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ORIGINAL PAPER

Resin polymer and corrosion casting of the porcine pelvi-calyceal system: a useful model for investigating new imaging and endoscopic techniques of the upper urinary tract

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Abstract We describe the use of polyester resin casting of the pelvi-calyceal (PC) system as a method of evaluating the accuracy of new three-dimensional imaging technology such as ultrasound and computerised tomography. Thirty-eight kidneys from large white pigs were used for the study. We describe the process of preparation of the kidney and polyester resin for injection into the PC systems. The setting process of the resin is an exothermic reaction with an associated change in consistency. The PC systems of the kidneys were injected with resin in a controlled manner and casts obtained by maceration of the kidneys. Some of these kidneys had been distended previously with 11% glycerol and three-dimensional ultrasound reconstructions of their PC systems were compared to resin casts to assess accuracy of the reconstructions. Thirty-eight casts were created out of which 13 were poor. The quality of the casts improved with practice and pelvi-calyceal morphology could be faithfully recreated. Controlled perfusion and watching for signs such as a "turgid feel" of the kidney help avoid pelvi-calyceal disruption. Anatomically accurate casts of the kidney PC system can be created using polyester resin with the technique described. These casts can be a useful research and training tool with urological and radiological applications.

Keywords Polyester resin · Casting · Porcine kidney · Model · Endourology · Radiology

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Introduction

The use of casting in anatomical studies goes back centuries. Famous proponents include Leonardo da Vinci and John Hunter using materials including latex, polyester resin, silicone based fluids, wax [1] and more recently acrylic resin [2].

Polyester resins have been described as being ideal for anatomical work since 1970 [1] and have advantages over previously available materials including resistance to shrinkage and maintenance of anatomical integrity. They are also strong and extremely durable [1, 3].

We have used casting of the renal pelvi-calyceal system (PCS) as a method for evaluation of the accuracy of new three-dimensional (3D) imaging techniques using ultrasound (US) [4, 5]. In this paper we describe the method used to obtain these casts, how they have proved valuable for research studies and also discuss future applications.

Materials and methods

Ethics approval was obtained from the Wandsworth Research Ethics Committee as well as from NHS Research and Development (St. George's Healthcare NHS Trust). Thirty-eight kidneys were obtained from large white pigs (Fresh Tissue Supplies, Horsham, Essex, UK). The kidneys

arrive fresh and can be frozen for use. If frozen, the kidney should be defrosted in tepid water as rapid defrosting in hot water can result in tissue destruction. The kidneys are dissected to identify the ureter. This is often enmeshed in perihilar fat along with the artery and vein. Identifying the ureter may be difficult. The hilar arrangement may not necessarily follow the textbook order of renal pelvis situated posteriorly with the artery and vein anteriorly. The artery is usually the thickest structure with branches and the vein the thinnest. We dissected all tubular structures keeping as much ureteral length as possible. Excess fat was removed before intubating the ureter with a 5F flexible catheter (Tempo 5, Cordis Corporation, USA) (Fig. 1).

The polyester resin is unsaturated and needs to be saturated with a styrene monomer to allow solidification. A catalyst can aid this process by reducing working temperatures (called cold-setting) and thus hasten the hardening process. Resin and catalyst mixing should be performed in a ventilated fume cupboard. Resin manufacturers provide information regarding the amount of catalyst needed for curing a known quantity of resin. For Resin A (Scott Bader Company Ltd, Wollaston, Northants, UK), 2 ml of methyl ethyl ketone peroxide catalyst (Polyfibre, Birmingham, UK) is required for each 100 g of resin. We used 2 g of Jasmine (polyester) Colour Paste (Llewellyn Ryland Ltd, Birmingham, UK). During mixing the temperature was recorded using a digital thermometer with a steel probe (WideRng Probe Thermo, Maplin Electronics, Barnsley, UK). A graph was prepared showing the changes in temperature of this resin mixture over time (Fig. 2). After application of the catalyst, the consistency of the resin mixture was noted to turn from gel-like to firm and subsequently hard. Gel-like consistency was evident at 25–26°C and hardness occurred at 100°C. The mixture turned to a firm consistency in 22 min at an ambient temperature of 20°C.

Each kidney was mounted on a board with a 19 gauge decompressing needle inserted into the highest point of the PCS in order to expel trapped water and air during resin injection. This point can only be estimated and placing the needle in an optimum place comes with experience. A prior knowledge of the PC system in relation to the renal parenchyma is helpful. A 20 ml syringe was used to draw the mixture directly from the preparation pot as soon as the temperature of the mixture rose to 21°C. This allowed sufficient time (about 20 min—see above and Fig. 2 graph) to comfortably inject at least two kidneys before the consistency of the mixture changed. The syringe was attached to a 16 gauge venflon inserted into the distal ureter secured with a silk suture. The resin was injected at a steady low pressure, watching the decompression needle for overflowing resin and signs of a distending kidney. Once resin was noted to arise in the needle, injection was stopped, and the ureter clamped. The kidney was left at room temperature for 24 h to allow the resin to set.

Resin casts were extracted by macerating the kidney in 20% sodium hydroxide solution. For each kidney this equated to a solution of 160 mg sodium hydroxide in 800 ml of distilled water. Kidneys were stored in a fume cupboard in a container containing the sodium hydroxide solution for 48 h to obtain complete tissue dissolution. The eroded parenchyma was washed off the cast under running water to leave the PCS cast remaining.

Some of the kidneys were selected for comparison with radiological models. Prior to casting, the PCS was distended (pressure-controlled) with 11% glycerol. Volume rendered (VR) 3D models/videos of the PCS were then

Fig. 1 Kidney and ureter after dissection

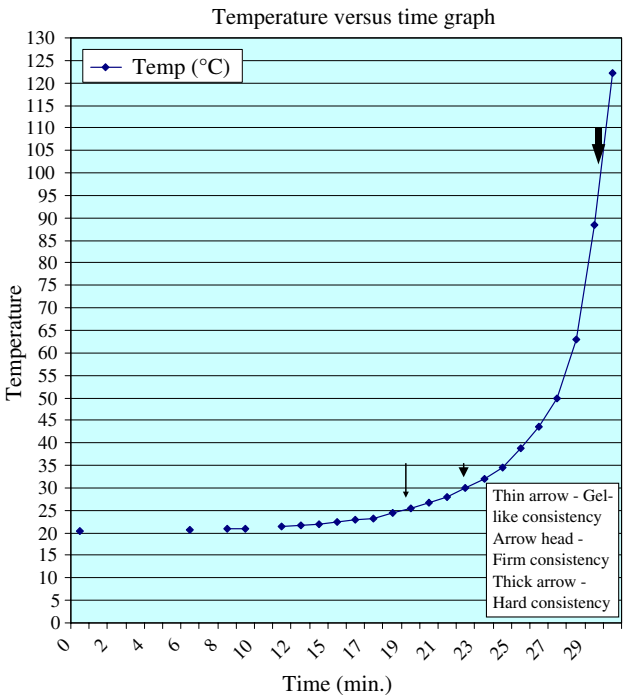

Fig. 2 Temperature of the resin-catalyst mixture plotted against time

created using a 3D ultrasound system (GE Logiq 9, GE medical systems, USA) on a workstation and compared to the subsequent cast of the PCS.

Results

The PCS was likely to be at risk of calyceal disruption when resistance to injection was noted, resin overflowed from the decompression needle or the body of the kidney developed a turgid feel.

Of the 38 PCS casts created 13 were poor (34%). The majority of these casts were our early casts and constituted part of our "learning curve". A cast was considered poor if there was calyceal disruption with loss of forniceal architecture, the infundibula could not be identified or if their origins could not be clearly seen (because of over-distension) and if there was pyelo-venous backflow. The main technical problem encountered was disruption of the PC anatomy by over-zealous perfusion. Some kidneys were also not of optimal freshness and may have undergone autolysis prior to freezing. Some examples of poor and good quality casts are provided in Figs. 3 and 4.

The results of this study including the comparison of PCS casts with 3D volume rendered ultrasound imaging (Fig. 5) were presented at the 2004 American Urological Association meeting [4].

Fig. 3 Normal cast of the pelvi-calyceal system. All the calyces are well demonstrated, as is the renal pelvis and upper ureter. Note the sharply defined fornices of the undilated calyces. There is no evidence of calyceal rupture, therefore the cast is considered of good quality

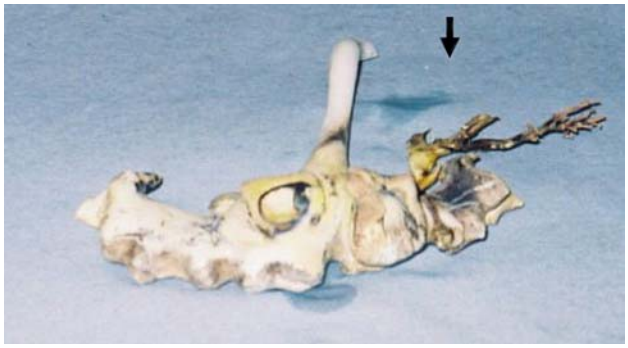

Fig. 4 The picture shows pelvi-calyceal disruption with pyelo-venous backflow. The calyces are poorly seen, the fornices or the calyceal margins are ill-defined and resin has extruded into the renal veins (*Arrow*)

Discussion

Resin casting has proved valuable in several clinical research studies [2, 3, 6–8] including vascular corrosion cast studies in APP23 transgenic mice [2] and vascular corrosion casting of major cerebral arteries after sub-arachnoid haemorrhage in rats [6].

In urology, resin casting has been used to study the anatomy of the collecting system and the safety of percutaneous access to the human PC system [9]. Our understanding of the performance of partial nephrectomy has been helped by

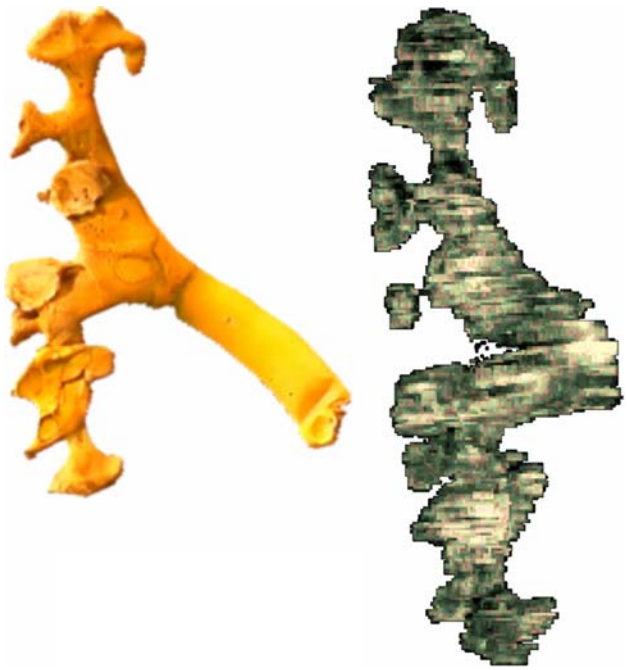

Fig. 5 Cast of the pelvi-calyceal system (*left*) with corresponding 3D volume rendered reconstruction created using ultrasound (*right*)

studying casts of the renal vasculature and collecting system [10]. The pig kidney has been shown to be a useful animal model for training in urological procedures, owing to the many similarities between pig and human intra-renal arteries [3].

We have described a reproducible method for casting anatomically faithful models of the porcine PCS which have proved valuable controls during the assessment of novel 3D imaging techniques. This method has been useful for both macroscopic and microscopic studies, with modifications being made based on the particular study; for example, the addition of gold-palladium for electron microscopy [2]. Therefore, though it has been the reference method for most casting studies, to our knowledge a detailed breakdown of the basic process has not been visited in the literature for some time. The method described in this paper also simplifies the casting process utilising current, commercially available and relatively inexpensive materials and instruments familiar to clinicians, which is particularly useful for those not trained in anatomical preservation techniques. The use of fresh tissue and thermally guided injection timing are valuable points of technique. Very sophisticated new casting studies have been also recently described such as fluorescent imaging cryomicrotomy, which still starts with the traditional resin (acrylic) but does away with corrosion and uses digital cameras to visualise vessels with diameters as small as 40 μm [11].

Casts of the PCS are able to display the complexity of the PCS anatomy, and as such can be extremely useful three-dimensional anatomy teaching tools for trainee interventional radiologists and urologists. Urology trainees are keen to be competent in or specialise in percutaneous (endourological) intervention (such as stones treatment and tumour ablation). To this end, porcine kidneys can potentially be implanted in models and punctured, with or without artefacts placed within them [12–15]. Consequent resin casting of the PC system and vessels can then clearly show the tract and provide valuable feedback regarding accuracy and safety. Such training is vital in this day and age when gaining competency "away from the patient" on the laboratory bench is fast becoming the norm [12] and tight training budgets always calls for cost effectiveness on the part of trainers [16].

Conclusions

Casts of the porcine PCS are readily generated and reliably reproduce the complexity of the PCS anatomy. They can act as useful research and training tools with both urological and radiological applications. We recommend further application of this technique in the investigation of novel imaging technology and in the training of tomorrow's urologists and interventional physicians.

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