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Lesions of myocardial capillary vessels during open-heart surgery

K. Kyösola[1] and L. Rechardt[2]

[1] Department of Thoracic and Cardiovascular Surgery, University Central Hospital, Helsinki
[2] Department of Anatomy, University of Helsinki, Helsinki, Siltavuorenpenger 20, SF-00170 Helsinki 17, Finland

Summary. In a clinical series of patients undergoing open-heart surgery, capillary lesions in the myocardium were common when hypothermic chemical cardioplegia was used for myocardial protection during aortic cross-clamping. It seems obvious that the resulting oedematous swelling of the capillary wall, especially that of the endothelial cells, may constitute an anatomic intraluminal obstacle to myocardial reperfusion, thereby further delaying the recovery. After (mere) topical cooling, only minor capillary changes were observed. In contrast to the oedematous transformation described above for the former group, capillary endothelial cells and pericytes of the latter were diminished in cellular volume.

Key words: Cardiac surgery – Capillary vessels – Myocardium

Introduction

Protection of the heart from ischemic anoxic injury in the course of cardiac surgery is of utmost importance in order to ensure adequate postoperative cardiac function. Topical cooling of the heart and hypothermic chemical cardioplegia have been widely used for myocardial protection. The effectiveness of these techniques has been studied also with the electron microscope. A large range of pathological changes after the cold ischemic anoxic asystole or the combined cold and chemical ischemic cardioplegia has been described in the literature. (For ref., see e.g. Volkmer et al. 1977; Döring et al. 1978; Jynge et al. 1978; Buckberg 1979; Cunningham et al. 1979; Fenchel et al. 1979; Beyersdorf et al. 1980; Lucas et al. 1980; Roberts et al. 1980; Rosenfeldt et al. 1980; Schaper et al. 1980). Most interest has focused on the myocardial cell itself, while other cardiac structures have received relatively little attention. Thus, studies concerning capillary lesions are rare (Herdson et al. 1965; Penttilä et al. 1974; Schaper et al. 1980). However, the state of the capillary vascular bed is one of the determinants of the immediate

Offprint requests to: L. Rechardt at the above address

Table 1. Composition of the cardioplegic solution

a) The stock solution:	
$CaCl_2 \times 2H_2O$	16.5 mg
KCl	74.5 mg
$MgCl_2 \times 6H_2O$	162.5 mg
Aq. ad iniect. ad (pH 6.4)	1 ml
b) The final solution infused into the coronary arteries:	
The stock solution	20 ml
5% glucose solution	980 ml
Solu-Medrol^R (Upjohn)	250 mg
c) The calculated electrolyte content/1000 ml in the final solution:	
Ca^{++}	2.25 mmol
K^+	19.98 mmol
Mg^{++}	15.99 mmol
Cl^-	56.46 mmol

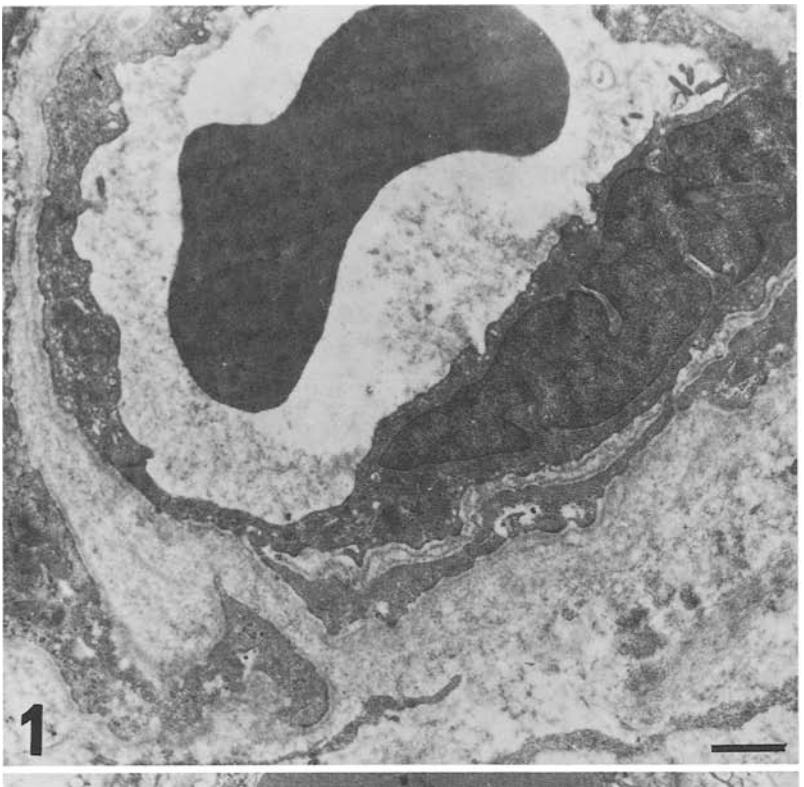
recovery after the corrective phase. The present paper deals with our observations on intramyocardial capillaries in the course of cardiac surgery, when either topical cooling or hypothermic chemical cardioplegia was used for myocardial protection.

Patients and methods

The material included 10 patients who underwent aortic valve replacement operation under topical cooling of the heart (with $+4°$ C physiologic saline solution) during the aortic cross-clamping, and 10 patients who underwent either aortic valve replacement (5 patients) or coronary bypass surgery (5 patients) under hypothermic chemical cardioplegia (+associated local cooling of the heart with slushed ice). The composition of the cardioplegic solution is given in Table 1. The aortic cross-clamping time varied from 50 min to 70 min. Biopsies were excised from the right atrial myocardium 1) before starting the extra-corporeal circulation (controls) and 2) after coronary reperfusion, at decannulation, and processed for electron microscopy: fixation in ice-cold 5% glutaraldehyde in 0.1 M phosphate or cacodylate buffer (pH 7.2) for 5 h, post-fixation in 1% osmium tetroxide for 1 h, dehydration in graded series of aethyl alcohol, embedding in an epon-araldite mixture, staining of the ultra-thin sections with 2.5% lead citrate and saturated uranyl acetate. The sections were viewed and photographed with a Philips EM 300 electron microscope.

Fig. 1. Electron microscopic view of a capillary from the control right atrial myocardium before starting extra-corporeal circulation. Notice the thin-walled endothelial cell with evenly distributed chromatin in the nucleus. The basal lamina is partly thin, in some areas thicker, but is clearly distinguished. Glutaraldehyde and OsO_4 fixed. Lead and uranyl stained. The bar represents 1 μm length

Fig. 2. Electron microscopic view of a capillary from the right atrial myocardium (the same patient as in Fig. 1) after hypothermic chemical cardioplegia. The endothelial cell shows oedematous changes with vacuolization. The nucleus is shrunken with changes in the chromatin distribution. Basal lamina is swollen. Procedures and the length of the bar as in Fig. 1. *V*= vacuole; *BL*= basal lamina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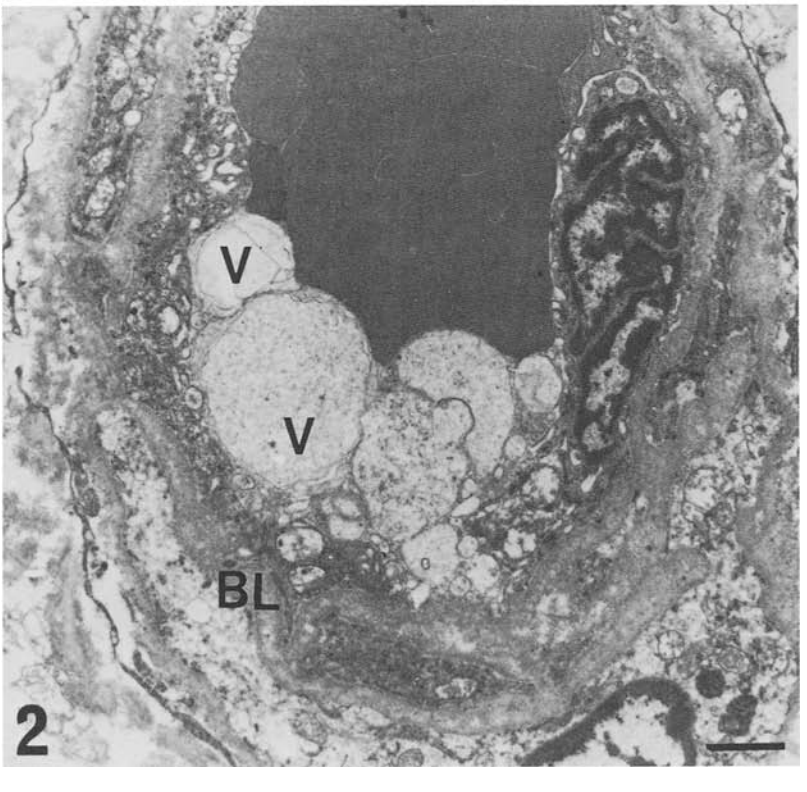
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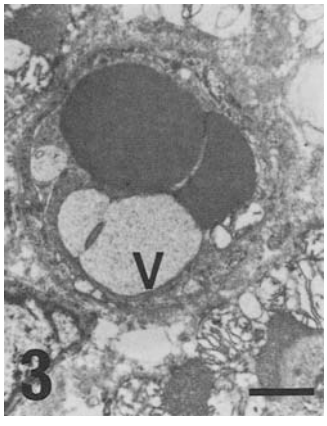

Fig. 3. Electron microscopic view of a capillary from the right atrial myocardium after hypothermic chemical cardioplegia. The lumen of the capillary is occluded by two red blood corpuscles and endothelial vacuoles (*V*). Procedures as in Fig. 1. The length of the bar is 3.5 μm

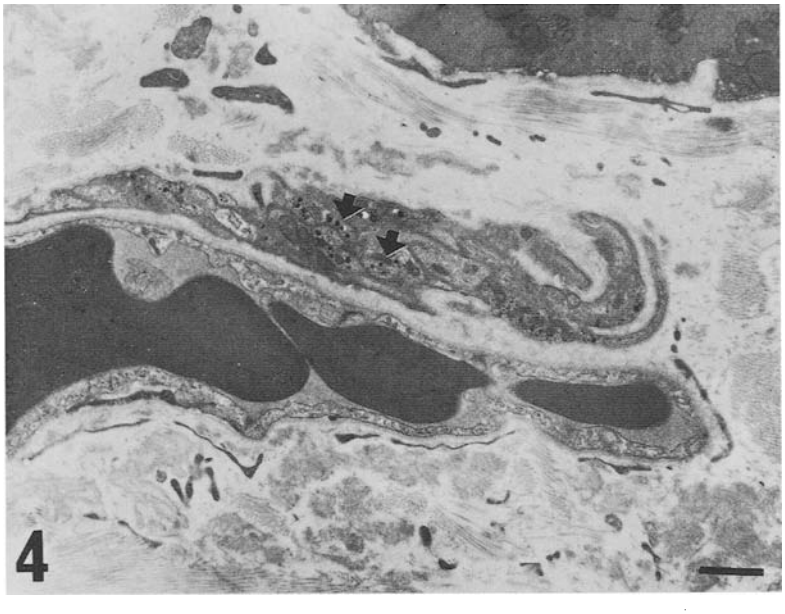

Fig. 4. Electron microscopic view of a capillary from the right atrial myocardium after topical cooling of the heart. The endothelial cells do not show oedema, the capillary wall is thin. In the longitudinal section of the capillary several blood cells are seen. A well preserved nerve bundle in the vicinity of the vessel shows nerve terminals with small dense cored vesicles (*arrows*). Procedures and the length of the bar as in Fig. 4

Results

In the control specimens, which were excised before starting the extra-corporeal circulation, the capillary lumina were open (Fig. 1). Red blood corpuscles, were seen freely passing the lumina. The endothelial cells were thin with distinct cytoplasmic margins. Small villi were projecting into the lumen. The nuclei showed evenly stained chromatin. The basal lamina were clearly distinguished but showed sometimes moderate thickening as seen in Fig. 1.

After the hypothermic chemical cardioplegia (and coronary reperfusion) moderate oedema of the endothelial cells was seen in 7 cases, severe swelling and damage in 3 cases (Figs. 2, and 3). In severely damaged capillaries the endothelial cells showed clumping and margination of the nuclear chromatin (Fig. 2). In the swollen globular mitochondria, paling and clearing of the matrix, distortion, disruption or lysis of the cristae and of the inner and outer mitochondrial membranes was observed. Occasionally lysis of complete mitochondria and myelin figures were seen in the endothelial cells (Fig. 2). Large cytoplasmic vacuoles filled with finely granular material or large empty vacuoles protruded from endothelial cells and bulged in to the capillary lumen (Figs. 2 and 3). The enclosing basal lamina was thick and oedematous (Fig. 2).

The capillary lumen was filled with finely granular material. Sometimes up to three red blood cells were observed within the capillary lumen, suggesting a local widening of the capillary vessel caused by an occlusive obstacle down-stream in the vessel, possibly by swelling and bulging of endothelial cells. The degree and extent of capillary injury was not correlated with any operate variable.

After the procedure of mere topical cooling (and subsequent coronary reperfusion) no or only minor capillary changes were seen (Fig. 4). In contrast to the oedematous changes, described above, the capillaries were often shrunken. The endothelial cells and pericytes then exhibited diminished cellular volumes. Endothelial cell swelling was never observed in this group.

Discussion

The preservation of the endothelial cells during ischemic anoxia seems to be better than of the myocardial cells of the same region, at least in normothermia (Herdson et al. 1965; Penttilä et al. 1974). However, the vascular endothelium may be significantly damaged by ischemia during hypothermic chemical cardioplegia, and the changes regress only slowly upon reperfusion (Schaper et al. 1980). The present study supports the findings of Schaper et al. (1980). It thus seems obvious that micro-vascular damage during hypothermic chemical cardioplegia may temporarily inhibit myocardial perfusion locally, thereby further delaying the recovery. The method of (mere) topical cooling did not favour oedematous transformation of the capillaries. However, there is now a general consensus that the method of combined cold and chemical cardioplegia ensures a better general preservation of the heart than cardiac hypothermia alone. Obviously efforts should be directed towards more appropriate composition of the cardioplegic solution. In fact, it has been shown that the amount of myocardial swelling or dehydration caused by different solutions is related to the fluid constituents, rather than to their infusion pressures or volumes, and that protein is not a necessary constituent, if the osmolarity of crystalloid cardioplegic solution is raised sufficiently, to 370 mOsm. (with mannitol) (Buckberg 1979). The cardioplegic solution used in the present material is obviously not ideal in preventing cellular oedema.

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