Comparative tensile and relaxation experiments on fresh and glutaraldehyde-treated porcine aortic valve tissue

Comparative Tensile- and Relaxation Experiments on Fresh and Glutaraldehyde-Treated Porcine Aortic Valve Tissue

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Introduction.

In order to obtain better insight into the factors which govern the life-span of bioprostheses, comparative experiments have been performed with porcine aortic valve tissue in fresh condition as well as being treated with glutaraldehyde. The glutaraldehyde-treatment is commonly applied to biological tissues which are to be used for manufacturing bioprostheses. The main purpose of the treatment is to eliminate the antigenic components and to produce stable irreversible cross-linkages between the collagen-molecules (1).

In the investigation, described in the present paper, the elastic and viscoelastic material properties of leaflet tissue were determined using the experimental procedure developed by Sauren (6) and based upon the material model for soft tissues in simple elongation as described by Fung (3). Each tissue strip was investigated before as well as after the treatment with glutaraldehyde. By this way changes in material properties can be attributed to the process applied.

Materials and methods.

All specimens used in the experiments were strips approximately 3 mm wide. They were cut in the circumferential direction from the leaflets of porcine aortic valves (see: fig. 1). After mounting and preconditioning the tissue strips, the actual experiments were started. A detailed description of the experimental procedure is given in (6), p.p. 52-56.

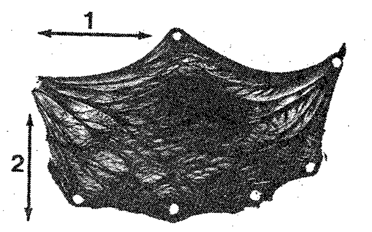

Fig. 1: Leaflet of porcine aortic valve:
1: circumferential direction
2: radial direction.

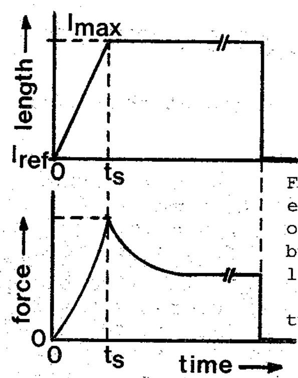

Fig. 2: The actual experiment: straining of the specimen, followed by maintaining the length at l max.

ts: straintime (~0.1s)

After measuring the fresh leaflet strips, the tissues were treated, according to the method of Carpentier (1). As described by Broom (2), the glutaraldehyde-treatment for manufacturing a bioprosthesis is applied to a whole intact valve under a hydrostatic pressure of about 100 mm Hg. This condition was simulated in the experiments by treating the leaflet strips under a preload of approximately 0.3 N. This load corresponds with the physiological strain value of about 0.07 (see also fig. 3), being the average local strain in the circumferential direction in the leaflets of an intact porcine valve under an internal hydrostatic pressure of 100 mm Hg, as measured stereophotogrammetrically by Missirlis and Chong (4). The treated specimens were subjected to the same experimental procedure.

The elastic behaviour is defined by the stress-strain relation measured when straining to lmax (see fig. 2). The viscoelastic behaviour is to be characterized by the reduced relaxation function: $G(t) = \sigma(t)/\sigma(t=0)$. Strictly speaking, G(t) can only be determined from the load response of the specimen to a step change of the length. As it is physically impossible to realize a true step change, a finite time interval ts of about 0.1 sec. was considered (fig. 2).

We will present some characteristic preliminary data as found for two tissue strips. Furthermore, as a reference, the results of 3 leaflet strips of a Hancock bioprosthesis (Mitral-tricuspid; model 342 R, 31 mm) will be given.

Results and discussion.

Typical results for the stress-strain relations and the reduced relaxation functions for the fresh, the treated and the Hancock leaflet tissue are shown in figures 3 and 4. In table 1 the results are given for the reduced relaxation function at t=100 s., and also the geometric data are listed.

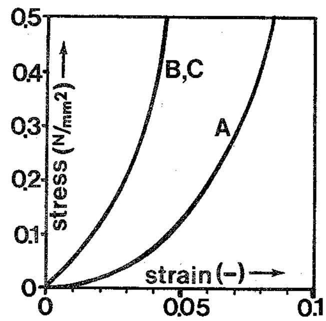

Fig. 3: Typical stress(σ)-strain(ϵ) curves for different tissues:
A: fresh
B: treated
C: Hancock

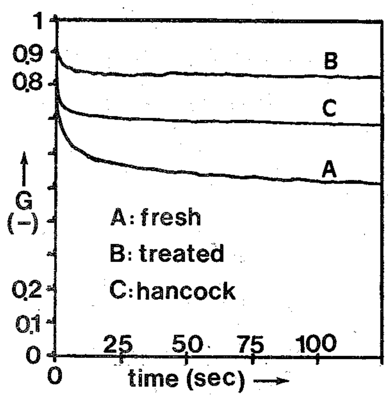

Fig. 4: typical curves for the reduced relaxation function G versus time.

TISSUE	G(t=100 s) (-)	lref (mm)	thickness (mm)
FRESH 1	0.52	9.8	0.68
2	0.61	10.9	0.94
TREATED 1	0.84	10.1	0.35
2	0.85	11.1	0.58
HANCOCK 1	0.69	10.0	0.50
2	0.68	9.7	0.27
3	0.66	10.3	0.43

Table 1: Characteristic results of the measurements: viscoelastic- and geometric parameters.

From this it is concluded that due to the glutaraldehyde-treatment the stress-strain curve shifts towards the stress-axis and that the tissue becomes stiffer in the region of low strain as well as in the region of high strain. This shift might be explained from the state of the collagen fibres which are coiled in the fresh unloaded tissue (2). When this tissue is strained, first the collagen fibres rearrange and uncoil, which process in the treated tissue took place during preload. Possibly, this stretched state is preserved due to the treatment. Thus the collagen fibres are being loaded at the very beginning of stretching, which explains the shift of the stress-strain curve mentioned.

The thickness decreases about 40% as a result of the glutaraldehyde-treatment. In the normal physiological situation three different layers can be distinguished in the leaflet tissue (5): i) a layer of elastin fibres, oriented in various directions; ii) a layer of loose connective tissue and iii) a layer of collagen bundles, oriented in the circumferential direction. The decrease in thickness, due to the glutaraldehyde-treatment, may be explained by reduction of the layer of loose connective tissue between the layers of elastin fibres and collagen fibres. Optical inspection of the side-walls of the leaflet strips, cut in radial direction, before and after treatment supports this suggestion. Due to the treatment the viscoelastic parameter G(t=100) changes: the total amount of relaxation decreases about 60%. This may be the result of the reduction of the layer of loose connective tissue. Most probably the composition of the layer out of mucopolysaccharides and glycoproteins mainly determines the viscoelastic properties, which composition obviously is strongly affected by the treatment.

From the findings for the Hancock bioprosthesis it may be concluded that its elastic properties correspond to the results obtained with the tissue treated at 100 mm Hg. The viscoelastic properties of the Hancock valve however range in those corresponding with the fresh and treated condition.

Finally it is concluded that due to the glutaraldehyde-treatment both the elastic and viscoelastic behaviour of the leaflet tissue change considerably.

Acknowledgements.

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