New Flexible Vascular Adhesive for Use in Cardiovascular Surgery

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At the present time, the search for a satisfactory vascular adhesive has not yielded a substance generally accepted for clinical use. The desirable characteristics of such an agent, however, are generally appreciated, and include: (1) flexibility; (2) minimal tissue toxicity; (3) rapid adherence to the vessel wall; and (4) a cellular structure to permit ingrowth of surrounding connective tissue. The current laboratory investigation was undertaken to evaluate a group of polyurethane resins that combine many of the attractive characteristics included in the list of desirable physical properties.

Material

The polyurethane prepolymer resin used in this investigation was the reaction product of a group of polyisocyanates and polyols. The polyisocyanates included toluene diisocyanate and p,p'-diphenylmethane diisocyanate; the polyols were polyesters, polyethers, or an alcoholized vegetable oil.

In general, polyurethane resins can be produced as completely reacted resins or as reactive isocyanate containing prepolymer which are cured by the addition of a polyol as a second component. The position and quantity of isocyanate groups in the prepolymer molecule, together with the molecular weights of both the prepolymer and polyol, determine the physical properties (flexibility, hardness, tensile strength, and curing time) of the final polymer obtained.

Experimental Method

Longitudinal and transverse incisions (1.0 to 3.0 cm.) were made in arteries and veins of two series of experimental animals. In group I (25 mongrel dogs), the aortae and inferior venae cavae were utilized; in group II (25 dogs), femoral or carotid arteriotomies were performed.

In order to avoid partial obstruction of a vessel lumen by entry of resin through the incision, the edges of the arteriotomy or venotomy were everted by the placement of a single no. 6-0 silk suture. The in situ diameter of the incised vessels ranged between 2.0 and 20 mm.

A uniform technique for application of the resin was found to be necessary in order to achieve consistent results: (1) all attached connective tissue was meticulously excised from the adventitia of the vessel; (2) the vessel wall was carefully dried, either with a gauze sponge or by exposing the surface of the vessel to a stream of helium gas; (3) a priming coat (containing an isocyanate and catalyst mixture) was then applied with a paint brush and allowed to dry for at least 30 seconds; and (4) a coat of resin was then utilized to cover the incision in the vessel and approximately one-half of the circumference of the adjacent vessel wall. Polymerization commenced upon contact between the resin and adventitia, and this process was completed within two minutes.

In all experiments involving small arteries or veins (5 mm. or less in diameter), a small polyethylene tube (1.0 to 3.0 mm. in diameter) was inserted into the lumen of the vessel to serve as a stent. This preliminary step prevented narrowing of the vessel lumen during the polymerization process.

Results

The polyurethane prepolymer resins used in this investigation formed a firm, stable, elastic end product which adequately sealed vascular incisions in 50 dogs (figs. 1 and 2). The patency rate was 90 per cent, with failures (thrombosis) present in five animals secondary to sepsis or inadvertent obstruction of the vessel lumen by polymer. Gross and histopathological studies (one week to six months following application of the polymer) disclosed no interference with fibrous or endothelial repair of intimal and medial defects. Chronic inflam-
Figure 1
Left: A 1.0-cm. right femoral arteriotomy with the edges of the incision separated by traction sutures of no. 6-0 arterial silk. All overlying connective tissue has been excised from the adventitia of the vessel. Right: The same vessel with the vascular incision sealed by a polyurethane polymer. A single arterial suture (no. 6-0 arterial silk) was placed in the center of this incision to evert the edges and prevent polymer from entering the lumen of the vessel.

Figure 2
Left: A 1.5-cm. linear incision in the abdominal aorta of a dog. Traction sutures are again seen in the center of the incision. Right: The same incision sealed with polymer.

formation surrounding the plastic was mild in the great majority of instances.

The polyols and polyisocyanates employed were not sterilized prior to use in the experimental animal. However, bacterial cultures (aerobic and anaerobic) of all component materials failed to yield any growth.

Discussion

The polyurethane resins utilized in this study are of the reactive prepolymer type. Reactive isocyanate groups readily combine with the available hydrogen atoms in substrate tissue and result in exceptional adhesion via true chemical bonds, as well as through intermolecular (Van der Wall) forces. In addition, these isocyanate groups can react with moisture (evolving carbon dioxide), which builds up the size of the polymer end product. Thus, a cellular structure is obtained which eventually permits the ingrowth of surrounding connective tissue and provides additional strength for the vascular closure.

The low incidence of thrombosis following adhesive closure of both arteriotomies and venotomies directly reflects the importance of two polyurethane polymer properties: relative chemical inertness and flexibility. In addition,
pathological evaluation of polymer-coated vessels indicates that these characteristics are maintained for at least six months following implantation. Longer-term evaluation is now under way in a third group of experimental animals, and should provide data concerning the durability of these materials.

Summary
1. Preliminary studies of polyurethane resins of the reactive prepolymer type indicate that they may be of considerable value in experimental and clinical cardiovascular surgery as adhesive agents.

2. These resins combine hardness, elastomeric (rubber-like) properties, and chemical inertness which persist unchanged for periods of at least six months.

3. The position and quantity of isocyanate groups in the prepolymer molecule, together with the molecular weights of the prepolymer and polyol, determine the physical properties of the final polymer obtained.

4. Exceptional adhesion between the polymer and blood vessel wall is a result of the reaction between available hydrogen atoms in the substrate tissue and the isocyanate groups in the prepolymer.
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