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Original Article

Utility of Three-dimensional Multiple Planar Volume Reconstruction and Transparency Lung Volume Rendering as a Stand-alone Imaging Technique for Diagnosis and Pre-operative Evaluation of Tracheo-esophageal Fistula

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Abstract

Introduction: The newer advances in the multi-detector computed tomography (CT) with the variegated post-processing options such as three-dimensional (3D) multiple planar volume reconstruction (MPVR), 3D transparency lung volume rendering (TL-VR), and virtual bronchoscopy have not only simplified the diagnostic approach to an infant with primary or secondary tracheo-esophageal fistula (TEF), but also has reduced imaging time and radiation dose.

Aim: Evaluate utility of 3D MPVR and 3D TL-VR as a stand-alone imaging technique in the diagnosis and pre-operative depiction of primary or recurrent TEF.

Materials and Methods: Infants with a clinical diagnosis of TEF - in whom preliminary imaging like Kiddigram, Barium swallow, and conventional CT were inconclusive - were enrolled for the study. 10 infants were evaluated over a period of 2-year, from January 2014 to December 2016. Noncontrast thin-section CT (Philips Ingenuity 128 Slice) was done, post-processing was done with 3D MPVR and TL-VR. Imaging findings were correlated with per-operative records.

Results: Of the 10 infants, 3 had primary TEF and 3 had recurrent TEF. 3D MPVR and TL-VR done accurately demonstrated the orifice and the tract in all 6 on MPVR, 4 were depicted on TL-VR. 2 infants suspected to have TEF based on other imaging modalities, the thin section CT with 3D MPVR and TL-VR did not demonstrate a fistulous tract; the surgical outcome in these 2 was negative. The other 2 infants, with normal MPVR imaging, were followed up for 3/12 with satisfactory clinical outcomes. An accurate correlation with per-operative findings was noted with positive predictive value of 100% and negative predictive value of 100%.

Conclusion: 3D MPVR and 3D TL-VR are novel post-processing techniques which have simplified pre-operative evaluation of TEF, rendering other imaging modalities largely redundant. It is an invaluable imaging tool that not only aids in prompt early diagnosis but also offers excellent pre-operative imaging depiction of the size, location and course of tract, particularly in patients with recurrent TEF.

Key words: 3D MPVR and TLV-VR, MDCT, TEF

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INTRODUCTION

The reported incidence of esophageal atresia (EA) and tracheo-esophageal fistula (TEF) is approximately one in 3000-4500 live births.[1,2] Even in cases of EA, the majority have an associated fistulous tract existing between the trachea and distal esophageal pouch. Pivotal to determining

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the surgical approach and technique in patients with EA and distal TEF, is the understanding of anatomical location of the esophageal pouch, the inter-pouch gap, up-growth of tracheobronchial tree and the presence or absence of a fistulous tract, these factors not only influence the surgical approach but also determine the post-operative strategy and prognosis.[2,3]

Contrary to imaging in primary TEF, a recurrent TEF can prove to be one of the most challenging problems to diagnose and manage. Associated with high morbidity, recurrent TEF rarely closes spontaneously and typically requires surgical repair.[3-5] The incidence of recurrent TEF has been reported to be about 10% in most series.[6-8] Recurrent TEF is more common following an anastomotic leak as this may lead to the formation of an abscess which eventually erodes into both trachea and esophagus leading to the formation of a secondary fistula. Anastomotic dilatation is also one of the contributory factors in re-communication. As a result of repeated dilatations, mucosal tear, progressive weakening of the suture line and peri-esophagitis may lead to recurrence of fistula. Fiber optic pediatric bronchoscopes and/or endoscopes may not be as an easy option in terms of availability of equipment and expertise. These techniques are invasive, time-consuming, not very comfortable for the child and are not always contributory.[7-10]

Recent advances in the arena of post-processing of multi-detector computed tomography (MDCT) source imaging data such as reconstruction techniques with three-dimensional (3D) multiple planar volume reconstruction (MPVR), 3D transparency lung volume rendering (TL-VR), and virtual bronchoscopy (VB) have rendered a new dimension to accurate anatomical depiction of pathology pertaining to hollow viscera. MDCT can generate VR images of the trachea and esophagus quickly and noninvasively, show the anatomy and 3D relation between the two structures more clearly and accurately, and provide valuable guidance for any surgical approach.[5,8] 3D MPVR is a reliable and straightforward technique which not only provides a multidirectional view but also enables optimal anatomical location and relationship to adjacent organs.

This study focuses on the ability of 3D MPVR and 3D TL-VR to demonstrate primary and recurrent TEF with primary non-contrast MDCT data by 128 slice MDCT. Exact location of the fistula if present and status of the lungs can thus easily be demonstrated by MDCT. Post-processing these studies with maximum intensity projections (MIP) and VR allows a 3D evaluation of the fistula tract.

The reconstruction technique involves creation of new and customized visual representations by applying mathematical algorithms to the originally acquired data. The technique extracts one single parameter of the volumetric data and produces two-dimensional (2D) reconstructions and then creates a 3D model, which can be further manipulated for visualizing complex structures. Such operations are used in Shaded surface display volume rendering technique (SS-VRT) and VB techniques. Data can also be generated from a semi-automated input given by the operator which is fundamental for curved plane reconstructions. MPVR and 3D TL-VR are excellent techniques to use objectively. A technique like minimum intensity projections (Min-IP) is a 2D data visualization method that enables detection of low-density structures in a given volume. Only the lower Hounsfield value structures are represented regardless of their plane of location. For example, by performing a Min-IP mapping of the thorax before administration of contrast, an image of the bronchial tree can be generated since the bronchi, being air-filled, are the least dense structures of the thorax (Figure 1) significantly reducing the time required to analyze complex multiplanar or nonlinear structures. SS-VRT is a technique that creates a 3D visual illustration of CT volumetric data for display from any desired perspective. SS-VRT images provide a sensation of three-dimensionality that is significantly superior to other VRTs.[11-13]

MATERIALS AND METHODS

All infants who presented with recurrent infections and varying degrees of respiratory distress during the period of March 2014 to July 2015, in whom a diagnosis of primary TEF or recurrent TEF was considered, were enrolled for this study. All these infants underwent the primary imaging studies, viz., chest and abdominal radiograph (Kiddigram), barium swallow, conventional CT with oral contrast

Figure 1: Kiddigram (plain radiography of chest and abdomen) air esophagogram and gaseous distention of the gastrointestinal system

(3 mm slice sections), endoscopy and bronchoscopy with conflicting and/or inconclusive diagnosis. These infants then were subjected to non-contrast CT by 128 slice-MDCT. Infants were sedated and body straps were used to immobilize the patients so as to decrease motion artefacts.

About 10 infants with mean age of 8 months were preoperatively evaluated with non-contrast enhanced CT scan using 128 slice MDCT, at 64 mm × 0.625 mm collimation (Philips Ingenuity Core^{128} CT). All scans were performed from the level of larynx to the diaphragm CT scan protocol was as follows: 100 kVp, z-axis automatic tube current modulation, a mean calculated CTDI dose of 1.35 mGy, Pitch of 0.58 and 0.5 s rotation and time, and 512 × 512 matrix. The scanning time was approximately 3-4 s. Images were reconstructed in the axial plane at a 0.677 mm interval with a standard reconstruction algorithm.

Real-time interpretation was undertaken on a thin-client or a stand-alone workstation using a combination of VRT, MIP, Min-IP, multiplanar reformations (MPR), curved planar reformations and 3D TL-VR protocol and VB. The use of oblique or curved reconstructions to visualize the path of fistulous tract provided added diagnostic information. The total image processing time was 20-30 min in each patient. MPR images provide more information about esophageal walls and the surrounding tissues than MPVR or TL-VR. View of the original axial and MPR images was indispensable before the measurement of MPVR and TL-VR. Imaging features were corroborated with per-operative findings to assess accuracy.

RESULTS

Of the 10 children, three children were diagnosed to have primary TEF and three with recurrent TEF. Post-processing with MPVR revealed the orifice of TEF in 6 cases, while TL-VR images showed the orifice of TEF in 4 cases (Table 1). Good correlation of the findings was noted both on MPVR and 3D TL-VR. One child with recurrent TEF in whom the pediatric endo-bronchoscopy was suggestive of post-operative residual blind ending sinus, in whom other imaging modalities were inconclusive, thin section noncontrast MDCT with 3D MPVR and 3D TL-VR demonstrated the tract to the left main bronchus with an diverticular outpouching secondary to infection (Figure 2a and 2b). Two children with clinical suspicion of TEF had air esophagogram with gaseous dilatation of the gastrointestinal tract; these were subjected to surgery based on conventional CT which demonstrated a dubious

Table 1: Investigative pattern in patients with suspected TEF, non-contrast thin slice MDCT data with 3D MPVR/VRT and 3D TL-VR corroborated with per-operative findings

Status/patient numbers	Primary imaging modalities	3D MPVR/VRT/3D TL-VR on MDCT	Post-operative outcome
Clinical history suggestive of TEF: 3 infants	Kiddigram: Air oesophagogram with gross dilatation of the stomach, patchy areas of consolidation with collapse in the lungs Barium swallow: Tract not demonstrated, though orifices were visualised on endobronchoscopy	Fistulous orifice and the tract were demonstrated in all three infants	Surgical intervention MDCT findings were confirmed
Clinical suspicion of TEF-4 (2+2)	Kiddigram: Air oesophagogram with gross dilatation of the stomach, patchy areas of consolidation in the lungs Barium swallow: Negative in all four, and paediatric endobronchoscopy did not reveal an orifice CT (conventional protocol) with oral contrast: Suspicious tract noted in two patients, two patients had consolidation with collapse with possible TEF	Fistulous orifice and the tract were not visualized in all four children	In view of recurrent respiratory tract infection and possibility of tract noted on conventional CT, Surgical exploration was resorted to in two patients, however no tract was detected 2 patients were not subjected to surgery. Only follow up. Patient was normal on 3 months review
Post-operative. status with recurrent LRTI and growth retardation raised the clinical suspicion of secondary TEF in 3	Kiddigram: Air oesophagogram with gross dilatation of the stomach Barium swallow: Negative CT (conventional protocol) with oral contrast: Negative Pediatric endobronchoscopy: Blind ending outpouching noted, reported as a sinus, no residual fistula	Residual fistulous tract in 2 Recurrent tract in 1	Surgical intervention was done based on non-contrast thin slice CT findings Per-operative findings were concordant with MDCT findings
Total cases suspected TEF: 10	Conventional CT with oral contrast: False positive in 4 (due to artefacts) Barium swallow: Negative in 6	False positive: Nil False negative: Nil	Accuracy: PPV and NPV 100%

TEF: Tracheoesophageal fistula, MDCT: Multi-detector computed tomography, 3D: Three-dimensional, MPVR: Multiple planar volume reconstruction, VRT: Volume rendering technique, TL-VR: Transparency lung volume rendering, CT: Computed tomography, LRTI: Lower respiratory tract infection, PPV: Positive predictive value, NPV: Negative predictive value

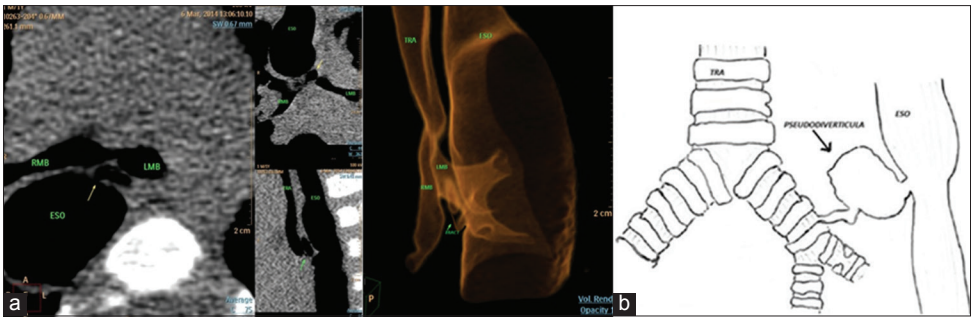

Figure 2: (a) Multi-detector computed tomography reconstructed image three-dimensional (3D) multiple planar volume reconstruction and 3D transparency lung volume rendering: Esophageo-bronchial fistulous communication with pseudo diverticulum, demonstrated in an infant, failing to thrive and distressing respiratory infections, with history of old surgical repair for tracheoesophageal fistula and esophageal atresia 6 months earlier. (b) Schematic representation pseudo diverticulum with esophagio-bronchial fistula

tract, thin slice MDCT and post-processing however did not demonstrate the fistulous tract. However, in view of the air esophagogram (Figure 1) and suspicion of a tract on conventional CT the infants were subjected to surgery; the surgical outcome in these two was negative for a fistulous tract. Retrospective evaluation of conventional CT done elsewhere revealed the tract was secondary to an artefact. The other two children with similar findings, in whom the imaging was normal, were followed up for 3 months; they had no recurrence of symptoms.

Thin section MDCT used in conjunction with 3D MPVR and TL-VR correlated well with the findings at surgery with positive predictive value (PPV) and negative predictive value (NPV) of 100% as opposed to barium swallow wherein the PPV was 60%, but NPV was only 40% and conventional CT protocol (3 mm with oral contrast), false positives resulted in unnecessary surgical intervention and exploration owing to streak artefacts.

DISCUSSION

The newer advances in the MDCT, reduced imaging time with low dose imaging options, the variegated post-processing options such as 3D MPVR, 3D TL-VR and VB and endoscopy options has simplified the diagnostic approach to a child with primary or secondary TEF. Volume rendered images of the trachea and esophagus can be quickly and noninvasively generated with excellent delineation of the anatomy and 3D relation between the two structures. Imaging information thus obtained is invaluable in providing guidance for surgical approach to cases of primary or secondary TEF.[4,5,8] This study highlights the ease with which the non-contrast thin slice acquisitions can be performed and the dubious role of other conventional imaging modalities available till date. In all our patients, the anatomic structures were optimally delineated, excellent 3D rendering of the pathology aided in surgical exploration, particularly in infants with recurrent TEF.

One study by Tam *et al*.[11] mentioned that axial images can be difficult to interpret; a fistula may be demonstrated only partially or missed and his study mentioned that direct sagittal CT has been used in newborns to accurately diagnose EA and TEF, enabling visualization of the entire length of the esophagus, complete with atresias, fistulas, and gap length. The better detection of site of fistula by axial images in this study can be explained by the use of 128 slice MDCT that provides high resolution images than the older versions of CT scanners used in the study by Tam *et al*. In our limited experience, axial imaging was found to be the best imaging plane for detection of orifice of the fistula, demonstration of the tract was best noted in the sagittal/oblique MPR and 3D TL-VR followed by the coronal MPR images.

3D MPVR images, 3D TL-VR, and virtual tracheo-bronchoscopy play a corroborative role to the diagnostic data obtained over thin axial images and facilitate visualization of the complex anatomic features enabling a better pre-operative orientation to the surgeon.[5] Virtual tracheo-bronchoscopy findings were concordant with the endoscopy and bronchoscopy findings in two patients pertaining to the orifice; however, the communication could not be demonstrated owing to the size and plane of the tract.

The importance of radiation dose in pediatrics cannot be overlooked. Radiation dose is deemed as an important issue in pediatrics as it is well-established fact, the lifetime cancer mortality risk attributable to CT examinations is considerably higher than in adults and although a modern CT gives low-grade exposure; this examination is still associated with radiation hazards.[13-15] However considering, the number of X-rays and imaging the infants were subjected to before the present CT, the cumulative dose

is often overlooked, particularly in infants with recurrent TEF, the component of cumulative dose is significant, in such case scenarios, this CT protocol can be resorted as primary imaging option.

In this study, we used automated anatomic modulation software and neonate application with selection of appropriate scanning parameters to significantly minimize radiation dose. In infants where in there is clinical suspicion of TEF, primary or secondary, we advocate prompt imaging with thin section non-contrast MDCT with utilization of the post-processing MPVR and 3D TL-VR tools of diagnosis as the first line of radiological investigation.

CONCLUSION

With the advent of MDCT with post-processing techniques such as 3D MPVR, 3D TL-VR and VB techniques, there is a paradigm shift in the imaging approach to evaluation of TEF. A single modality approach has not only rendered imaging cost-effective but also radiation friendly in terms of cumulative cost and radiation incurred with repeated studies. Particularly in patients with recurrent TEF, this mode of imaging has revolutionized the pre-operative diagnostic approach ensuring prompt diagnosis and excellent delineation of pathology for the operating surgeon. Good accuracy and excellent anatomical depiction has scored over the conventional imaging options available till date, rendering the same largely redundant.

Although the numbers evaluated in our study is small, the results obtained are significant. One modification to our imaging technique was air instillation via the nasogastric tube which was resorted to in patients with collapsed esophagus or absent air esophagogram.

We strongly advocate the use of these post-processing techniques which is available across all vendors in most of the MDCT suites, particularly in evaluation of infants with secondary trachea-esophageal or broncho-esophageal fistula wherein there is substantial morbidity with delayed diagnosis.

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