CT ANGIOGRAPHY IN COMPLEX UPPER EXTREMITY RECONSTRUCTION

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Computed tomography angiography is a new technique that provides high-resolution, three-dimensional vascular imaging as well as excellent bone and soft tissue spatial relationships. The purpose of this study was to examine the use of computed tomography angiography in planning upper extremity reconstruction. Seventeen computed tomography angiograms were obtained in 14 patients over a 20-month period. All studies were obtained on an outpatient basis with contrast administered through a peripheral vein. All the studies demonstrated the pertinent anatomy and the intraoperative findings were as demonstrated in all cases. Information from two studies significantly altered pre-operative planning. The average charge for computed tomography angiography was $1,140, compared to $3,900 for traditional angiography.

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INTRODUCTION

Vascular imaging is often necessary for pre-operative planning of complex upper extremity reconstructions. Digital subtraction angiography (DSA), magnetic resonance angiography (MRA), and duplex ultrasound have all been used to evaluate the vasculature (Disa et al., 1997; Hutchinson, 1993). Although digital subtraction angiography is considered the gold standard, it has limitations including that it mainly evaluates the arterial system and gives little information regarding the venous anatomy or soft tissue anatomic relationships, and it is relatively expensive. Digital subtraction angiography also has significant potential complications, including those related to arterial access (bleeding, haematoma, thrombosis, pseudoaneurysm, arteriovenous fistula) and the contrast medium (AbuRahma et al., 1993; Dublin et al., 1997; Katz and Kohl, 1994; Sakamoto et al., 1994).

Magnetic resonance angiography is another imaging modality that has been used for pre-operative evaluation prior to reconstructive surgery. One potential benefit of MRA is that it is less invasive than traditional angiography (Disa et al., 1997; Koelemay et al., 2001; Manaster et al., 1990; Mast, 2001). However, MRA is highly susceptible to movement artefact (due to long acquisition time) and it provides poor visualization of intravascular calcifications and bony landmarks. Furthermore the test cannot be performed if the patient has metallic implants in situ. Lastly, patients with claustrophobia do not tolerate the procedure well (Mast, 2001).

Computed tomography (CT) angiography is a relatively new procedure that provides high-resolution vascular images and detailed images of the adjacent bone and soft tissue. It is relatively non-invasive, with injection of the contrast medium through a peripheral vein. The accuracy of arterial visualization provided by CT angiography is comparable to that of DSA, and venous phase images are easily obtained (Rubin et al., 1995). Additionally, three-dimensional reformatting allows for excellent appreciation of anatomic relationships between bones, soft tissues, and the vascular system. Application of CT angiography is becoming more widespread, both for major vessel evaluation (thoracic and abdominal aorta) and smaller vascular beds such as the cerebral, pulmonary, renal, and mesenteric arterial systems (Gracias et al., 2001; Rubin et al., 1995; Wilms et al., 1996). Recently, our group has reported the potential utility of CT angiography in planning microsurgical reconstruction (Klein et al., 2003).

Indications for upper extremity vascular imaging are varied. In cases of trauma, indications include abnormal distal pulses, signs of haemorrhage, limb ischaemia, turbulent blood flow, injury of an adjacent structure (nerve injury or severe skeletal fracture), or a penetrating injury close to a major vessel (Rose and Moore, 1988). In particular, there is a high incidence of arterial injury in blast injuries and gun shot wounds. In addition, patients with non-traumatic vascular insufficiency with either diminished peripheral pulses or clinical signs of ischaemia may require imaging of the upper extremity vasculature. Vascular malformations or tumours near to vessels may also require imaging to assess their resectability and determine the extent of involvement of the vasculature (Disa et al., 1997).

We report our initial experience with the routine use of CT angiography for vascular assessment in cases of complex upper extremity reconstruction.

PATIENTS AND METHODS

Seventeen CT angiograms were obtained in 14 patients from March 2001 to November 2002. All had been referred for a soft tissue and/or bony reconstruction and had an abnormal vascular examination, symptoms of vascular insufficiency (cold intolerance, positional weakness and parasthesiae with associated loss of pulse), or a history of a crush injury. Fourteen of the 17 CT angiograms were obtained to evaluate the upper extremity of interest, and three were obtained to evaluate the vascularized fibular donor site before an upper extremity reconstruction.

All images were performed on an outpatient basis using either a four detector-row Somatom Volume Zoom CT scanner (Siemens Medical Systems, Erlangen, Germany), or an eight or 16-row General Electric LightSpeed CT scanner (General Electric Medical Systems, Milwaukee, WI). An initial scout image was obtained to determine the scan volume. After placement of a 20-gauge intravenous catheter in a vein in the antecubital fossa of the contralateral arm, a dynamic timing-bolus acquisition was performed. Time to peak enhancement at this level was determined by region-of-interest analysis and used as the scan delay for the CT angiogram.

Non-ionic contrast with 300 mg I/ml (Omnipaque) was administered intravenously with a power injector (EnVision CT, Medrad, Indianola, PA) at a rate of 5 ml/s. The total volume of contrast administered was determined by the product of the scan time (s) and the injection rate. The following scan parameters were used: 1.25 mm nominal section thickness, beam pitch 1.5, and $4 \times 1\,mm^2$ mode on the Volume Zoom and $8 \times 1.25\,mm^2$ or $16 \times 1.25\,mm^2$ modes on the LightSpeed scanners.

Computed tomography data were transferred to an Advantage Windows 4.1 workstation (General Electric Medical Systems, Milwaukee, WI) for the creation of alternative visualizations using volume rendering, curved planar reformations, and maximum intensity projections. All studies were interpreted by a single staff radiologist with expertise in CT angiography (G.D.R.) and evaluated for arterial variants and anomalies, the presence of vascular disease, and bone and soft tissue anatomy.

Several criteria were utilized to assess the suitability of CT angiography for routine use in upper extremity imaging. These included clarity of the images, correlation with the intraoperative findings, complications related to the study and the cost of the study compared with digital subtraction angiography.

RESULTS

Seventeen CT angiograms were performed in 14 patients with a mean age of 37 (range 5–65) years (Table 1). Eight were men and six were women. Twelve patients were undergoing reconstruction of traumatic injuries, six of which were acute. Five patients were being evaluated for symptomatic vascular insufficiency. The upper extremity was studied in all patients, as well as the lower extremities of three patients in whom fibula free flaps were planned. One patient had a shellfish allergy, and premedication with Benadryl and SoluMedrol was administered.

There were no complications related to the CT angiograms, and all studies were technically adequate. Six patients had abnormal peripheral vascular examinations and their computed tomography angiograms all revealed defects which were consistent with the clinical findings. Two patients with normal pulses had significant abnormalities on CT angiography (vascular calcifications and incomplete palmar arch).

Intraoperative findings were as predicted by CT angiography in all cases. Information from two studies

Table 1

Patient	*Age*	*Sex*	*Study*	*Indication*
1	58	M	UE	*Hand ischaemia*
2	65	F	Upper Thorax	Subclavian pseudoaneurysm
3	46	F	UE/LE	Fibrous dysplasia (s/p proximal radius resection)
4	31	F	UE	*Palmar* wrist ganglion with vascular compromise
5	20	M	UE	Avulsion injury, open elbow
6	18	F	UE	Degloving injury
7	59	M	UE	Crush injury, exposed flexors
8	18	F	UE	Crush-avulsion, exposed bone
9	61	M	UE/LE	Crush injury, segmental bone loss
10	57	M	UE	Crush injury
11	16	M	UE	Near amputation (arm)
12	37	M	UE/LE	Both bone forearm fracture, segmental bone loss
13	5	M	UE	Supracondylar fracture, vascular compromise
14	23	F	UE	Crush-avulsion, exposed tendon

(Cases 7 and 9) significantly altered the preoperative planning, with both showing sub-optimal recipient vessels for a vascularized tissue transfer. We did not feel patient number seven had a suitable target vessel and the leg vessels of patient number nine had significant calcifications. Therefore, plans for free flap reconstruction were aborted.

We also performed a cost analysis of CT angiography at our institution. The average CT angiogram charge was $1,140, while for traditional arteriography it was $3,900 (professional fees included). The average costs for extremity duplex ultrasound was $450 and for upper extremity magnetic resonance angiography it was $2,500.

Case reports

Case 3

This 46-year-old woman with a history of fibrous dysplasia had undergone a resection of her proximal radius 20 years previously. She presented with painful progressive wrist instability with proximal migration of the distal radius. The operative plan was to reconstruct the radius with a vascularized fibula flap. Computed tomography angiography was performed on the forearm and both lower extremities and the study demonstrated a normal forearm arterial tree and three-vessel runoff to the foot bilaterally (Fig 1). These images demonstrate the spatial anatomic information attainable with volume rendering. Proximal radial reconstruction was performed with a free fibula flap and a radial head prosthesis without complication.

Case 4

This 31-year-old woman had 5 years previously suffered a laceration to the ulnar aspect of her wrist, with injury to ulnar artery and nerve, and several flexor tendons. Repair of all these structures, except the artery, had been performed at an outside medical center. She presented to our clinic with a palmar wrist ganglion over her radial artery and complaints of cold intolerance. Physical examination revealed an intact radial artery directly abutting the $2 \times 2\,cm^2$ ganglion, and no palpable ulnar artery. A CT angiogram was obtained to evaluate her vasculature (Fig 2). One of the benefits of CT angiography is the ability to add and subtract bone and soft tissues from the vasculature and to highlight objects of interest. This study demonstrates this ability, clearly showing the intimate association of the radial artery with the ganglion. *Of note*, *the*

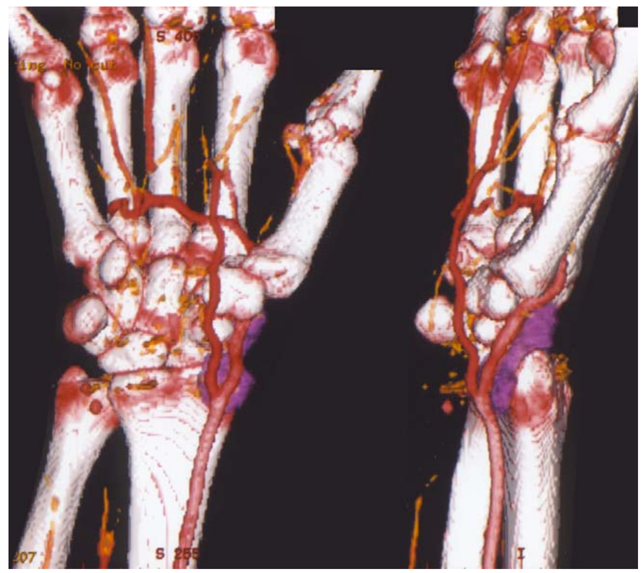

Fig 2 Hand CT angiogram of a patient with previous ulnar artery laceration and a symptomatic palmar wrist ganglion.

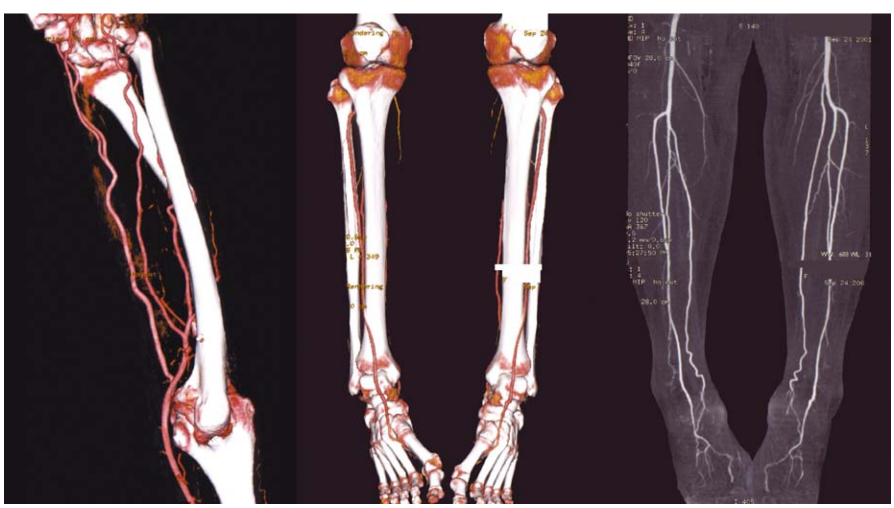

Fig 1 Upper and lower extremity CT angiogram revealing normal vasculature in a patient with a proximal radius defect following to resection for fibrous dysplasia.

resolution of current generation CT scanners is not high enough to study the digital vasculature. The patient eventually declined reconstruction of the ulnar artery, and ganglion excision was performed without event.

Case 8

This 18-year-old woman was a passenger involved in a rollover motor vehicle accident in which her dominant hand suffered a dorsal crush avulsion injury to the level of bone. The vascular examination revealed weak radial and ulnar pulses. The pre-operative plan was to use either a reversed radial forearm flap or a lateral arm free-flap to resurface the dorsum of the hand. A CT angiogram was obtained to assess the radial artery since it was within the zone of injury. This demonstrated normal upper extremity vascular anatomy (Fig 3), and the patient underwent a reversed radial forearm flap reconstruction without complications.

Case 9

This 61-year-old man was involved in a motorcycle accident and sustained an open comminuted Monteggia fracture with a radial head dislocation and soft tissue loss. Initial debridement and external fixation were performed at an outside facility. Postoperatively, the patient developed osteomyelitis requiring debridement and significant bone resection. Both upper and lower extremity pulses were normal and there was symmetric flow on Allen's test. Due to his history of massive crush injury, CT angiography of the upper extremity was performed as well as bilateral lower extremity CT angiograms to evaluate the vasculature for potential free fibular donor sites (Fig 4). There was minimal interference from the external fixator (EBI, Parsippany, New Jersey), except on the axial views. Lower extremity CT angiograms demonstrated severe calcifications bilaterally. Based on the extent of the vascular disease, a one-bone forearm procedure was performed instead of a free fibula reconstruction.

DISCUSSION

Computed tomography angiography is a relatively new technique which is capable of providing high-resolution

Fig 3 Normal upper extremity CT angiogram of a patient with exposed bone and tendon following a dorsal hand crush-avulsion injury.

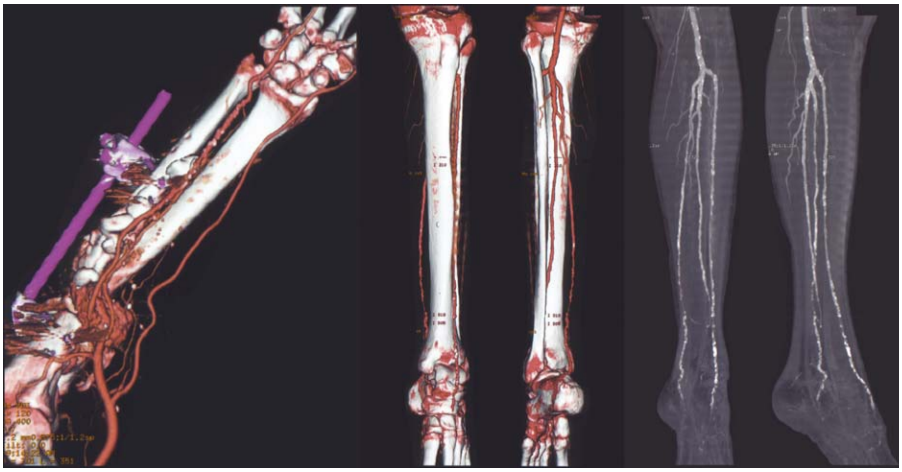

Fig 4 A Monteggia fracture with severe comminution and bone loss following a high-energy injury. Upper and lower extremity CT angiograms reveal extensive arterial calcification in the ulnar artery and lower extremity vessels. (Note the minimal interference from the external fixator).

vascular imaging. In this study, we examined the utility of CT angiography for imaging of the upper extremity following trauma, as well as for patients with symptoms of vascular insufficiency. Although angiography is the standard technique for vascular imaging, the potential complications, high cost and prolonged recovery period make conventional angiography less desirable for routine use.

CT angiography has many advantages over traditional angiography. It demonstrates more anatomical detail and has the ability to add and subtract bone, soft tissue, hardware, arteries and veins to provide unparalleled spatial detail. In addition, CT angiography is performed by contrast injection through a peripheral vein, eliminating the risks associated with arterial puncture. Three to five per cent complication rates have been reported for arterial puncture and include bleeding, haematoma, thrombosis, arteriovenous fistula and pseudoaneurysm (AbuRahma et al., 1993; Dublin et al., 1997; Katz and Kohl, 1994; Sakamoto et al., 1994). Furthermore, the radiation exposure with conventional angiography is nearly four times the amount with comparable CT angiography (Rubin et al., 2001).

When compared with traditional angiography, the acquisition time and examination cost of CT angiography are significantly lower. Given the short acquisition and processing times and the need for only a peripheral intravenous catheter, we have been able to obtain these studies on as required, even in emergencies, basis. The cost of traditional angiography includes the study itself, the interventional radiology suite time, reading of the study, and the hospital stay (following a conventional angiogram patients must have 6 hours of bed rest) (Dublin et al., 1997). At our institution, the average CT angiogram charge was $1,140 and for traditional arteriography it was $3,900, including professional fees. The amount of contrast required for each procedure was approximately equivalent and, thus CT angiography does not decrease the risk for renal failure.

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