Clinical Applications of Crystal Vue Technology: A Review

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Abstract: Three-dimensional (3D) imaging plays an important role in the construction of normal anatomy and abnormal structures. The 3D images can be obtained through computed tomography, magnetic resonance, ultrasonography (US) and other technologies with different values and prospects. 3D-US imaging has unique advantages such as being radiation-free, time-saving and cost-effective. The Crystal Vue is a novel 3D-US rendering technology that provides valuable information in several obstetrical and gynaecological studies. This review focuses on the application of Crystal Vue technology in the evaluation of foetal skeleton, maxillofacial region, central nervous system, digestive tract and abnormally invasive placenta, cervical pessary, and ureteral stones.

Key words: Crystal Vue technology; Three-dimensional ultrasound image; Skeleton; Maxillofacial; Central nervous system; Digestive tract; Abnormally invasive placenta; Cervical pessary; Ureteral stone

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Introduction

In the past decade, great progress has been made in three-dimensional ultrasound (3D-US) imaging of the foetus. Compared with two-dimensional US (2D-US), 3D-US can construct multiple planes and volume images and provide more detailed information and a global view of the target structures [1]. 3D-US does not involve radiation and is more economical than CT and MR, which can also reconstruct into 3D images [2].

In recent literature, few 3D-US technologies can display cleft palate, as well as cleft palate without cleft lip [3]. In the first trimester foetal central nervous system can only be displayed locally in 3D format [4, 5]. Liu et al. has reported other 3D ultrasound technology to diagnose scar pregnancy [6]. A study reported useful diagnostic value of placenta accreta (PA) to predict haemorrhage, which has not been used in diagnostic classification yet [7]. Prenatal diagnosis of short-rib polydactyly syndrome has been reported using 3D helical

CT [8]. With new advances in US technology, 3D-US imaging would dramatically improve the visualisation of both normal and abnormal structures of the foetus and uterus for obstetrical and gynaecological applications. Crystal Vue (Samsung Medison Co Ltd, Seoul, South Korea) is a novel 3D-US imaging technology with user-friendly post-processing and volume image rendering capability. Several studies have used this technology and reported its usefulness and advantages. Image contrast enhancement technology can effectively distinguish between soft tissue and bone structure [9]. The resolutions of different soft tissues can be demonstrated using fine 3D reconstruction imaging. Sufficient information of the surface and deep structures can be obtained and displayed simultaneously [10]. The light source selection function of this technology enables the simulation volume image to display foetal structures [11]. The acquisition and post-processing times of the volume image are short, and images can be collected in batches [12]. The greyscale and inversion

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imaging modes can display the internal and external information of the target lesions [13]. Due to its unique image contrast enhancement properties, it produces a high resolution of different tissues, especially for those that have a significantly different acoustic impedance in vivo, and provide more diagnostic information [14, 15]. In this article, we review current studies using Crystal Vue technology for its applications in obstetrics and gynaecology.

Applications in Foetal Examination

Foetal spine and ribs

Dall'Asta et al. conducted a study to compare the images of the spine and ribs in a third-trimester normal foetus and a foetus with suspected skeletal dysplasia [9]. 2D-US of a foetus at 29⁺4 weeks' gestation showed normal spine and ribs, foetal movements, and amniotic fluid. Crystal Vue rendering and post-processing on the 3D-US image revealed clear ribs and vertebral interface with normal mineralisation of the ribs, and rib number could be identified. In another case, a foetus of 33⁺4 weeks' gestation was referred for the assessment of suspicious short and abnormally shaped long bones; on 2D-US, the foetus revealed all long bones as being below the 5th percentile but with normal mineralisation and no obvious fractures. The femur and humerus were bowed but the skull was normal. The thorax/abdomen ratio was on the 50th percentile. When Crystal Vue rendering was applied, the ribs could be visualised clearly. Abnormally short ribs with normal mineralisation and no fractures were shown. The wide spacing of the ribs and their slimness were in contrast to the normal case. The authors reported that Crystal Vue technology has made a step forward in improving antenatal skeletal imaging [9].

Foetal lip and palate

2D-US does not allow for clear visualisation of the posterior or secondary palate [16–18]. 3D-US technologies have provided the opportunity to develop novel approaches to identify foetal facial features and provide more informed counselling and adequate preparation for prospective parents. Dall'Asta et al. presented 2 normal cases, examined at 21- and 32 weeks' gestation [19]: 1 case of cleft lip, alveolar ridge, and hard and soft palates that had been diagnosed prenatally at 31 weeks' gestation and 1 case of isolated cleft of the secondary palate that had been diagnosed postnatally. US volume images were acquired transabdominally and post-processed by Crystal Vue and Realistic Vue rendering. Six European foetal medicine specialists assessed these images. All experts agreed that structures such as the hard palate, oropharynx, nasopharynx, and tongue base

can be imaged satisfactorily. However, the imaging effect of the soft palate remained controversial.

To avoid such above mentioned limitations, other authors complemented the palatal imaging technique and showed how such shadowing can produce an artefact, mimicking a cleft palate, unless the volume is acquired appropriately [20]. The main criterion required to ensure that the primary and secondary palate is contained in a US volume is to make sure that the insonation angle is frontal to avoid shadowing by the alveolar ridge [16]. The authors applied the following two practical approaches to acquire a volume without shadowing of the hard palate: (1) to start volume acquisition with frontal insonation in an axial plane that demonstrates the horizontal plate of the secondary palate and (2) to start volume acquisition in a cranially tilted median plane that demonstrates the shadow of the alveolar ridge above the palate [16].

First-trimester foetal central nervous system

It is usually difficult to examine the foetal central nervous system and ventricular system in great detail during the first trimester as these rapidly change. Image resolution limited visualisation of the complex anatomical structures of the central nervous system [21].

Shah et al. used Crystal Vue and Realistic Vue rendering to post-processed volume images of a foetus at 13⁺1 weeks' gestation and revealed a novel 3D impression of the foetal ventricular system compared to digitally reconstructed embryological models, demonstrated that the entire foetal ventricular system can be visualised in a completely new way and the structures can be imagined [10]. The relatively simple use of this technology may help to improve our understanding of neurodevelopmental changes in the first trimester. Furthermore, it is suggested that some markers of special diseases in the ventricular system can predict diseases of the foetal central nervous system in the second trimester (Fig.1 A). A US examination has been applied upon a foetus with 29th gestation week, clear 3D images of ventricular system were obtained using Crystal Vue rendering (Fig.1 B).

Normal foetal oesophagus and oesophageal atresia

Prenatal examination of the foetal oesophagus is challenging because the oesophagus is a very small, long muscular tube that is usually collapsed and not easy to be distinguished from the surrounding structures of the foetal chest, such as the aorta and the trachea. The incidence of congenital oesophageal malformation is approximately 1/3000, which is often caused by incomplete differentiation of the oesophageal and tracheal septum in the foregut [22]. Oesophageal atresia (EA) is the most common oesophageal malformation, which develops into enlargement of the blind end, and

most cases are often accompanied by tracheoesophageal fistula. EA can occur in isolation or as a manifestation of hereditary diseases or syndromes [23]. It is difficult to directly observe the signs of EA, which is usually diagnosed using indirect signs such as excessive amniotic fluid and small or no gastric bubble. However, the sensitivity of these indirect indicators is low, at approximately 40%–50%. Especially when complicated with tracheoesophageal fistula, amniotic fluid can enter the gastric bubble through the fistula. It was observed that alternative filling and emptying of the proximal oesophageal sac was a high specificity sign for prenatal diagnosis of EA [24]. Until recently, clinical application of direct observation of oesophageal US was rare [25, 26]. Because of its contrast-enhanced properties, Crystal Vue technology can easily separate the echo of different soft tissues [9, 19], which is expected to clearly

display the oesophageal structure. Dall’Asta et al. have proven that the whole course of the oesophagus up to the stomach (Figure 2) could be directly evaluated in the coronal plane in 74 (83.1%) cases, visualisation of the entire foetal oesophagus was not satisfactory in 9 (10%) cases because of technical factors involving poor acoustic window, and the whole course of the oesophagus could not be visualised in other 6 (7%) cases because of a persistently suboptimal foetal lie. All cases had an absence of congenital structural anomalies at postnatal follow-up. Crystal Vue technology was also applied on 2 fetuses with suspected obstruction of the upper gastrointestinal tract due to a small or absent stomach bubble on 2D imaging. There was a gap between the proximal and distal tracts of the foetal oesophagus in the coronal plane. At postnatal follow-up, the presence of isolated EA was confirmed in both cases.

Figure 1 (A) Visualization of foetal ventricular in early-pregnancy; (B) Visualization of foetal ventricular in late-pregnancy.

Figure 2 Antenatal visualisation of the intrathoracic and intraabdominal course of the normal foetal oesophagus in the coronal plane using Crystal Vue and Realistic Vue rendering technologies.

In summary, direct visualisation of the normal foetal oesophagus and demonstration of EA are feasible using 3D-US with Crystal Vue rendering. This finding may help prenatal counselling and optimise perinatal management of suspected EA cases.

Prenatal ultrasound diagnosis of foetal intestinal volvulus and intussusception

Volvulus and intussusception are serious life-threatening diseases in acute abdomen diseases, which are rare in the foetal period and can cause adverse pregnancy outcomes [27]. However, prenatal diagnosis is often missed and misdiagnosed. Volvulus is often secondary; is associated with intestinal malrotation, cystic fibrosis, and mesenteric dysplasia; and can also occur in an isolated form [28]. The typical 2D-US findings were dilation of the intestine, ‘vortex sign’, and ‘coffee bean sign’. Intussusception is a common acute abdomen in infancy and is a cause of intestinal atresia.

The ‘bread ring’ in a cross-plane is a typical sign of foetal intussusception, and the ‘sleeve sign’ can be seen at the long axis level [29].

Li et al. investigated the characteristics of prenatal US of the foetal intestinal volvulus and intussusception and analysed the misdiagnosis. Prenatal 2D-US and 3D-US features of 11 patients with foetal volvulus and intussusception were confirmed by prenatal US and/or postnatal confirmation. Among the 11 fetuses, 8 had intestinal volvulus and 3 had intussusception. Among the 8 cases with foetal intestinal volvulus, 6 were correctly diagnosed by prenatal US and in 2 cases were misdiagnosed. Among the 6 cases that were correctly diagnosed with foetal intestinal volvulus, 3 cases showed the typical ‘vortex sign’ on the 2D image and 1 case showed the ‘coffee beans’ sign, and 3D-US of all the 6 cases revealed that the intestines were ‘coiled’. The ‘bread ring’ sign appeared in 3 cases with foetal intussusception, among which 1 case was automatically detorsion intrauterine. Among the 11 fetuses, the pregnancy was terminated in 1 of the 11 fetuses, the pregnancy continued in 1 case, 9 fetuses were born and confirmed by surgery, and 1 fetus died after the operation. In conclusion, the intestinal volvulus and intussusception have characteristic sonographic features. During short-term foetal bowel dilatation with meconium peritonitis, the existence of these two acute abdomen diseases should be considered, whereas when it is accompanied by intestinal necrosis, typical signs of 2D-US are missing and 3D-US with Crystal Vue technology can aid in the diagnosis. Therefore, Crystal Vue technology might play a better role in the diagnosis of intestinal enlargement and more ascites.

Applications in Examination of Gynaecology

Diagnosing caesarean scar pregnancy with impending uterine rupture

Caesarean scar pregnancy (CSP) is a serious threat to maternal life, and its incidence increases with the increase in caesarean section rate [30, 31]. Several invasive treatment methods are available for CSP [31, 32], and early diagnosis can enable early treatment and reduce severe complications. US can provide diagnostic clues, and 3D-US on scar pregnancy has typical sonographic manifestations.

Lee et al. presented a 3D-US image of a CSP [33]. A 30-year-old pregnant woman who had undergone 2 caesareans presented with vaginal spotting and dull lower abdominal pain that was ongoing for 2 months. 3D-US imaging with Crystal Vue rendering showed caesarean scar dehiscence, and the lower uterine gestational sac bulged to the bladder, indicating a CSP. The cervical

canal was empty and the gestational sac was located in the scar, as indicated on laparoscopy findings.

Confirming different types of an abnormally invasive placenta

Prenatal diagnosis of an abnormal invasive placenta (AIP) and accurate typing can help to select the time and mode of delivery and reduce maternal mortality and disability rates [34]. US is the preferred method for the prenatal diagnosis and classification of AIP [35, 36].

Eight patients with anterior placenta previa underwent transabdominal 3D-US and 3D colour Doppler examination using Crystal Vue and Crystal Vue Flow at a median gestational age of 32^{+0} ($27^{+1} - 34^{+6}$) weeks; of these, 6 underwent one or more caesarean sections, and the remaining 2 had a history of AIP. The placenta was imaged along with the maternal bladder, and 3D colour Doppler was applied to map the vascularisation of the uterine–bladder interface. Volumes were obtained by automatic sweeps from sagittal section of the uterus bisecting the bladder, and Crystal Vue and Crystal Vue Flow were processed.

All pregnant women underwent elective caesarean section. All cases of hysterectomy were confirmed after birth based on intraoperative findings or pathology reports from the placental or uterine specimens. Among the 8 patients, 3 had placenta previa without accrete, 4 had placenta increta (PI), and 1 had placenta percreta (PP) with the placenta remained in situ at the time of the caesarean section. On Crystal Vue rendering and Crystal Vue Flow, in cases of placenta previa without accrete, a ‘tramline’ sign showing the appearance of the normal uterine–bladder interface in the perpendicular plane and without encroachment by irregular vascular patterns can be seen; in cases of PA, the ‘tramline’ sign with abnormal vascularity at the uterovesical fold shows partial or complete obliteration. The degree of vascular invasion and disappearance of the ‘tramline’ sign are related to the classification of AIP. When the placenta is implanted and perforated, the track sign disappears. As mentioned above, Crystal Vue rendering and Crystal Vue Flow can help determine blood flow patterns and different types of AIP, providing more personalised information.

Excessive placental invasion is a serious obstetric disease, and for making a surgical plan for this disease, it is crucial to determine the extent of placental villi invasion antenatally. Combining Crystal Vue technology with 2D-US can improve the diagnostic accuracy for detecting all types of the PA spectrum (PAS) located in the caesarean section scar area. PAS includes PA (attachment of the placenta to the myometrium without intervening decidua), PI (invasion of the trophoblast into the myometrium), and PP (invasion through the myometrium, serosa, and into the surrounding structures)

[37]. Chen et al have confirmed that 26 cases (96.30%) of PAS were correctly diagnosed, with only 1 case incompletely diagnosed, whereas 20 cases (74.07%) were correctly diagnosed, 6 cases were misdiagnosed, and 1 case was incompletely diagnosed by 2D-US [38]. Crystal Vue technology enabled perfect consistency between US and postoperative diagnosis.

Visualising cervical pessary with transvaginal image

Preterm birth as a cause of disease has resulted in nearly half of perinatal deaths [39]. One of the main causes of premature delivery is cervical dysfunction, and several management strategies exist [40]. Cervical cerclage is one of the strategies. Cervical pessary is a simple and inexpensive alternative to cerclage, which physically keeps the cervix in a closed state during pregnancy, similar to the cerclage effect, and makes the cervix toward the spine with the minimum pressure on the cervix [41]. Fernandes et al. performed 3D volume imaging for a 31-year-old primigravida who had a diagnosis of the short cervix (13mm) at 21 weeks' gestation and placed a cervical pessary around the cervix using a transvaginal probe [14]. They proved that Crystal Vue technology can accurately display the cervical pessary, prompt whether the position is correct, and improve the probability of a benign outcome.

Application in Other Organs

Diagnosing ureteral stones using transvaginal ultrasonography

Lee et al. diagnosed a ureteral stone at the ureterovesical junction in a 45-year-old woman [15]. The patient presented with low abdominal and low back pain. 2D-US transvaginal US revealed a mass behind the dilated cylindrical ureter with sound shadow. With Crystal Vue and Realistic Vue rendering technology, the internal and external contours of the urinary bladder, proximal end of the expanded ureter, and stones at the ureter-bladder junction could be detected. The results were confirmed by surgery after the examination.

Transvaginal US can clearly show the pelvic organs, including the ureter, ovaries, fallopian tubes, and pelvic cavity without radiation. It is widely used in obstetrics and gynaecology US. The lower urinary system, including the bladder, urethra, and distal ureter, can also be examined using transvaginal US [42]. 92.7% of experts and middle-level doctors have shown the distal ureter through pelvic US [42], 85% of ureteral stones are located in the distal ureter [43], and urinary system examination can be included in the daily pelvic examination. 3D-US reconstruction can provide more information for the evaluation of the low urinary system than 2D-US.

Conclusion

3D-US has been proven to have a high clinical application value. With Crystal Vue rendering, the normal anatomy and abnormal structures could be detected clearly as 3D images. By providing information about the real structure, this technology can prove its value in more clinical applications.

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Conflict of Interest

The authors have declared no conflicts of interest for this article.

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