Work in progress report - Experimental

Non-robotic thoracoscopic internal mammary artery preparation in the pig. A training model

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Abstract

Notwithstanding non-robotic, thoracoscopic preparation of the internal mammary artery (IMA) is a difficult surgical task, an appropriate experimental training model is lacking. We evaluated the young domestic pig for this purpose. Four domestic female pigs (30–40 kg body weight) were used for this study. Bilateral thoracoscopic preparation of the IMA was carried out under continuous, pressure controlled CO2 insufflation. A 30° rigid thoracoscope was inserted through a 10-mm port in the 5th/6th intercostal space (ICS) dorsally to the posterior axillary line. The dissection instrument (Ultracision Harmonic Scalpel) was inserted (5-mm port) in the 7th ICS at the posterior axillary line and the endo-forceps (5-mm port) in the 5th ICS at the posterior axillary line. Thoracoscopic IMA preparation in pig resulted more difficult than in man. A total of seven IMAs were prepared in their full intrathoracic length. A change in the preparation technique (lateral detachment of the endothoracic muscle) improved the safety of the procedure, allowing all four respective IMAs to be prepared safely, while the initial technique ensued an injury for 2 out of 3 vessels. The described young domestic pig model is suitable for experimental training of bilateral thoracoscopic IMA preparation.

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1. Introduction

Thoracoscopic internal mammary artery (IMA) preparation is a prerequisite for coronary artery bypass grafting through non-rib spreading minimal incisions [1]. However, closed chest thoracoscopic IMA takedown without telemanipulated robotic arms in the thoracic cavity is technically demanding and associated with a substantial risk of vessel damaging. Reliable surgical skills are therefore required in order to prevent lesions of the IMA and urgent conversions to the open technique. Previous studies have demonstrated that the pig is an ideal model to train complex minimally invasive surgical techniques in vivo [2, 3]. Thus, the aim of the present study was to evaluate the young domestic pig as an animal training model for bilateral endoscopic IMA takedown.

2. Material and methods

2.1. Animals

All experiments were performed in accordance with the German legislation on protection of animals, the European Convention on Animal Care and the 1996 NIH Guide for the Care and Use of Laboratory Animals. Four domestic female pigs of the Swabian Hall strain with a body weight of 30–40 kg were used for the study. The animals were kept at 21 ± 1 °C with daylight and free access to tap water and standard daily food. Before the experiments, the animals were kept fasting overnight with free access to water.

2.2. Anesthesia and positioning

After an intramuscular injection of ketamin hydrochloride (Ketavet; 30 mg/kg, Pfizer, Karlsruhe, Germany), xylazine hydrochloride (Rompun; 2.5 mg/kg, Bayer Schering AG, Leverkusen, Germany), and 1 mg atropine (Braun, Melsungen, Germany) for premedication, general anesthesia was induced by intravenous (i.v.) injection of etomidate (Etomidat-Lipuro; 1 mg/kg, Braun). Anesthesia was maintained by continuous i.v.-administration of thiopental sodium (Trapanal; 2–4 mg/kg/h, Altana Pharma Deutschland GmbH, Konstanz, Germany). Oral intubation was performed (7.5 ET Tube, Portex, Hythe, UK) and the animals were mechanically ventilated (Evita, Dräger, Lübeck, Germany) volume cycled with a tidal volume of 10 ml/kg, an inspiratory oxygen concentration of 30% and a positive end-expiratory pressure of 2 cm H2O. The animals were positioned in lateral decubitus position, alternating their right and left side for bilateral access. Upon completion of the experiment, animals were euthanized by overdosed intravenous injections of pentobarbital (Narcoren, Merial, Halbergmoos, Germany).
2.3. Surgical technique

Individual anatomical landmarks were marked on the animal's skin, including the posterior axillary line (PAL), the ribs 4–7, the inferior scapular angle and the lower border of the rib cage (RC) (Fig. 1). The camera port (10 mm) was placed in the 5th or 6th intercostal space (ICS) 3–4 fingers posterior to the PAL. The dissection instrument was introduced into the thorax through a 5-mm port placed in the 7th ICS at the PAL, the endo-grasper through a 5-mm port in the 5th ICS at the PAL. All trocars were from the Endopath valved series (Ethicon Endo-Surgery, Cincinnati, OH, USA).

A rigid 10 mm thoracoscope with 30° view angle was used (Karl Storz GmbH & Co. KG, Tuttingen, Germany). For dissection and preparation of the IMA we used two 5 mm thick, 32 cm long hand-activated instruments: the Ultracision Harmonic Scalpel Curved Blade and the Ultracision Harmonic Scalper Curved Shears powered by the Harmonic Scalpel Generator (Ethicon Endo-Surgery, Cincinnati, OH, USA) as well as Kelly’s-type thoracoscopic forceps. All trocars and instruments were inserted into the thoracic cavity during short periods of apnea (endotracheal tube physically disconnected from the ventilator) and/or complete lung collapse.

The thoracoscopic preparation of the IMA was carried out under continuous pressure controlled CO₂ insufflation (Karl Storz GmbH & Co. KG, Tuttingen, Germany). Endothoracic pressure was set at 8 cm H₂O. Gas flow was between 1–3 l/min.

3. Results

3.1. Surgical anatomy of the IMA

First, pilot studies were done on two cadavers from the local slaughterhouse to study the surgical anatomy of the IMAs in the pig. As in man, the IMAs take their origin from the subclavian arteries. The take-off angle is approximately 90° and the initial 5–6 cm of the IMAs (outer diameter (OD): 5–6 mm) with their big accompanying veins (OD: 6–12 mm) are visible through the endothoracic fascia. This part of the vessel lies anatomically behind and under the clavicle and thoracoscopically seen ‘behind’, i.e. cranial to the heart. Towards the sternoclavicular joint and along its course towards the diaphragm the vessel lies under a 1–2 cm thick muscle layer. The IMA itself gives rise to many intercostal branches which take off mostly from the anterior vessel surface. Special attention deserves one proximal (1st and 2nd ICS) and one distal (6th or 7th ICS) branch. They have a diameter of 3–4 mm and give immediately origin to two other branches, forming a ‘Y’-like vascular structure. The most distal IMA at the level of the diaphragm has a diameter of 2–3 mm. The internal mammary vein has a two- to threefold diameter compared to the IMA.

3.2. Thoracoscopic IMA preparation

A total of 7 IMAs were prepared in their full intrathoracic length. Endoscopically, the IMA was not visible upon entering the thoracic cavity. In the first two experiments preparation was initiated by incising the endothoracic muscle directly over the presumed course of the artery. This technique, although valid, was not safe enough: two out of three IMAs were injured, which led to a thoracotomy to control the bleeding. The technique was subsequently changed: preparation was initiated more laterally, at the sternocostal junctions (Fig. 2). The full thickness of the endothoracic muscle had to be cut down to the thoracic wall for a length of at least two or three ICS. Then the muscle was ‘peeled’ off the thoracic wall towards the sternum until the first distal (i.e. more lateral) segments of the IMA’s side branches became visible. With cautious preparation, the IMA and its vein were visualized and prepared as a pedicle in a semi-skeletonized fashion, artery and vein together without endothoracic muscle attached to the vessel pedicle (Video 1 online). At the superior thoracic outlet the thoracic cage became straight. At this angle (1st ICS) there was at least one important and bifurcated side branch. After this ‘curve’, which corresponded to the space between the first rib and the clavicle, the IMA lay directly under the parietal pleura and lacked of major side branches. The vessel could be followed up to the subclavian artery. Using this improved technique, all of

![Fig. 1. Anatomical landmarks for port placement (RC, inferior border of the rib cage; U, port for the dissection and coagulation device; C, camera port; G, grasper port; PAL, posterior axillary line; S, infero-posterior scapula border).](image)

![Fig. 2. Endoscopic view in the left thoracic cavity showing the endothoracic muscle (EM) between the ribs and the lateral sternum border (S). H, heart (in pericardium); R, ribs/sternocostal joints.](image)
the four respective IMAs were taken down completely and safely. In all cases adequate flow was confirmed at the end of the preparation by letting the vessel bleed freely. The duration of a one-sided IMA preparation was approximately 45 min when using the improved technique.

To deal with the limited space and the big and arrhythmia-prone heart, we interchanged instruments letting the thoracoscope enter the thorax through the distal port and sliding it between the thoracic wall and the pericardium avoiding pressure on the heart. Mechanical irritation of the heart while manipulating the rigid instruments caused three episodes of ventricular fibrillation in our series, twice in one animal and once in another. It was easily reversed by prompt external electrical defibrillation (200 J). With the takedown of one IMA completed, the animal was turned to the other side for preparing the contralateral IMA.

There were no injuries to the lungs or to other intrathoracic structures caused by trocar or instrument insertion or throughout the preparation of the IMAs.

4. Discussion

Truly minimally invasive coronary artery bypass surgery should be performed through a minimal non-rib spreading access, carried out off-pump and offer complete revascularization with – if possible and reasonable – exclusively arterial grafts [1, 4]. The procedure should be feasible without very expensive infrastructure such as complex robotic systems [5, 6], otherwise it would become a niche operation.

Preparation of the IMA under direct vision through a limited thoracotomy is feasible, but it requires significant rib spreading and distortion of the anterior thoracic wall [7]. Thus, thoracoscopic video-assisted IMA takedown is a prerequisite for a non-rib spreading minimal access approach. The procedure is technically demanding, even for surgeons with thoracoscopic skills, requiring specific dexterity and a sense for compensation for the lack of the 3rd dimension of the video-assisted thoracoscopic view. There are only limited possibilities to control significant bleeding from side branches or the IMA itself. Acquisition of such skills can be time consuming. An adequate experimental model could help surgeons to develop familiarity with this procedure and accelerate their learning process.

We explored the young domestic pig as the experimental animal considering its ubiquitous presence in Europe and its relatively low costs, factors that favor its wide use in facilities for experimental surgery. Gründeman et al. [2] used for their studies on the endoscopic approach in coronary surgery adult pigs (75–85 kg body weight) and robotic telemanipulation for the IMA takedown. In contrast, we preferred younger animals with a lower body weight (30–40 kg) to avoid the massive subcutaneous and intrathoracic deposits of fat tissue of the adult animals.

The young domestic pig revealed itself as a rather complex model: the tightness of the thorax, the thick endothoracic muscle which originates from the posterior sternal plate and ends on the posterior surface of the sternoclavicular joints, the variable vessel course, the numerous and multidirectional side branches, as well as the big and sensitive heart added to the difficulty of the endeavor. The task remains, however, feasible and dealing with these difficulties is a good training for the real life in the operating room. It will take significantly more than one hour for the first successfully prepared IMA, but for every additional one the time will shorten. Our clinical experience confirms the adequacy of the experimental model.

The choice of the 30° thoracoscope was made considering the configuration of the porcine thoracic cage. Our experience in these series confirmed this decision. Continuous, pressure controlled CO₂ insufflation provides adequate lung suppression, avoiding selective bronchial intubation and unilateral ventilation. There was no incident of lung injury upon entering the thoracic cavity. The cardiovascular effect of an intrathoracic pressure gradually brought up to 8 cm H₂O was negligible in our series. In our setting the operating surgeon initiated IMA takedown by holding the thoracoscope with the right hand and the Ultracision Curved Blade instrument with the left. This combination was sufficient for the incision of the endothoracic muscle and the initial peeling of the muscle towards the sternum. Later we exchanged the Curved Blade with the Curved Shears for better control of the side branches and more precise dissection of the muscle fibers. In addition, an endoscopic grasper was also introduced. The surgeon was operating with both instruments with the assistant following with the thoracoscope. The shape of the porcine thorax led to mechanical irritation of the heart causing three episodes of ventricular fibrillation. In all instances external electrical defibrillation was immediately successful. A continuous infusion of lidocaine could potentially offer some prophylaxis and will be considered in the future.

There are several options available for endoscopic dissection and coagulation [8]. The widely used hook coagulator is the less expensive of them. Previous own clinical experience, however, revealed smoke generation and the need for frequent and time consuming instrument changes for clip-application to bigger collateral branches as significant negative factors. We chose the Ultracision Harmonic Scalpel System as the cutting and coagulation device considering its low lateral thermic tissue damage, its effective coagulation capacity even in case of 2–3 mm side branches, as well as the relative low smoke generation [9, 10]. Hemostatic clips were not used for collateral branches, only for the main IMA prior to its division at the end of the procedure. There was no incidence of subsequent bleeding from already coagulated side branches. Avoiding hemostatic clips accelerates the procedure significantly. We did not have to interrupt the procedure for smoke evacuation. However, instead of smoke, the ultrasonic energy and the produced thermic energy created drops of water and de-
naturated protein, which splashed towards the optics of the thoracoscope, requiring quite frequent cleaning.

The intention of these experiments was to explore the suitability of the young domestic pig as a training model for thoracoscopic IMA preparation and not the proof of successful acquisition of technical skills. Therefore, results such as exact harvesting times, plateau-times and flow measurements were not evaluated. Due to the obvious anatomical differences between the human and the porcine thoracic cages this model does not offer adequate training with regard to ports placement. Our main focus, however, was the specific intrathoracic preparatory maneuvers. Therefore, and in conclusion, we recommend the young domestic pig as a suitable experimental training model for bilateral thoracoscopic IMA preparation.

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References


