Introduction
In numerous cardiac interventions a detailed knowledge of the intra-cardiac anatomy is necessary. Examples include radio-frequency ablation of arrhythmias, particularly when creating lines of block between anatomical non-conducting obstacles [1], and trans-catheter closure of atrial septal defects (ASD) where the size, shape and position of the defects are crucial for successful closure [2,3]. Recent advances in image processing allow three-dimensional (3D) reconstruction of intracardiac ultrasound and MRI images. Processing is off-line and can take from a few minutes to several hours. The 3D data can be manipulated to produce sections in any plane as well as rendered surfaces in any direction. Advantages over 2D representations include visualisation of the whole of the anatomy of interest and the relationship to surrounding structures. The aim of this study is to compare 3D reconstruction of intra-cardiac anatomy by TEE, ICE and MRI and to evaluate the potential of these techniques in planning and guiding transcatheter interventions.

Patients and Methods
Patients: Two patient groups were studied. Seven patients with structurally normal hearts were due to have catheter radio-frequency ablation of atrial tachyarrhythmias. Six other patients had ASDs, due for trans-catheter closure. The 13 patients had an MR examination prior to intervention and ICE during intervention. TEE was only performed on the ASD patients.

MRI: Studies were performed on a 1T Siemens Impact Expert scanner using a phased array body coil. After plan scans, a series of axial images (breath-hold spin echo, ECG gated) was acquired. For three patients cine gradient echo images (10 per cardiac cycle) were acquired. The image matrix was 256x256 pixels and the field of view was 300 x 180 mm. In-plane resolution was 1.172 and 1.562 mm/pixel, slice thickness 5 mm, slice interval 2 mm). 3D reconstruction was performed off line using commercially available software (Analyze, VTK) [4]. Images were segmented in a semi-automated fashion by seedling and thresholding using Analyze. Segmented images were rendered into 3D surfaces using VTK. A user interface developed in our laboratory was used to manipulate the surfaces, allowing visualisation from any direction. Furthermore, the surface can be sliced in any plane defined by the user, thus allowing visualisation of intracardiac structures.

ICE: ICE was performed during catheter intervention using commercially available 9F 9MHz ICE probes (Boston Scientific) with a standard pull back device and a Clearview ultrasound console. The ICE catheter was pulled back from the superior vena cava (SVC) to the inferior vena cava (IVC). Respiratory and ECG-gated radial ICE images were obtained. 3D images were reconstructed using commercially available software (TomTec).

TEE: TEE was performed on a Hewlett Packard 5500 echo machine with an omniplane TEE probe and 3D acquisition software. Following routine TEE assessment of the heart and ASD the defect was positioned in the centre of the image so that the defects edges were seen within the image for all the angles of imaging from 0° to 180°. Using ECG and respiratory gating a loop of one cardiac cycle was acquired for each 3° angle between 0° and 180°. Images were acquired in approximately 3 minutes. In 3 patients instead of respiratory gating the images were acquired during a 1 minute breathhold. The images were transferred to a dedicated workstation (TomTec) and reconstruction of 3D rendered visits took approximately 5 minutes.

Results and Discussion
Measurements: Comparative measurements were made by two independent observers. For arrhythmia patients, the following structures were measured for comparison between ICE and MRI: SVC, IVC, coronary sinus (CS), tricuspid valve annulus (TV) (maximum diameter and diameter orthogonal to this), and the SVC-IVC and IVC-TV (isthmical region) distances. For ASD patients, the maximum area of the defect during the cardiac cycle, the minimum rim towards the aorta, SVC and IVC were measured for comparison of the three imaging techniques. Agreement between the different techniques was good especially in the case of ICE and MRI (Fig 1) and inter-observer agreement was best for MRI.

Conclusion
We have been able to demonstrate 3D imaging of intracardiac structures using MRI, ICE and TEE. All three techniques provided high quality images, and correlation between them was good. 3D MRI had longer acquisition and processing time, but provided better visualisation of the area of interest in relation to surrounding structures. In our patients, MRI was useful in the planning of transcatheter closure of ASDs helping the cardiologist to determine the size and nature of device to be used. ICE and TEE had shorter acquisition and reconstruction times, allowing use during interventions both for ASD closures and ablation of arrhythmia. With the onset of MRI-guided cardiac interventions, 3D reconstruction of intracardiac images will be crucially important.

References