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A Prototype Simulator for Endovascular Repair of Abdominal Aortic Aneurysms

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A prototype simulator for training in endovascular repair of abdominal aortic aneurysms (AAA) has been developed. Employing transparent models of human AAA complete with renal, iliac and femoral arteries, this system allows accurate simulation of aortography, road-mapping, catheter guidewire manipulation and stent-graft deployment while obviating the need for ionising radiation.

Introduction

Abdominal aortic aneurysm (AAA) affects 3–6% of the elderly population over 65 years.[1,2] In England and Wales approximately 10 000 people die each year from rupture of their AAAs.[3] Surgical repair of the aneurysm, preferably before rupture, offers the best chance of averting death from this cause. However, the elderly population affected tends to harbour other manifestations of arterial disease especially in the coronary and cerebral circulation which adds to the risk of treatment.

Conventional open repair of AAA is associated with 5–10% mortality after elective operation and in excess of 50% mortality after emergency operation following rupture of the aneurysm.[3] Although the long-term results have yet to be evaluated, new minimally invasive techniques of endovascular repair may prove to be safer. These involve the fluoroscopically controlled placement of an aortic stent-graft via the femoral artery. Highly developed skills in guidewire and catheter techniques are required along with particular knowledge and understanding of the specific device and introducer system being used. We have developed a simulation system to facilitate development of these skills.

The Prototype Simulator

For simple training, a computer model of a highly simplified symmetrical human AAA, including the renal, iliac and femoral arteries (Fig. 1) was produced using average arterial dimensions.[4] The physical model was then constructed from two blocks of acrylic plastic by surface milling using a three-axis milling machine, with data generated by the computer model. The two machined blocks were polished and clamped together to form a transparent and water-tight AAA model. For advanced training, clear silicone rubber models of actual AAA aneurysms were produced by rapid prototyping techniques. The first stage was to perform a three-dimensional reconstruction (Fig. 2) of an actual aneurysm using the patient's spiral CT images. After producing the solid master model of the AAA by stereo-lithography, an investment casting process was used to fabricate the clear silicone rubber models for use in the simulation system.

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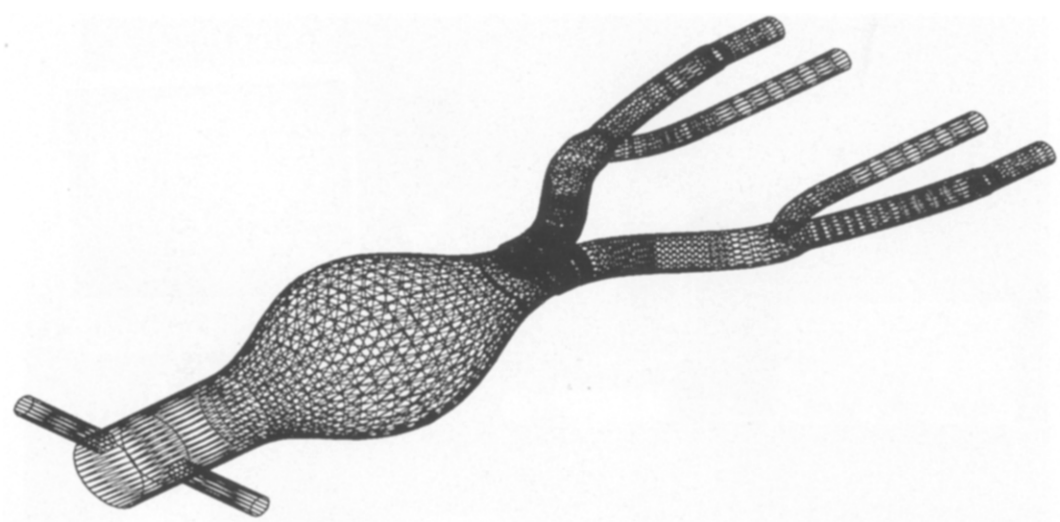

Fig. 1. Triangulated surfaces of a simplified AAA computer model having renal, common iliac, external iliac, internal iliac and femoral arteries. All the arterial segments lie on the same plane. A transparent and water-tight physical model was produced by surface milling of two acrylic plastic blocks which were then bolted together after polishing.

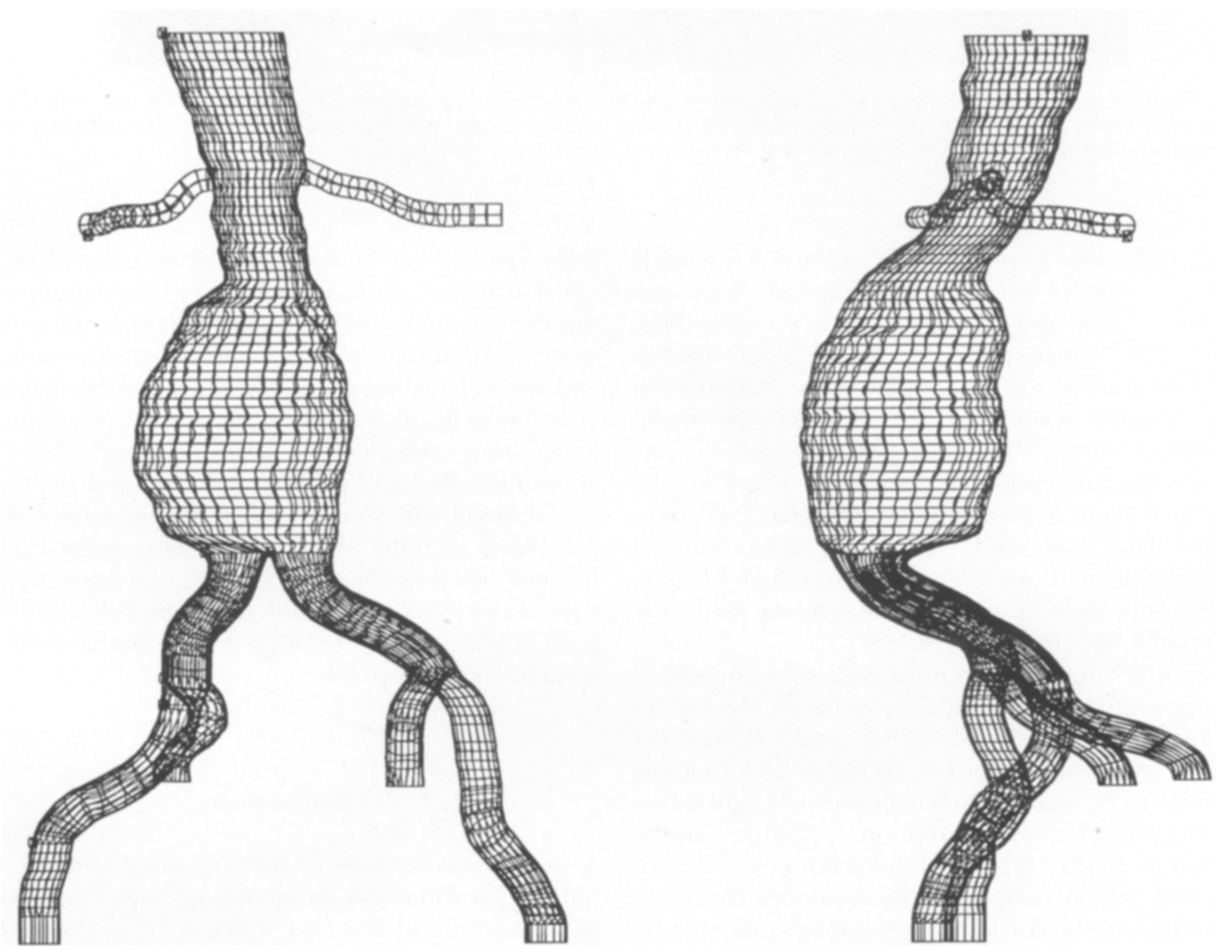

Fig. 2. Three-dimensional computer model of a patient's AAA treated with a bifurcated endovascular stent-graft. This model was reconstructed from the patient's preoperative spiral CT scan images. A clear silicone rubber model was then fabricated from the computer data using rapid prototyping techniques. Interpolated surfaces are shown in anteroposterior view (left) and lateral view (right).

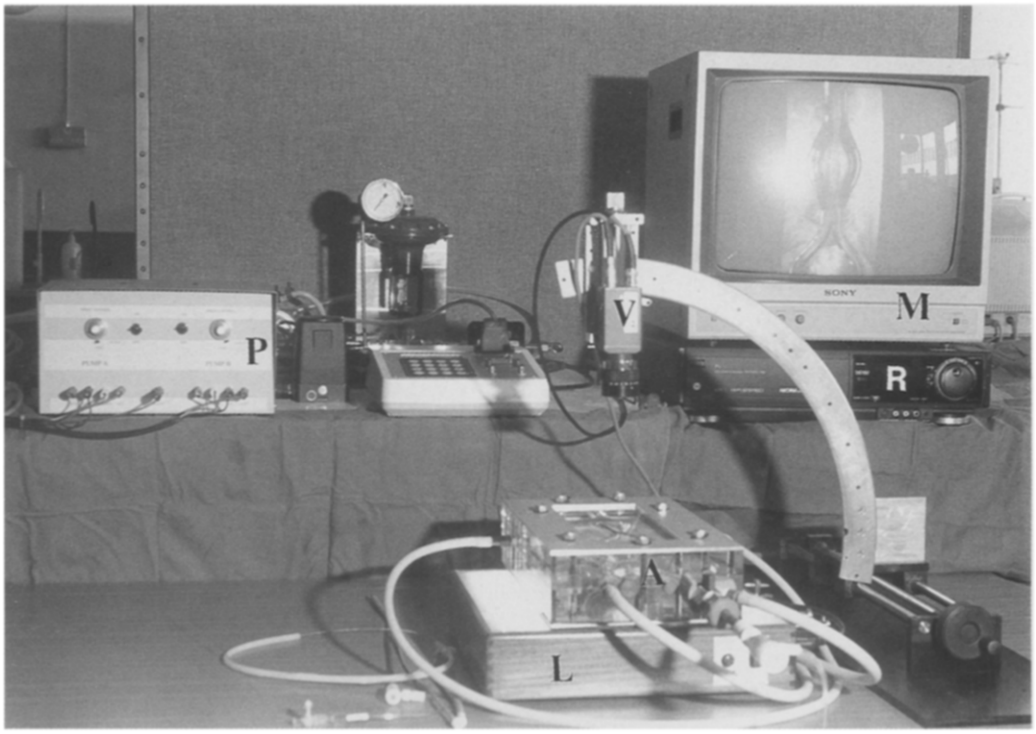

Fig. 3. Photograph of the uncovered training simulator showing the video camera (V) supported by an adjustable C-arm and movable gantry, AAA model (A), light-box (L), display monitor (M), video recorder (R) and pulsatile pump system (P). The computer which performs the video image acquisition and processing for mock aortograms and road-mapping is not shown.

Inlet and outlet ports are fixed to the AAA models at the suprarenal aorta, renal, internal iliac, and femoral arteries and connected to a pulsatile flow circuit. The outlet ports at the femoral arteries incorporate a self-sealing valve for the introduction of the delivery system and guide wires. The model is perfused with an aqueous glycerol solution. The flow waveform, representative of blood flow in the abdominal aorta is produced by a mechanical pump system.[5] Flow into and out of the model can be monitored by a flowmeter and controlled by gate valves. This system mimics the patient with the aneurysmal abdominal aorta.

To mimic "fluoroscopic imaging", a computerised imaging system using a monochrome video-camera was developed (Fig. 3). The AAA model is enclosed within a "torso" and posterior and lateral illuminations are provided by means of white fluorescent light tubes. The video-camera supported on a C-arm can be adjusted to display images of the anteroposterior, oblique and lateral planes on the monitor. The bony landmarks observed with X-rays can be simulated by means of a removable abdominal X-ray film placed underneath the model. The stent-graft may be delivered through the introducing port with a catheter of up to 24F. An aortogram to locate the renal arteries and target site can be simulated by injecting black ink via a catheter while initiating the acquisition of a number of video frames upon activation of a foot-switch. The frames can be reviewed on the monitor and normal real-time video display can be resumed after image acquisition with the selected pre-acquired image as a reference for "road-mapping". With the aortogram, the stent-graft is delivered and deployed at the target site. Every process is also recorded by the video recorder. When the whole procedure is finished, the exact location of the stent-graft may be checked by direct inspection of the model. The stent-graft can be retrieved through the suprarenal aorta for another round of practice.

Discussion

A simulation system is an important adjunct for training in endovascular stent-graft repair of AAAs. In a recent report, the Endovascular Graft Committee (representing the Joint Council of the Society for Vascular Surgery and the North American Chapter of the International Society for Cardiovascular Surgery and the Society of Cardiovascular Interventional

Radiology) stated "The training program must include adequate large animal experience (or mock circulatory model experience) to ensure technical proficiency with the usage of the device being evaluated".[6] Since animal models lack the necessary anatomy and dimensions of human AAAs, a mock circulatory model of correct anatomy and dimension is the preferred alternative.

In the development of the simulation system, we have incorporated those features considered to be important, namely the use of accurate models of human AAA, the ability to perform "aortograms" and "road-mapping" as well as provision of pulsatile flow of a blood analogue fluid. The simulator was designed to mimic as closely as possible all procedures encountered in the clinical situation without the use of ionising radiation. In order to provide realistic "fluoroscopic imaging" with the video-camera system, it is necessary to match the refractive index of the circulating fluid to that of the acrylic model. Because of the high refractive index of acrylic plastic, this is only partially achieved by using the glycerol solution. However, with models made of silicone rubber which has a refractive index of about 1.4, a good match in refractive indices can be achieved with the glycerol solution. Another advantage of using silicone rubber is that it has flexible properties like natural arteries and this facilitates the deployment of endovascular stent-grafts through tortuous vessels.

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