg et al. 2009]. In addition, exact knowledge of any changes in normal blood flow pattern across the outflow tracts is essential for making correct patho-anatomical diagnoses for further delineation of potential cardiac abnormalities [de Vore 1994; Nadel 2010].

With cranial angulation and tilting of the transducer from an four-chamber view, the five-chamber view is obtained. The left ventricular outflow tract (LVOT) appears bordered between the two atrioventricular valves, thereby showing the continuity of the posterior aortic wall with the mitral valve and the direct transition of the anterior aortic wall into the interventricular septum.

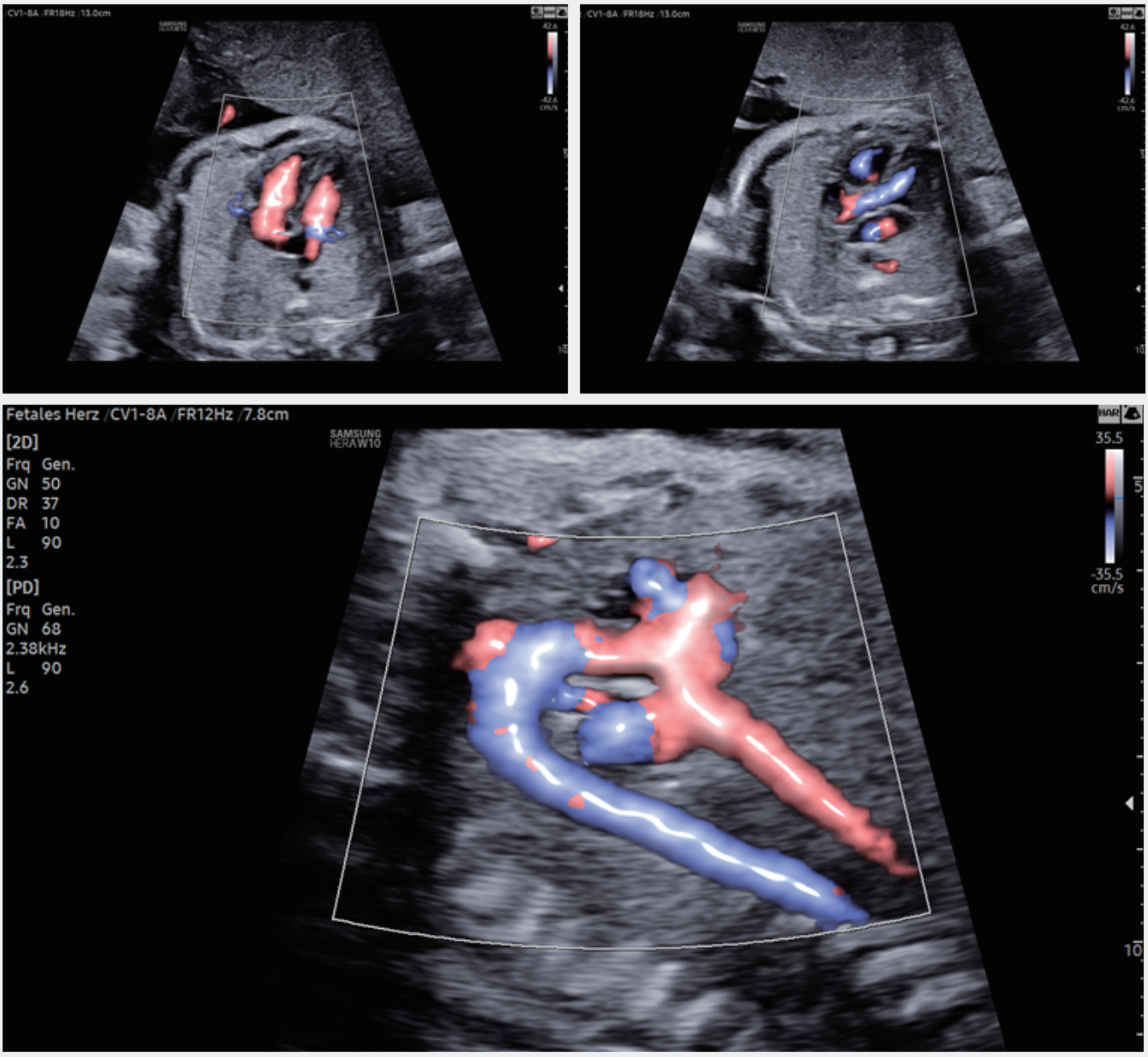

Fig. 3 Four-chamber view with color inflow across the Atrioventricular (AV) valves (left panel); five-chamber view showing aortic outflow (right panel) and aortic arch as seen with LumiFlow™ in HERA W10 (SAMSUNG MEDISON, CO. LTD., Korea) during conventional 2D scanning (lower panel).

For correct display of longitudinal views of the great vessels, the transducer should be rotated by 90 degrees (when starting from an exact axial plane) to obtain a sagittal view of the fetal chest. By shifting the probe slightly to the right and left parasagittal chest, three diagnostic planes are visualized – the aortic arch, ductal arch (with an angulation between 10° to 19° throughout pregnancy) and the bicaval view (Fig. 3 to 5). Exact depiction of these sagittal echocardiographic views reportedly appears to be one of the most challenging issues for less experienced operators. As stated above, application of 5D Heart™ reproducibly facilitates the acquisition of these planes.

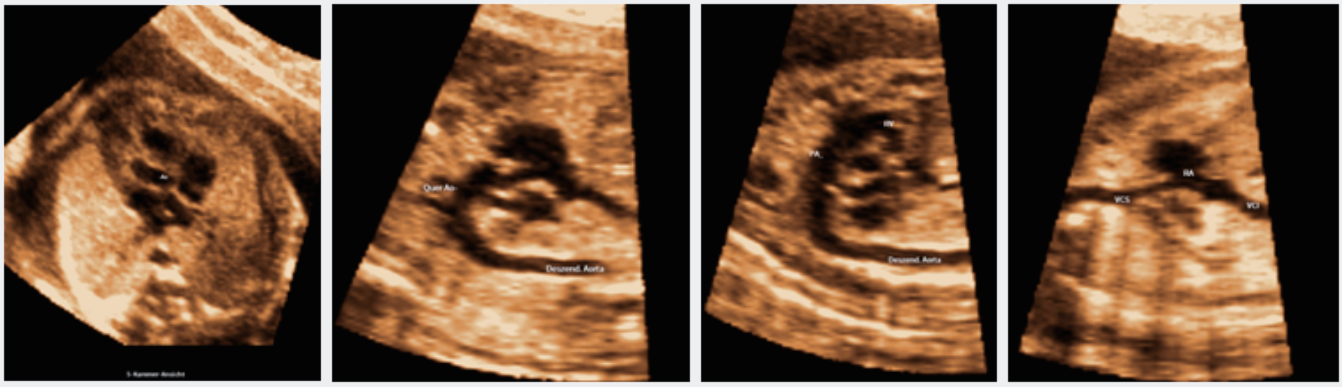

Fig. 4 Five-chamber view, aortic arch, ductal arch and bicaval view derived from semi-automatic reconstruction using 5D Heart™ (from left to right) showing normal anatomic integrity.

Material and Methods

After Doppler interrogation in 2D echo mode, image and Doppler adjustments and subsequent STIC volume acquisition obtained with the fetal spine between 5 and 7 o'clock (and less optimal between 3 and 9 o'clock), the 5D Heart™ technology was activated for volume reconstruction harboring color Doppler information for each of the nine diagnostic planes. 5D Heart Color™ are built-in, commercially available software installed on the high-resolution ultrasound system HERA W10 and WS80A (SAMSUNG MEDISON, CO. LTD., Korea). Details for system settings are well described in the aforementioned paper [Yeo & Romero, 2013].

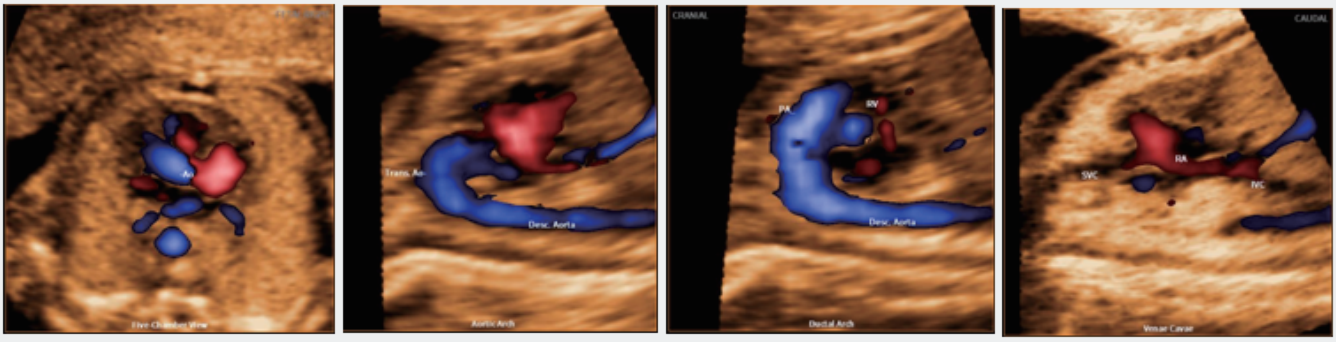

Fig. 5 Five-chamber view with color Doppler information, aortic arch, ductal arch and bicaval view and corresponding color flow mapping following 5D Heart Color™ application on color Doppler STIC volume datasets.

During a 4-year study period we stored STIC volumes of the heart of over 1,800 fetuses on which the workflow-based semi-automated 5D Heart™ software tool had been applied. The mean gestational age was 21.6 weeks (ranging from 11.0 to 38.0 weeks). One to 4 separate volumes were obtained per patient (mean 1.4 exams). The study population was comprised of 135 patients with congenital heart defects (minor and major lesions). In a subset of the enrolled volume datasets, we further studied the feasibility and clinical value of depicting additional color Doppler information using 5D Heart Color™ in each case, an extra volume postprocessed with 5D Heart™ w/o color was stored.

Results and Discussion

5D Heart Color™ allows a detailed analysis of blood flow hemodynamics in color Doppler STIC volumes in order to investigate normal (Fig. 6) and abnormal cardiac anatomy (Fig. 7). It has the potential to ease retrieval of even subtle volume data information in a standardized manner as stated above.

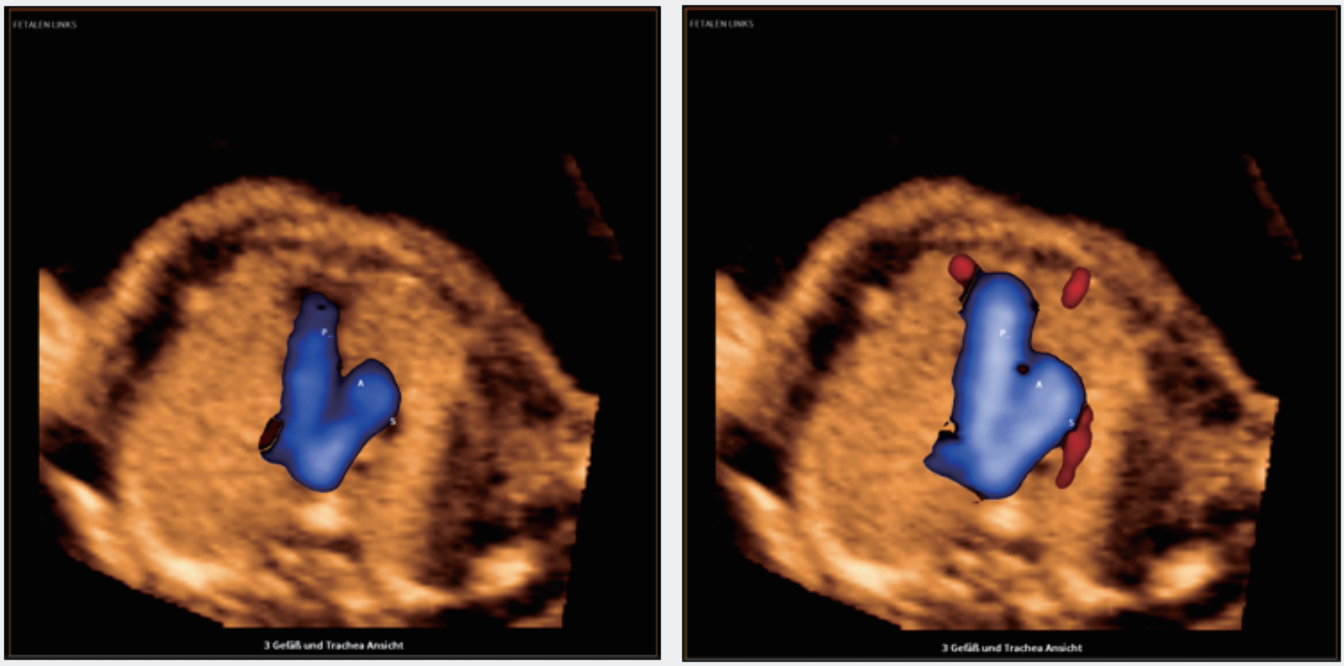

Fig. 6 Three vessel trachea view (3VT) depicting v-shaped connection of main pulmonary artery and transverse aortic arch via arterial duct (left panel), inflow of V. azygos into superior vena cava during cardiac cycle (right panel).

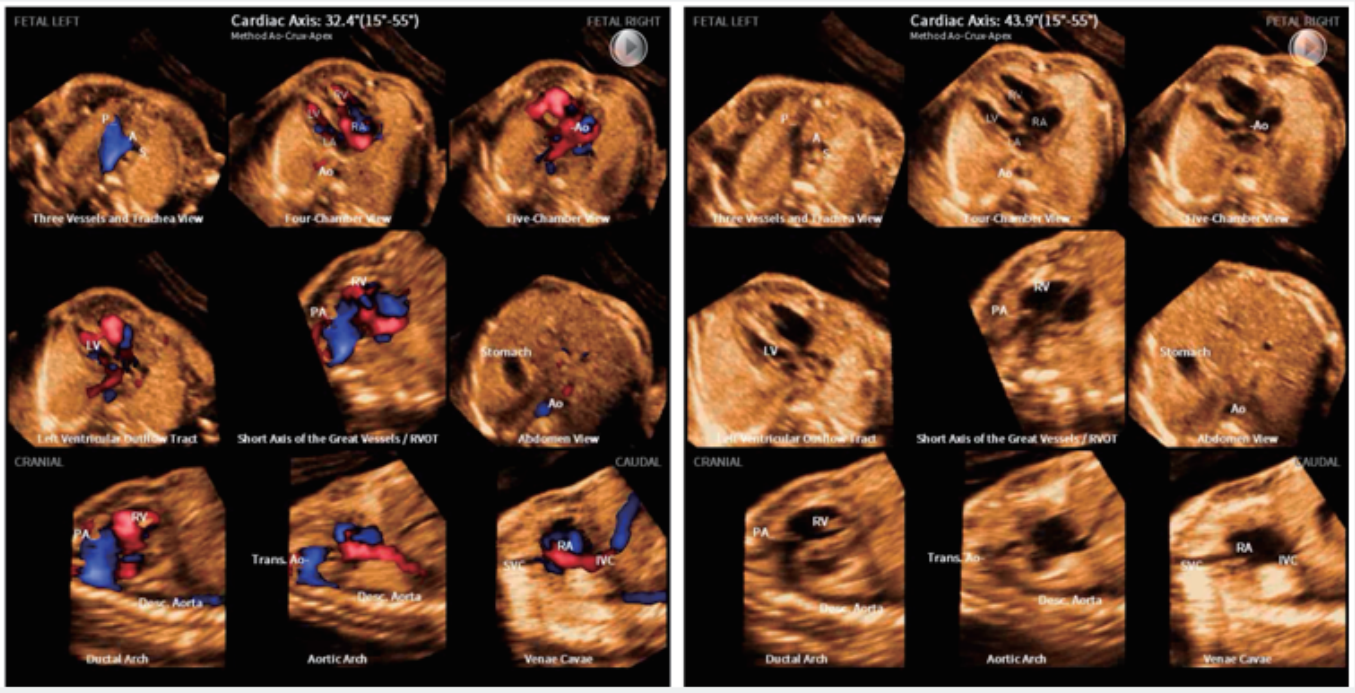

Fig. 7 STIC volumes resliced using 5D Heart Color™ (left panel) and 5D Heart™ technology (right panel) in a fetus with aortic coarctation.

As highlighted by Yeo and Romero in their aforementioned paper, additional assessment of color Doppler information in either five-chamber view (axial plane) or (para-)sagittal planes will give valuable information on cardiac structural and functional integrity and will contributes to a comprehensive fetal echocardiogram. Physiologically, in an axial five-chamber view systolic laminar blood flow signal in aortic root originating from the left ventricle is seen with normal aortic valve closing and non-regurgitant in diastole. In ductal and aortic arch view systolic perfusion either through main pulmonary artery and ductus arteriosus or ascending aorta and transverse aortic arch should be noticed with the head vessels arising from the latter. The bicaval parasagittal section shows normal blood flow through inferior and superior vena cava towards the right atrium (Fig. 5).

An abnormal color flow in the five-chamber view aids establishing the prenatal diagnosis in case of LVOT obstruction/disproportion (Fig. 8, 9 & 10) or abnormal relationships of the great vessels as seen in conotruncal anomalies such as tetralogy of Fallot, transposition of the great arteries, double outlet right ventricle and truncus arteriosus.

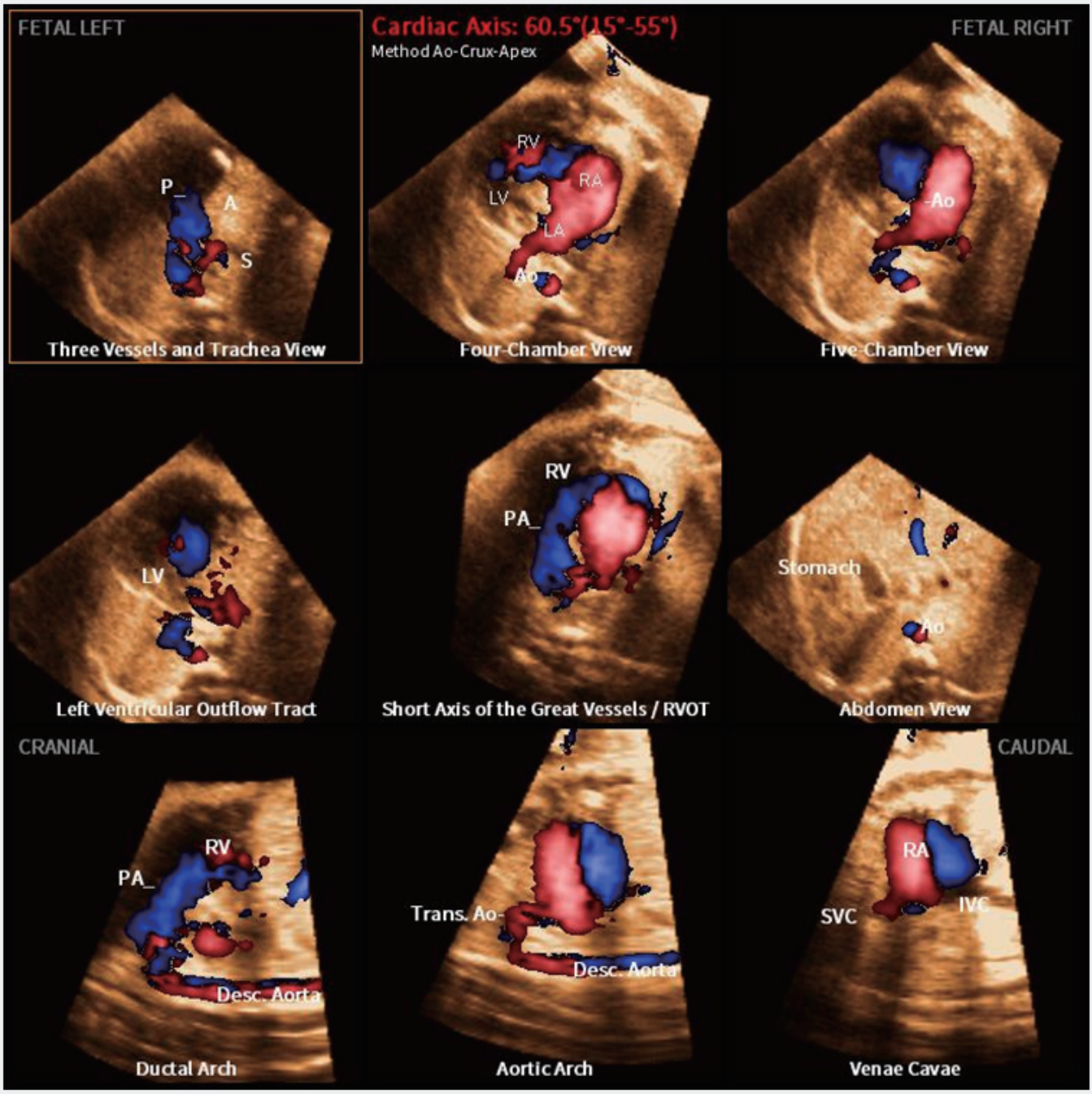

Fig. 8 Reconstruction of all nine diagnostic planes with 5D Heart Color™ in a fetus with hypoplastic left heart caused by mitral and aortic atresia. The anatomic changes are readily displayed in eight out of nine planes showing reversed filling of the transverse aortic arch (3VT, aortic arch view), no color signal in the left-sided heart and outflow tract (four-chamber, five-chamber, LVOT views) and consecutive enlargement of the right atrium (four-chamber, five-chamber, right ventricular outflow tract (RVOT), aortic arch and bicaval views).

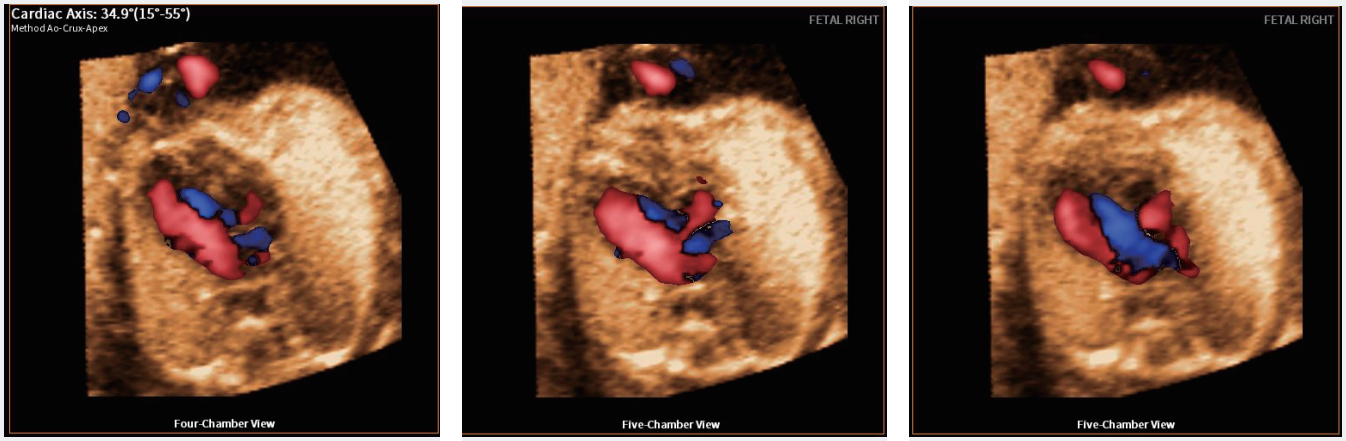

Fig. 9 Diagnostic planes in a case of tricuspid atresia with missing color filling of the right heart seen in four-chamber view (left panel) revealing a perimembranous inlet-ventricular septal defect (VSD) and an unaffected aortic root in five-chamber view throughout cardiac cycle.

Fig. 10 Diagnostic planes in hypoplastic left heart with missing color filling of left-sided structures seen in four-chamber view (left panel) and no detectable color flow in the ascending aorta in five-chamber (middle and right panel).

An abnormal shaping or narrowing of the ductal or aortic arches displayed with added color information will give valuable information regarding an abnormal filling pattern as seen in obstructive lesions of the inflow and/or outflow tracts (e.g. AV or semilunar valve stenosis, hypoplastic left and right heart, coarctatio aortae).

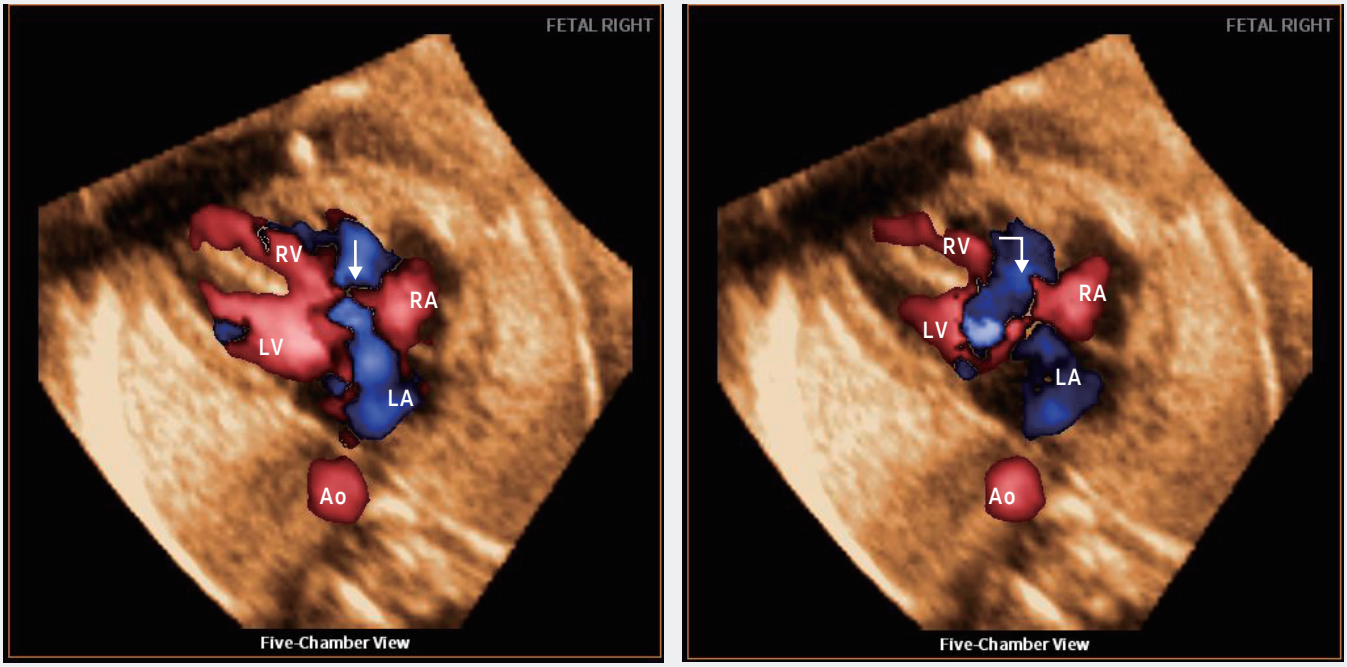

Fig. 11 Color Doppler flow in a fetus with double outlet right ventricle (DORV). Five-chamber view illustrates no outlet vessel originating from the left ventricle but from the right ventricle (left panel, straight arrow) and an additional large perimembranous VSD (right panel, angled arrow).

Preliminary data confirmed a direct dependency of spine location on the rate of successful plane reconstruction when using 5D Heart™. However, it seems reasonable to apply the tool even in those cases where the recommended fetal (spine) position could not be achieved. On the contrary, in case of perpendicular orientation of the fetal heart compared to the insonated ultrasound beam Doppler frequency, shifts in color STIC volumes are markedly diminished which might have an impact on correct interpretation of the reconstructed diagnostic planes. However, from our perspective for comprehensive cardiac assessment, both volumes for 5D Heart™ and 5D Heart Color™ are needed.

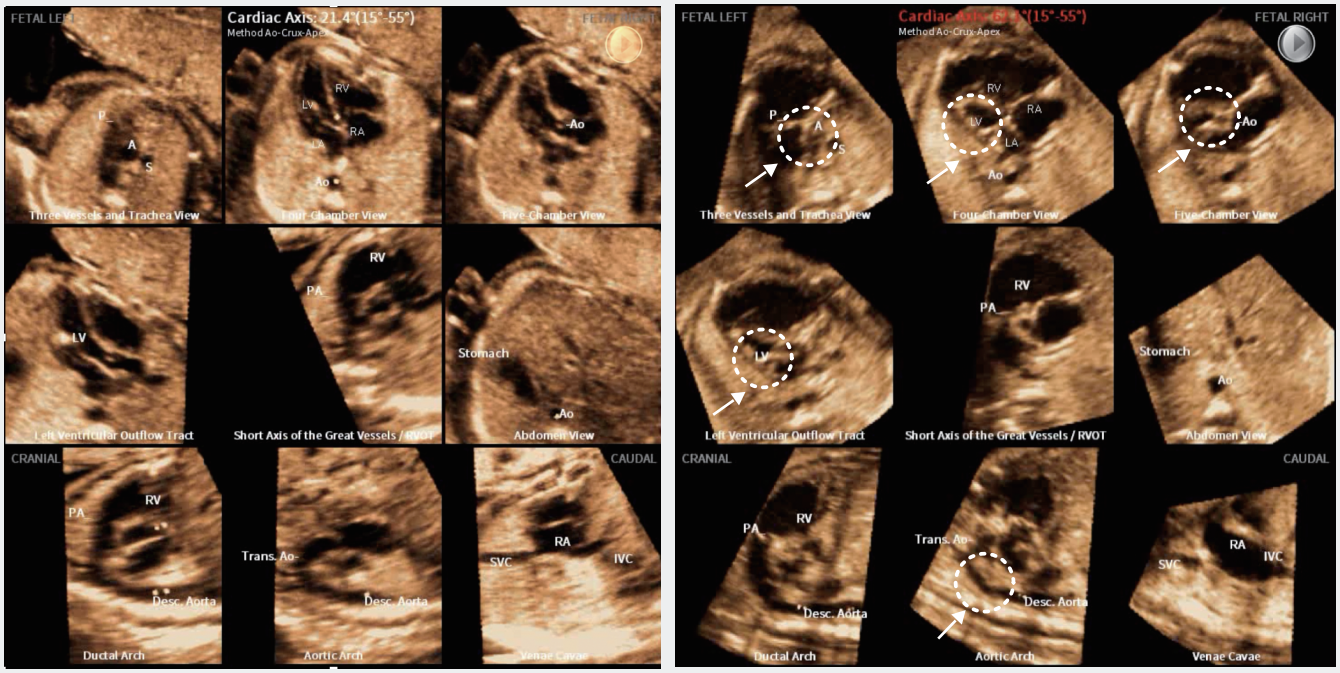

Fig. 12 Comparison of normal fetal heart after 5D Heart™ application (left panel) and the reconstructed diagnostic planes in case of a hypoplastic left heart (right panel). Hypoplastic left-sided structures are encircled (arrow). Thus, most of the valuable information may readily be retrieved without color Doppler interrogation but lacking important functional and hemodynamic detail.

5D Heart Color™ and VIS-Assistance

An additional key feature integrated in the main program is Virtual Intelligent Sonographer Assistance (VIS-Assistance), an operator-independent tool specifically designed for further improvement of successful diagnostic plane reconstruction. Its application following volume re-slicing using 5D Heart™ provides more information on the given cardiac views and its surrounding structures via navigational movements around defined pivot points [Yeo and Romero 2013]. In order to take full advantage of this volume-based fetal echocardiography VIS-Assistance interrogation allows both in-depth-analysis of reconstructed planes and, if needed, image adjustment thereby increasing diagnostic confidence as exemplified in Fig. 13.

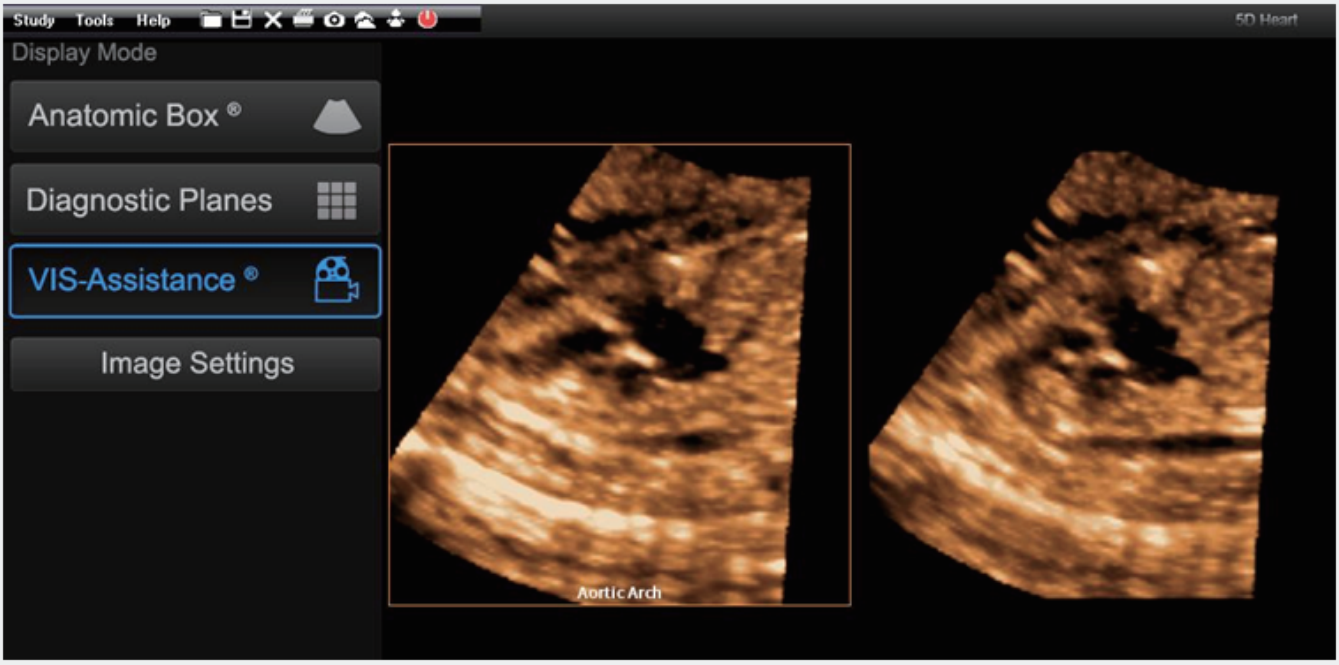

Fig. 13 Reconstructed diagnostic plane of the aortic arch (left panel) and corresponding image after adjustment following VIS-Assistance application showing normal-shaped aortic arch (right panel).

Conclusion

Color Doppler FINE as implemented in 5D Heart Color™ is considered to act as an adjunct to volumetric assessment of fetal cardiac anatomy as it yields important reproducible information on cardiac function particularly in fetuses affected by congenital heart defects.

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