Rapid Communication

Transvenous echo Doppler in baboons: a new window to the cardiovascular system

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Abstract

Ultrasound examinations of the heart and major peripheral arteries have been performed as separate procedures; both potentially limited by suboptimal views in certain subjects and the inability to obtain ideal pictures of particular intracardiac structures. Transvenous ultrasound may offer new advantages in certain areas, we therefore studied six adult baboons using a single-plane 5.5–10 MHz transducer mounted on a 10 French (10F) catheter, introduced via the right femoral vein and positioned under fluoroscopic control. Imaging and Doppler studies were performed to delineate cardiovascular anatomy as well as ventricular function response to positive (dobutamine) and negative inotropic (esmolol) agents. The procedure was safe and feasible in all cases. Clear and novel two-dimensional and flow information were obtained from the iliac arteries, descending aorta, both renal artery origins, ascending aorta, including the aortic arch, main pulmonary artery and its bifurcation, as well as head and neck vessels. Novel intracardiac views were obtained, including right ventricular long axis, left ventricular apex and ‘flask’ views of the left ventricle. Excellent dynamic information for left ventricular function was also available [e.g. myocardial $V_{max}$ of the anterior left ventricular wall was $6.8 \pm 2.5$ cm/s at rest, $14.6 \pm 5.5$ cm/s after dobutamine ($P = 0.009$) and $4.5 \pm 1$ cm/s after esmolol ($P = 0.03$ compared with control)]. We conclude that, in adult primates, transvenous ultrasound safely and reliably provides novel information of cardiovascular structure and function.

Introduction

Ultrasound has been firmly established as an important diagnostic tool in the investigation of the cardiovascular system for the last three decades. For the most part, however, this has evolved as two separate entities; ultrasound of the heart (echocardiography) and ultrasound of the peripheral vessels (vascular Doppler). In the field of echocardiography, advances in technology such as colour-flow Doppler, harmonic imaging and tissue Doppler imaging have brought about refinements in image quality and resolution, as well as additional information regarding myocardial function [1]. Despite these improvements, however, both patient and technical factors continue to pose problems in echocardiography. A small, but significant proportion of subjects have poor quality echocardiographic studies [2]. In addition, the standard transthoracic and even transoesophageal views have potential intracardiac ‘blind spots’, which makes images of certain cardiovascular structures unobtainable, even in the most ideal subjects.

A transvenous catheter containing a fully functional ultrasound transducer has recently been developed (Acuson Pty Ltd., Mountain View, CA, U.S.A.). This may provide a novel way of imaging the heart as well as the major peripheral arteries in one procedure. A phased array single-plane ultrasound transducer with a frequency range of 5.5–10 MHz is mounted on to one
Figure 1 Transvenous steerable ultrasound catheter utilized in this study

Top panel: the 10F transvenous steerable ultrasound catheter utilized in this study (catheter seen at left, steering apparatus in centre and at right of the Figure). Bottom panel: fluoroscopic image showing the position of the radio-opaque transducer at the catheter tip (black arrowhead) in the superior vena cava, during imaging of the aortic arch.

METHODS

Baboons (Papio hamadryas) were chosen for the study because of the similarity of their cardiovascular system to humans. The study was approved by the Central Sydney Area Health Service Animal Welfare Committee. Six healthy adult male baboons weighing 21–25 kg and aged 6–9 years were selected. Each animal was taken from the baboon colony to the hospital holding premises and was under the care of a veterinarian experienced in their handling, at least two days prior to the procedure. The baboons were anaesthetized with ketamine according to a protocol described previously [3]. The ECG rhythm was monitored continuously.

A standard percutaneous femoral venous puncture was performed and a 10.5F venous sheath inserted using the Seldinger technique and a series of dilators. The ultrasound catheter was then inserted through the sheath and guided under fluoroscopic control. The transvenous ultrasound catheters were donated by Acuson Pty Ltd.

In all cases, the catheter was successfully introduced into the iliac veins, inferior vena cava, superior vena cava, head and neck veins and informative intracardiac views were obtained. The imaging frequencies used were 5.5–10 MHz. The average time from the venous puncture to completing the peripheral vascular scan was 43 ± 12 min, for the two-dimensional intracardiac study was 15 ± 6 min, and for completion of the left ventricular function study was 34 ± 8 min. Throughout these studies, our priority was the exploration of novel information rather than the speed of the procedure. Average fluoroscopy time was 11 ± 5 min. Each study was recorded on videotape in addition to being stored as digitally-acquired images, which were later transferred to magneto-optical discs.

The procedure was found to be safe with no evidence of cardiac perforation, heart block, bradycardia or valve damage. No tachyarrhythmia was noted at any stage in any animal, other than occasional single ventricular beats. All animals recovered promptly and were normally mobile and eating well on the day of the procedure. One had a small femoral haematoma only. All six baboons studied had normal vessels with no evidence of atherosclerosis and normal cardiac anatomy and function, except one who was found to have mild central aortic regurgitation demonstrated on colour Doppler.

Descriptive data are expressed as means ± S.D. Left ventricular function after intervention was compared with baseline conditions using paired Student’s t tests, with each animal serving as its own control. Significance was inferred at P < 0.05.

RESULTS

In all cases, arteries adjacent to the peripheral veins were imaged as the catheter was advanced; the right and left iliac arteries from the iliac veins; descending aorta, left and right renal arteries and the hepatic veins from the inferior vena cava; and the carotid arteries from the jugular veins. Retroflexion of the catheter was often utilized to create a ‘stand-off’ effect, allowing clearer visualization of both the near and far walls of the arteries. Wherever possible, pulsed-wave and colour-Doppler analysis were carried out.
Transvenous echocardiography in baboons

Figure 2  Doppler imaging of the iliac and renal arteries
Top panel: two-dimensional image of the iliac bifurcation, showing the left and right iliac arteries, with colour Doppler depicting the blood flow within the vessels. Bottom panel: colour Doppler showing a long segment of the left renal artery.

The catheter was then pulled back into the superior vena cava, and the aortic arch and pulmonary arteries were imaged (Figure 1, lower panel). It was then withdrawn into the right atrium and advanced into the high and low right ventricle, providing images of the right and left ventricles and all four cardiac valves. Dynamic studies of left ventricular function were then performed. Two-dimensional, tissue Doppler images, colour M-mode and pulsed-wave velocities were recorded from the anterior left ventricular wall in the ‘paraseptal base’ view at rest. Via a peripheral cannula, the positive inotropic agent dobutamine (at 5 min incremental doses of 5 μg/kg body weight per min, 10 μg/kg per min and 20 μg/kg per min) and then the negative inotrope esmolol (after a 10 min break, at a dose of 0.3 μg/kg per min for 10 min) were given and all measurements were repeated.

The iliac bifurcation and the right and left iliac arteries were imaged from the iliac veins. As the left and right iliac arteries were on slightly different planes to each other, they were usually imaged separately by twisting the catheter slightly one way and back, except in one instance when they appeared in the same plane (Figure 2, top panel). Pulsed-wave Doppler analysis was carried out on the left iliac artery, but not the right, because its flow was perpendicular to the ultrasound beam. Both the infrarenal and suprarenal abdominal aorta were easily visualized from the inferior vena cava. By retrofexion of the catheter, as described previously, both the near and the far walls were clearly defined.
The renal arteries were imaged consistently in all animals, with a long proximal segment of the left renal artery usually seen easily as the catheter was advanced up the inferior vena cava. Given that the frequency of the transducer allowed a depth of penetration close to 10 cm, almost the full length of the left renal artery was visualized. Then, by applying slight torsion and decreasing the depth to bring the near field into focus, the origin and a short proximal segment of the right renal artery were identified as this vessel crossed the inferior vena cava (Figure 2, bottom panel). Accurate pulsed-wave Doppler could be carried out on both renal arteries, as they were parallel to the beam of the Doppler. These showed a low-resistance flow pattern, with a significant proportion of flow continuing throughout diastole.

By guiding the catheter into the jugular veins, both right and left common carotids and their bifurcations were imaged. Internal carotids were followed to their main branches and colour and pulsed-wave Doppler could be obtained from each side.

From the superior vena cava, we were able to obtain unique views of the great arteries in all of the animals (Figure 3). We have referred to these as the ‘aortic sweep’ and ‘pulmonary sweep’ respectively. The ‘aortic sweep’ follows the aortic arch and ascending aorta from the aortic valve and the root around the arch to the upper descending aorta. We were able to acquire clear images of this region and to carry out colour-flow and pulsed-wave Doppler analysis. The aortic and pulmonary valves were also seen side by side in the aortic root view. Similarly, the main pulmonary artery, up to its bifurcation into left and right pulmonary arteries, was seen in the ‘pulmonary sweep’.

The intracardiac views were easily obtained by guiding the catheter to the right atrium. The view of the left ventricle including the sub-aortic region and the aortic valve (termed the ‘flask’ view) has been used as our orientating view (Figure 4, top left panel). The left coronary artery was identified in all animals from this view (originating from a position above the aortic valve cusp and coursing down inferiorly), and studied with colour and pulsed-wave Doppler. The right coronary artery was more difficult to locate.

By rotating the catheter anti-clockwise from the ‘flask’ view, a unique view of the tricuspid valve and the right ventricle in long axis (to its apex) could be acquired (Figure 4, top right panel). The next sets of views were obtained by advancing the catheter through the tricuspid valve into the right ventricle and imaging the left ventricular ‘paraseptally’. The paraseptal base view (from
Figure 4  Intracardiac views obtained with the ultrasound catheter
Top left panel: ‘flask’ view showing the left ventricle (LV) and aortic root (AO). LVOT, left ventricular outflow tract. Note the open aortic valve. Top right panel: right ventricle (RV), long-axis view showing the tricuspid valve (TV) and body of the RV. RA, right atrium. Bottom left panel: ‘paraseptal base’ view showing the base of the left ventricle from the high right ventricle. Bottom right panel: ‘paraseptal apex’ view showing the left ventricular apex (lv apex) from the low right ventricle.

the high right ventricle) showed the left ventricular base with the septum closest to the right ventricle and the anterior wall at the lower part of the picture (Figure 4, bottom left panel). The two-dimensional images revealed a clearly defined blood/endocardial surface, enabling assessment of ventricular contraction. The paraseptal apical view (from the low right ventricle) showed the left ventricular apex in all cases (Figure 4, bottom right panel). The mitral valve was not as clearly visualized, as the transducer in the right ventricle was situated in a plane that was mostly anterior to the plane of the valve.

The dynamic studies of left ventricular function were carried out using the paraseptal basal view. The myocardial contraction and relaxation was evaluated by tissue Doppler imaging to measure the peak myocardial velocity of the left ventricular anterior wall at rest (6.8 ± 2.5 cm/s), after dobutamine 20 µg/kg body weight per min (14.6 ± 5.5 cm/s, P = 0.009 compared with baseline) and esmolol 0.3 mg/kg per min (4.5 ± 1 cm/s, P = 0.03 compared with baseline). The change in the contractility was easily appreciated when displayed as colour M-mode (DTI™) and the end-diastolic and end-systolic anterior wall thickening measured.

A multimedia adjunct showing left ventricular function during dobutamine infusion, as seen through the transvenous probe placed at the apex of the right ventricle, and colour Doppler flow in the abdominal aorta and left renal artery (branch seen inferior to the aorta on the image) with the ultrasound catheter in the inferior vena cava is available from URL: http://cs.portlandpress.com/cs/099/cs0990141add.htm

DISCUSSION

This study of transvenous ultrasound in adult baboons has demonstrated its safety and feasibility, and allowed the acquisition of novel information on cardiovascular anatomy and function from each of the animals studied. Advantages included relative ease of use, the high quality of cardiovascular imaging obtained and the possibility of performing a single procedure to scan the status of the peripheral vessels and great arteries as well as the heart. This would be of relevance, for example, in ischaemic heart disease, where vasculopathy and cardiac dysfunction might co-exist, and clinically useful information could be obtained about both without the time and expense of multiple ultrasound procedures.

The clear images of the iliac bifurcation, abdominal aorta and the renal arteries are examples of the potential
of this device as a new investigational tool in vascular disease. In renal artery stenosis, external duplex ultrasound scans have been used in screening but have not proved to be sensitive or specific enough for definitive diagnosis [4]. Renal scintigraphy, another test for renal artery stenosis, relies on the differential uptake and excretion between the two kidneys and has low sensitivity in bilateral renal artery stenosis [5]. Renal angiogram remains the current gold standard, but requires arterial puncture and the use of contrast agents that may be contraindicated in renal failure. Transvenous ultrasound may aid in the diagnosis of renal artery stenosis; prospective studies would be required in humans to explore this possibility.

Other areas of interest for this ultrasound catheter might include imaging of the great arteries, especially the aortic arch and the pulmonary artery bifurcation. These structures are often not well seen on trans-thoracic or trans-oesophageal echocardiography. Therefore the diagnosis of ascending aortic dilatation, dissection or atheroma, as well as pulmonary artery origin stenosis in congenital heart disease states, may be facilitated by this technique.

Good views of tricuspid valve and pulmonary valves as well as the right ventricle may enhance the diagnosis of right heart pathology. For example, the right ventricular long-axis view provides excellent images of right ventricular contractility. The tricuspid valve is well seen, enabling the diagnosis of tricuspid endocarditis, Ebstein’s anomaly and/or the direct estimation of right ventricular hypotension if tricuspid regurgitation is present. The right ventricular outflow is also well seen, potentially useful in congenital heart diseases, such as native or repaired tetralogy of Fallot.

Novel left ventricular views included the ‘flask’ view, particularly of the sub-aortic region, and the paraseptal apical view, which clearly shows the apex of the left ventricle. This might enhance the detection of apical aneurysms, mural thrombi and small apical infarcts, which may escape detection with conventional methods of ultrasound investigation. Furthermore, this technique might be suitable for monitoring regional left ventricular wall motion during high-risk coronary angioplasty procedures, analogous to trans-oesophageal echocardiographic monitoring of left ventricular function during coronary bypass surgery. Although we did not specifically aim to calculate ejection fraction in this study, this might be feasible, given the excellent left ventricular views obtained.

There are a number of potential disadvantages and limitations of this ultrasound technique. The procedure involves local anaesthesia, a venous puncture and fluoroscopy guidance. Having only a single plane transducer confines the images to only one plane (unless the transducer is rotated through 90 degrees, which is not always possible given the lack of space in the veins or the right heart). For example, no short-axis view of the right ventricle could be obtained, despite an excellent long-axis view. The catheter is large and is occasionally difficult to manoeuvre easily, which limits potentially informative views (for example, from inside the coronary sinus). Only limited views are available of the right iliac arteries, and mitral valve and atrial septal views are less easily obtained than in trans-oesophageal echocardiography. Furthermore, there is a theoretical risk of rupture or damage to the intracardiac structures. For optimal use, ‘dual-skilling’ in cardiac catheterization and echocardiography might be advisable.

The main limitation of this study is that it has been carried out in baboons and not in humans. Although the anatomy of the baboon and the human cardiovascular systems are very similar [6], there are some subtle differences that may impact on the applicability of the findings from this study. For example, in baboons, the superior vena cava is relatively longer and the aortic arch lies more caudally within the thorax. The branching pattern of the aortic arch in baboons consists of two major branches (left subclavian and an innominate artery that divides in to right subclavian and right carotid as well as left carotid arteries). These differences, plus the smaller size of the baboons compared with normal adult humans, may have to be taken in to consideration when extrapolating the findings of this study to humans. In addition, as all of the animals studied were healthy, we have not yet assessed any cardiovascular pathology.

In conclusion, transvenous ultrasound safely and reliably provides novel information on cardiovascular structure and function in healthy adult primates. Further studies on primates and humans with cardiovascular pathology will be required to define the role of this potentially exciting new technique in clinical practice.

NOTE ADDED IN PROOF

Since the time of writing this article, the catheter has been approved by the Food and Drug Agency (U.S.A.) for cardiac monitoring of electrophysiological procedures in humans.

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