IMPLICATIONS OF DISTENSION ON THE DESIGN OF ARTERIAL GRAFTS

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ABSTRACT

An examination of current literature shows that little consideration has been given to distensibility properties of arterial grafts and that those currently being used represent small strain systems. Using angiographic techniques, we have observed diametral variations of the major arteries to be considerably larger than those reported by previous investigators. Evidence is presented to show that there may be advantages to incorporating host-vessel distension in arterial grafts.

INTRODUCTION

The failure of synthetic vascular grafts as a result of thrombosis, anastomotic disruption and aneurysm formation is common. As pointed out by a major manufacturer of arterial grafts, "modifications and improvements (over the past 15 years)... have been more in the direction of strength and healing qualities for the prosthetic grafts, rather than specific considerations for the change in circumferential distensibility".[1] Our angiographic measurements of large diametral variations for normal vessels would indicate that distensibility should be considered in the design of arterial grafts.

DISTENSION OF THE MAJOR ARTERIES OF MAN

In this study, measurements have been made using cineangiography to determine the percentage variation in diameter (PVD) of the major arteries under normal conditions of pulse pressure. The details of our experimental methods are described elsewhere.[7,13,21] The results show that the aortic, femoral and iliac vessels all have a PVD in excess of 10%.

This distension is considerably larger, by a factor of two or more than the results reported by previous investigators using surgery and strain gauges or other displacement-type transducers. Peterson,[2] Patel,[3] and Greenfield[4] have all measured distensions of less than 5% using various strain-gauge techniques. Gardner[5] has presented angiographic data from which one can calculate aortic PVD's in excess of 10%. Recently Arndt[6] in Germany has demonstrated normal diametral variations for the carotid arteries of 14.3% using ultrasonics.

Figure 1 is a plot of the PVD for the thoracic aorta comparing our measurements using angiography with those of Greenfield[4] using strain gauges. Strain-gauge techniques give measured diameter variations about 5 percentage points lower than those obtained from angiography. Surgical and strain-gauge methods tend to de-emphasize the magnitude of arterial distension.

DISTENSION PROPERTIES OF ARTERIAL GRAFTS

Previous discussion of graft elasticity has been primarily concerned with flexibility and longitudinal strain. There are few reports of quantitative distensibility studies.

Eiken[10](1961) pointed out that "non-viable prostheses do not have, or will soon lose, their distensibility as they heal by scar tissue forming around and invading the graft wall and, thus, they behave more or less like rigid tubes". Schultz[9](1967) described the results of a preliminary study on distension properties of teflon and dacron grafts. He indicated that these materials all showed PVD's of less than 1%. Hokanson[8](1968) measured the dynamic compliance of arterial grafts commonly used in cardiovascular surgery. Table 1, taken from his results, shows a diametral variation for these grafts of less than 1% (pulse pressure = 50 mmHg). Woven grafts tend to have a low compliance; whereas, knitted grafts have a natural elasticity within the stitches. Although the lack of elasticity characteristics of woven fabric can be temporarily overcome by using crimped tubing, the corrigations are quickly lost after implantation. Hokanson pointed out that, because of the ingrowth of fibrous tissue, after only one year of implantation, a dacron knitted graft had less than one-third of its original compliance.

RELATION BETWEEN DISTENSION AND GRAFT FAILURE

Comparing the foregoing values for arterial grafts with our angiographic results on arterial distension, it is obvious that synthetic grafts have far lower distensions than normal arteries. Both Hokanson[8] and Schultz[9] have made reference to the disparity between host vessel-graft distensions and how this could place undue stress on the graft sutures. They based their arguments on *in vitro* measurements showing arterial PVD's of less than 3%. If a difference in distension of 2 percentage points is sufficient to warrant consideration of suture line stress, then the observation of 10 percentage points should certainly justify attention.

Distal Suture Line Disruption: The implantation of a plastic prosthesis is almost a prerequisite in the formation of an anastomotic aneurysm. One feature peculiar to these aneurysms is their high incidence at the distal end.[8,11,12] Some investigators suggest that this may be due to the grafts crossing areas of flexion.[12] Others indicate that the fate of the graft is not significantly influenced by whether the graft passes by the joint or not.[11] Based on suture line stress, it is possible to speculate yet another reason for the predominance of these aneurysms distally.

Schultz's data shows that the distensibility beyond an area of atheroma is somewhat larger (by 120%) than that of the normal artery. This factor could account for additional strain at the distal suture line of synthetic bypass grafts.

Occlusion: Mustard[14] and Sears[15] have demonstrated that zones of high shear in the circulatory system and areas of boundary layer separation or reverse velocity gradients lead to activation of the clotting mechanism. Eiken[10] showed that fibrous tissue deposits occur at points of expansion in a graft. The localization of these deposits corresponded with the sites of turbulence. The question which must be more fully studied is whether the transition between a relatively distensible vessel (e.g. PVD 10%) and a non-distensible graft (PVD 1%) predisposes to graft thrombosis.

Alterations in Graft Properties: The fact cannot be ignored that, after implantation, properties of the prosthesis will change from that of the purely synthetic material to that of the less distensible synthetic, scar-tissue matrix.

SOME EVIDENCE IN FAVOUR OF DISTENSIBLE GRAFTS

Only a few investigators have attempted to include elasticity in the design of arterial grafts. The main problem in the past has been to ensure that other properties (e.g. strength and durability) were not sacrificed in the process. Most of the "elastic" grafts have proven unsatisfactory for this reason.[17-19] In 1958 Szilagyi[18] reported findings on an elastic Dacron prosthesis. Though distensible, it tended towards "slippage" and unravelling. In spite of these limitations, animal experiments using long aortic bypass implants showed excellent long-term patency rates and a retention of the initial tensile strength.

Table 1 illustrates that knitted dacron grafts have a larger compliance than woven dacron or knitted and woven teflon. Woven dacron has been reported by Crawford[16] to have one of the highest success rates in the treatment of occlusive disease.

The saphenous vein autograft commonly used in arterial surgery represents a highly distensible system. Hokanson[8] reported its distension to be more than 6 times that of knitted dacron or teflon prosthesis and 50 times that of the woven grafts. It is also recognized as being one of the most successful graft materials.[20] It is characterized by a low incidence of thrombosis and suture line failure. The few reports of anastomotic aneurysm formation indicate no predilection for either the proximal or distal end.[20] In contrast with the much higher incidence of synthetic graft distal suture line disruption, its success indicates the need to consider distension as a design parameter.

CONCLUSION

Major arteries undergo much larger diameter variations than have been reported in the past. The grafts currently available have not been designed to simulate this property. Although sufficient evidence is not available to establish the relative importance of this factor on graft failure, it appears that distensible grafts might result in a lower incidence of suture line disruption and thrombosis.

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Figure 1. Comparison of Strain-Gauge Data[4] and Angiographic Data

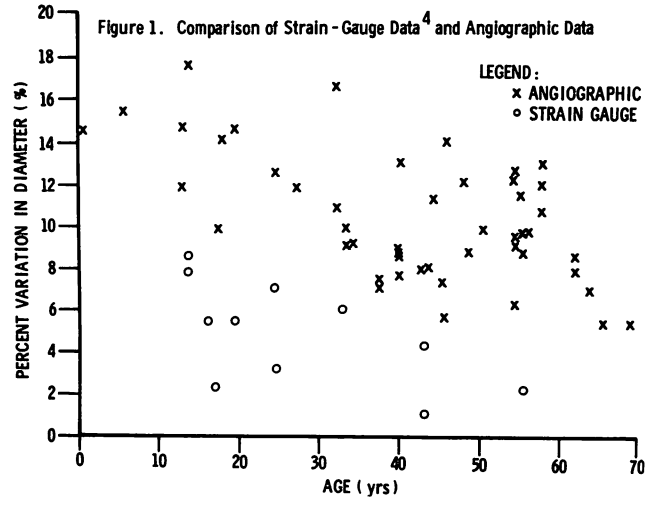

TABLE 1 Distension Properties of Arterial Grafts

(Data taken from Hokanson[8])

Graft Material	Circumferential Distension (%ΔC/50 mmHg ± S.D.)
Woven Dacron	0.08 ± 0.03
Knitted Dacron	0.75 ± 0.06
Woven Teflon	0.09 ± 0.03
Knitted Teflon	0.69 ± 0.05