Acute effects of tourniquet occlusion and intraluminal shunts in beating heart surgery

Jens Wippermann, Johannes M. Albes, Harald Brandes, H. Kosmehl, Raimund Bruhin, Thorsten Wahlers

Department of Cardiothoracic and Vascular Surgery, University Hospital Jena, Bachstr. 18, 07743 Jena, Germany
Department of Pathology, University Hospital Jena, Jena, Germany

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Abstract

Objective: MIDCAB and OPCAB revascularization is currently performed with temporary tourniquet occlusion of the coronary artery to achieve a bloodless surgical field. However, a trauma of the vessel wall due to snaring sometimes occurs. The use of temporary intraluminal shunts (TILS) have recently been advocated as an alternative. The aim of this experimental study was to evaluate the acute ultrastructural effects of TILS versus tourniquet occlusion on the coronary vessel wall.

Methods: Twelve pigs (40 ± 3 kg) were investigated. In group A (n = 6) the left anterior descending (LAD) artery was temporarily occluded with a tourniquet over 20 min. In group B (n = 6) a commercially available silicone TILS (1.5-mm diameter, 12-mm length, AnastaFlo, Research Medical Inc.) was placed in the LAD. After 20 min perfusion the TILS was removed and the insertion was repaired. After 30 min reperfusion all animals were killed. Three LAD territories of each animal were examined histopathologically by scanning electron microscopy (SEM), light microscopy (LM) and transmission electron microscopy (TEM).

Results: SEM revealed ultrastructural alterations in both groups. While marked intimal rupture appeared in all animals of group A, only two of the six animals of group B exhibited superficial endothelial abrasions. LM showed differences of intimal thickness in all groups while TEM revealed severe edema of subendothelial tissue in four of six animals in group A.

Conclusion: The intimal lesions observed after tourniquet occlusion in our experimental off-pump surgery model confirmed other recent studies. In contrast, utilization of TILS caused only minor damage of the vessel wall. The endothelial abrasions detected in this group may be a consequence of micro-dislocations or insertion maneuvers. Chronic studies are necessary to verify as to whether the mild injury after TILS insertion will result in a reduction or even absence of de-novo stenoses compared with tourniquet occlusion.

Keywords: Temporary intraluminal shunt; Temporary intraluminal shunts; Beating heart surgery; Endothelial injury; Tourniquet occlusion; De novo stenosis

1. Introduction

Beating heart surgery has gained worldwide popularity. To obtain good visualization and a stabilized operative field most MIDCAB and OPCAB revascularizations are performed with temporary occlusion of the respective coronary artery. However, there may be the possibility of a trauma of the vessel wall related to the coronary snaring maneuver and myocardial stunning. As an alternative, temporary intraluminal shunts (TILS) have recently been developed. This device has been designed to facilitate coronary anastomoses by providing perfusion distal to the anastomoses site, maintaining a bloodless field, and reducing the need for external pressure on the vessel (Fig. 1). The aim of our study was to investigate the acute ultrastructural effects of TILS versus tourniquet occlusion on the coronary vessel by using scanning electron microscopy (SEM), light microscopy (LM) and transmission electron microscopy (TEM). For this we developed a new experimental model to compare different occlusion techniques in beating heart surgery. In our initial experiment...
coronary snaring was performed with non-elastic monofilament suture.

2. Material and methods

2.1. Animal care

This study was approved by the Animal Care and Use Committee of the Friedrich-Schiller University Jena. All animals received humane care in compliance with the ‘Guide for the Care and Use of Laboratory Animals’ as revised by the National Institutes of Health in 1985.

2.2. Animal preparation

Twelve domestic pigs, weighing 37–43 kg, were anesthetized with intravenous injection 150 μg/kg per min propofol (Disoprivan 2%, Emulsion, Astra Zeneca, Germany) and bolus injection of 2–5 μg/kg fentanyl (Fentanyl-Janssen, Janssen Cilag, Germany), tracheal intubation was performed, and mechanical ventilation was started. The animals were placed in a supine position. After preparation, a 19-gauge detaining needle was inserted into the right carotid artery and a 4F catheter was placed into the external jugular vein for measurement of blood pressure. Median sternotomy was performed, the heart was exposed by incising the pericardium and heparine (150 U/kg) was given. In group A (n = 6) a 1-cm segment of the left anterior descending (LAD) artery was superficially prepared. Two non-elastic monofilament (4-0 Prolene, Ethicon Inc., Somerville, NJ, USA) sutures were placed 2 cm apart proximal and distal to the anastomotic site by performing a wide stitch around the LAD in order to achieve a tourniquet. The LAD was opened between the two tourniquets and the tourniquets were snared with utmost care just until the blood flow ceased. The LAD incision was then closed using an 8-0 Prolene suture. After 20 min the tourniquets were released.

In group B (n = 6) a commercially available silicone TILS (1.5-mm diameter, 12-mm length, Anastaflo®, Research Medical Inc.) was placed in the LAD through a 2-mm longitudinal incision. In every case the shunt diameter was slightly oversized compared to the respective size of the coronary artery. For the TILS insertion maneuver the proximal LAD was briefly occluded to obtain a bloodless surgical field. Insertion usually required not more than 35 s by using the shunt-shuffle technique [5]. After 20 min perfusion the shunt was removed and the insertion was closed by a 8-0 Prolene suture. After 30 min of reperfusion the animals of both groups were killed by injection of pentobarbital 16% solution (Narcoren, Merial, Germany).

2.3. Procurement of tissue

After excision of each heart the LAD was isolated en bloc and carefully dissected from the adherent epicardial tissue. Coronary artery cylinders were removed from the areas of occlusion or placement of the TILS olives 7 mm apart from the insertion on each side. One cylinder of each group was investigated by SEM the other one by LM and subsequently by TEM if alteration was noticeable. Control samples were obtained from the untreated segments of the same coronary artery (Fig. 1).

2.4. Histological analysis

The tissue specimens were preserved by using 2.5% buffered glutaraldehyde and transferred to the Institute of Pathology. Samples were divided for LM, which was followed by TEM and SEM assessment. Latter samples were dehydrated through an ethanol series and freeze-dried. The tissue specimens including the coronary endothelial surface were coated with gold and analyzed by SEM (LEO 1450 VP/REM, Oberkochen-Zeiss, Germany). The analysis was performed by an independent pathologist in a blinded fashion, who graded the alterations: grade I, normal appearance; grade II, blood cells deposited without endothelial delamination; grade III, few endothelial cells delaminated; grade IV, many endothelial cells delaminated; grade V, marked exposition of subendothelial matrix. Grades II–III were considered as minor damage, grades IV–V as a severe injury.

3. Results

Ultrastructural alterations were detected in both groups. However, distinct differences regarding frequency, intensity
and expansion were observed (Table 1). In the TILS group SEM revealed superficial endothelial abrasions in only two of six animals, while in the Tourniquet-group marked intimal lesions appeared in all animals. Intimal ruptures could be located directly at the sites of previous snaring (Figs. 2 and 3). None of the untreated coronary artery segments exhibited endothelial lesions larger than grade II. In the TILS group by LM three negative findings and three animals with mild to moderate injuries of the endothelium were revealed, whereas five cases with severe intimal damage were identified in the Tourniquet-group. These findings were confirmed in the subsequent TEM exhibiting a focal absence of endothelium accompanied by severe edema of subendothelial tissue. The TILS group showed only a mild extracellular edema of the subendothelial layer (Figs. 4 and 5).

4. Discussion

Off-pump surgery has been recognized to be less invasive than conventional coronary artery bypass grafting (CABG) in terms of inflammatory response and subsequent myocardial injury associated with cardio-pulmonary bypass (CPB) [6–8]. Two surgical approaches have become popular in beating heart surgery. MIDCAB, in which

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<td>occlusion</td>
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<td>N=6</td>
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Grade I, normal appearance; grade II, blood cells deposited without endothelial delamination; grade III, few endothelial cells delaminated; grade IV, many endothelial cells delaminated; grade V, marked exposition of subendothelial matrix. Grades II–III were considered as minor damage; grades IV–V as a severe injury.

Fig. 2. SEM-intima after TILS: scanning electron microscopy (magnification 149 \( \times \)) showing the intima of the coronary artery with delaminated endothelial cells after TILS insertion (grade III).

Fig. 3. SEM-intima after tourniquet-occlusion: scanning electron microscopic view (magnification 75 \( \times \)) of coronary artery after tourniquet occlusion. Marked loss of endothelial cells with exposition of the subendothelial matrix, representing grade V of endothelial damage.

Fig. 4. LM/TEM-intima after TILS: (A) light micrograph overview (HE-stain) of the coronary artery after TILS removal. Arrow depicts a moderate intimal lesion. (B) Electron micrograph of this area (magnification 6400 \( \times \)) showing endothelial abrasion with mild extracellular edema.
the patient is operated via a small left anterior thoracotomy and OPCAB, in which a full sternotomy is performed. For obtaining a bloodless surgical field different devices like tourniquet occlusion, TILS and gas-jet insufflation have been developed. Currently, some surgeons perform beating-heart coronary artery surgery with polypropylene sutures snared on the target vessel. However, several authors have already demonstrated the occurrence of endothelial injury after tourniquet occlusion and/or gas insufflation to clear the anastomotic site [12,13]. Recently, a direct relationship between the severity of snare-induced arterial lesions and the occurrence and extent of subsequent atherosclerosis in the respective area has been reported by Gerola and colleagues [14]. Perrault and colleagues have demonstrated endothelial dysfunction as a sensitive marker of intimal injury predisposing thrombosis, spasm and intimal hyperplasia [15].

We used morphological investigations of the vessel wall at the site of device application. In our present study, the adverse effects on the coronary endothelium caused by tourniquet occlusion were demonstrated by electron and LM. The marked intimal lesions observed after snaring of the coronary artery confirmed the results of other recent studies [16,17]. In contrast, only minor superficial damage, which did even not occur regularly, was seen when using TILS. Shunting therefore appears to be a valuable alternative in order to reduce endothelial damage, although the device should be appropriately sized according to the vessels diameter. The blood flow provided distal to the anastomosis site prevents potential intraoperative ischemia resulting in arrhythmias and myocardial stunning [3].

Limitations of the study: in our Off-pump model we used healthy domestic pigs. Atherosclerosis and chronic endothelial injury predisposing further intimal damage was therefore absent in these animals. However, our findings were supported by Hangler et al. in an elegant study [18], who described similar results when locally occluding the coronary artery in patients with ischemic cardiomyopathy intraoperatively directly prior to heart transplantation. Another limitation is the particular mode of tourniquet occlusion. A multitude of occlusion techniques exist [19,20]. Some surgeons prefer elastic ligatures while others use silicone tubes as additional cushions anterior to the vessel. A variety of commercially available stabilizing plates with integrated ligature loop tighteners are also utilized. The benefit of a particular tourniquet technique can therefore only be elucidated in a different study comparing several of the aforementioned strategies. In this context, however, one has to consider that the applied tensile strength to the ligature itself is paramount to material, employment mode, and strategy.

We conclude that the use of TILS is less traumatic than tourniquet occlusion in off-pump surgery. Only minor intimal injury due to the silicone olives was seen. The few observed superficial endothelial abrasions in the TILS group may be a consequence of the surgical insertion maneuver and/or intraluminal micro-dislocation during anastomosis. A chronic study has already been initiated to verify as to whether the mild injury after TILS insertion will result in a reduction or even absence of de novo stenoses compared with tourniquet occlusion. These results may have an impact on the current clinical practice.

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References


