Harvesting bilateral internal thoracic arteries via a novel subxiphoid approach vs. the conventional lateral thoracic approach – results of an experimental study

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Coronary artery bypass grafting (CABG) is associated with low morbidity and mortality, and provides reliable long-term results. However, the invasiveness of this procedure and the requirement for cardiopulmonary bypass result in longer hospital stays.[1] When pedicled, sequential, or free aortocoronary ITA is utilized, the clinical and angiographic outcomes of bilateral internal thoracic artery (ITA) grafting are superior to those of single ITA grafting with supplemental vein grafts.[2] Bilateral internal thoracic artery (BITA) grafting has also been identified as an independent predictor of lower rates of angina recurrence, late myocardial infarctions, and lower numbers of composite endpoints for cardiac events.[2] The minimally invasive direct coronary artery bypass (MIDCAB) technique combines the advantages of limited surgical access with the benefits of off-pump surgery and leads to faster patient recovery, but it is restricted to the revascularization of a single vessel in one area of the heart.[3]

Endoscopic surgery further limits the dexterity and depth perception of the surgeon. In addition, working through trocars limits the freedom of movement and introduces an inverted instrument response and variability in the excursion of the inserted instrument tip from the body cavity. [4] These disadvantages require surgeons to acquire new techniques and practices for performing complex surgical maneuvers during endoscopic procedures, such as challenging dissections and suturing.[4,5,6] In this regard, robotic telemanipulation is a powerful tool as it further minimizes surgical access, particularly during the harvesting of an entire length of BITAs.[7,8] Moreover, robotic telemanipulation allows further optimization of minithoracotomy incisions for coronary anastomosies.[1] We introduced a robotic telemanipulation system (the da Vinci ™ Surgical System [Intuitive Surgical Inc., Sunnyvale, CA, USA]) in December 2005. The technological advantages of the system includes a true three-dimensional endoscope that provides a high-resolution binocular view of the surgical field, an instrument system capable of 7° of freedom and 2° of axial rotation to mimic human wrist movements and tremor filtration, and a motion-scaling system to enhance surgical dexterity.

Here, we performed a new linear BITA harvesting approach, via a subxiphoid approach using robotic manipulation, and compared it the conventional lateral thoracic approach in an animal model.

Methods

Phase I: Simulator model

Baseline settings were determined by performing a simulated experiment to evaluate the changes in the exfoliation range, depending on the position of the endoscopy port, for specific operational procedures using the Standard da Vinci ^{TM} Surgical System (Intuitive Surgical Inc.) in conjunction with a 30^{o} angle-up camera. The instrument ports were symmetrically placed on the right and left side of the camera port. A movable axis for each port was placed horizontally, 20 cm above the table, and the angle of the instrument arm was adjusted to approximately 45°. The distance between the right and left instrument ports was defined as "a," and the distance between the movable axis of the camera arm (base point) and the marked point on the movable axis of the instrument port as "b" (Figure 1).

For the positioning of the ports, Group 1 (a = 10 cm, b = 1 cm) and Group 2 (a = 6 cm, b = 1 cm) formed an isosceles triangle, and Group 3 (a = 10 cm, b = 0 cm) and Group 4 (a = 6 cm, b = 0 cm) (Figure1) a straight line. An inverted triangle pattern was excluded as it interfered with the arms.

Video footage was recorded from the top of the instrument arms during operation to calculate the range of motion for each pattern (Figure 2), using Hakarundesu PRO software (Kazuyoshi Natsume, Shizuoka, Japan). The range of motion for each pattern, in the horizontal and vertical planes, was calculated to obtain the area described by the range of motion of the instrument arms, and the resultant areas between the different patterns were compared. This procedure thus optimized the placement of the instrument ports.

Phase II: Animal experiments

The subjects for the second phase of the study comprised of 12 pig carcasses obtained from our animal facility, with a median weight of 30.8 ± 4.9kg (range, 28–38kg). All experimental procedures were performed in accordance with the “Principles of Laboratory Animal Care,” formulated by the National Society for Medical Research, and the “Guide for the Care and Use of Laboratory Animals,” prepared by the Institute of Laboratory Animal Resources of the National (USA) Research Council.

Linear harvesting technique via subxiphoid approach

A surgical cart was positioned at the head of the table and a pig carcass in the supine position, in which a 3–cm incision was made under the xiphoid process along the median line. The subxiphoid incision served as the camera port for the robotic system, and enabled the insertion of a 30^{o} angle-up camera. A lifting retractor was inserted behind the sternum, through the subxiphoid incision, and lifted horizontally. The instrument ports were symmetrically placed on the right and left side of the subxiphoid incision, under direct vision through the camera (Figure 3). We determined the optimal port positions from the results of Phase I, and utilized the port position of Group 3 for Phase II (see Results). The BITAs were dissected via a 30^{o} angle-up camera. The skeletonized harvesting technique employed was similar to that of open or endoscopic surgery, and involved blunt and sharp dissections made with an EndoWrist cautery hook (Intuitive Surgical) on one robotic arm and EndoWrist deBakey forceps (Intuitive Surgical) on the other. The ITA was harvested from its adhesion site on the first rib to the first bifurcation on the sixth rib, and the branches were coagulated or clipped endoscopically (Figure 4).

Conventional lateral thoracic approach

Given our understanding that the lateral approach method was already widely established and ideal port position had already been determined, we neglected to conduct basic experiments to determine port position in the present study and conducted our experiment in accordance with the standard method [18]. Three incisions were made in the 2nd, 4th, and 6th intercostal spaces slightly medial to the anterior axillary line. A port was inserted through the middle incision, and a 30^{o} angle-up camera was inserted. The left and the right instrument ports were inserted under direct vision through the camera. A surgical cart with three mechanical arms was attached to the camera and the instrument arm ports.

After finishing both procedures, the BITAs were proximally transected (Figure 4), and the conduit lengths of the free left internal thoracic artery (LITA) and the right internal thoracic artery (RITA) were compared along with the total harvesting times.

Statistical Analysis

The subxiphoid approach and the conventional lateral thoracic procedure were conducted on six pig carcasses. All data were expressed as mean ± standard deviation. Comparative analyses were performed using the Mann-Whitney *U* test and SPSS 11.0 software (SPSS, Chicago, IL, USA).

Results

Phase I: Simulator model

The vertical range of motion for each Group was as follows: Group 1 (183.3 cm^2), Group 2 (181.9 cm^2), Group 3 (182.9 cm^2), and Group 4 (178.8 cm^2). The horizontal range of motion for each group was as follows: Group 1 (287.3 cm^2), Group 2 (276.3 cm^2), Group 3 (417.4 cm^2) and Group 4 (405.2 cm^2) (Figure 5). In the vertical direction there was little difference in the range of motion among the four patterns. In the horizontal direction, however, the range of motion was greater for Groups 3 and 4, with the three ports positioned in a straight line affording a greater range of motion (Figure 5). These results suggest that the theoretically optimal position was obtained when the right and left instrument ports were placed as far apart as possible, and all of the ports were set in a horizontal straight line. These principles were applied as the basic operational procedure in the animal experiments. We determined the ideal port positions based on the results of Phase I, used port position Groups 3 for Phase II

Phase II: Animal experiments

All BIMAs were successfully harvested in a skeletonized fashion. After harvesting BIMAs, they were proximally transected and the lengths of the free grafts were compared.

The average length of the LITAs (free grafts) was 11.7 ± 1.90 cm using the subxiphoid approach compared with 9.17 ± 0.74 cm when using the conventional lateral thoracic approach (P=0.0131). The average length of the RITAs was 11.8 ± 1.69 cm via the subxiphoid approach, compared with 8.88 ± 0.58 cm in the lateral thoracic approach (P=0.00824) (Table 1). The length of both conduits was significantly longer when the subxiphoid approach was used, as compared to the lateral thoracic approach.

The total mean time for the robotic harvesting of LITAs via the subxiphoid approach was 39.7 ± 13.2 min, compared with 43.3 ± 13.7 min using the lateral thoracic approach (P=0.521). RITA harvesting via the subxiphoid approach averaged 34.7 ± 8.14 min, compared with 52.3 ± 8.21 min using the lateral thoracic approach (P=0.0130) (Table 1). The mean harvesting time for RITAs using the subxiphoid approach was thus significantly shorter than that of the lateral thoracic approach.

Discussion

Harvesting BITAs with robotic assistance via the subxiphoid approach appears to be an effective technique. Although cardiac surgery has lagged far behind other specialties in the development of robot-assisted minimally invasive surgery, significant advances have been made and encouraging reports have emerged.[9,10,11,12] The superiority of ITA as a conduit has been well established for long term patency and event free survival. Robotic assistance has allowed for BITA grafting to be performed through a minimally invasive access method. Based on the animal model results, the length of both conduits was significantly longer when the subxiphoid approach was employed, as compared with the lateral thoracic approach. In addition, the average harvesting time for RITAs, using the subxiphoid approach, was also significantly shorter than in the lateral thoracic approach. Thus, robot assisted BITA harvesting through the subxiphoid approach appears to be safe and provides more grafting material than the thoracic approach.

Endoscopic beating-heart surgery was the initial field of interest for robot-assisted minimally invasive surgery as the technical challenge of this procedure surpassed the traditional reach of endoscopic techniques.[5,6,13] However, the three-dimensional visualization, magnification, and the technical dexterity afforded by these robotic systems also allows for precise harvesting of BITAs in a totally skeletonized fashion. In 1999, Watanabe et al. reported the first case of a endoscopic CABG on a beating heart.[4] There have since been several reports concerning the utility of robotic ITA harvesting procedures, including robotic BITA harvesting and robotic coronary artery anastomoses. Further, there has been a case report of robotic BITA harvesting via the subxiphoid approach.[14] With the advent of robotic assistance, the time required for BITA harvesting has been significantly reduced.[15,16]

When the rib cage is elevated during the subxiphoid approach, the lower ribs project directly forward, which moves the sternum away from the spine and increases the anteroposterior diameter of the chest by 20%.[17] A major advantage of the linear harvesting BITAs, via a subxiphoid approach with robotic assistance, is the provision of sufficient working space, as a result of the sternal elevation. In addition, superior hemodynamics are associated with the technique when compared to the lateral thoracic approach, since it does not require an increase in the intrathoracic pressure using gases such as carbon dioxide (CO_2) during the harvesting of the artery. Further, as single-lung ventilation is unnecessary during the harvesting of the BITAs, this procedure is effective for cases involving respiratory complications. Thus, the possibilities of performing conscious CABG are broadened.

Here, we have demonstrated that via a linear approach, the harvesting of a longer length of the artery is possible and the time required for detachment is shorter. This may be due to the simplified and more efficient management of the arterial branches afforded by improving the surgeon's field of vision during the harvesting of the artery. Unlike the conventional lateral thoracic approach, in which the ITA is seen from the long axis, the proposed subxiphoid approach facilitates the easier identification of the branch arteries as they are viewed along the short axis. In the subxiphoid approach, LITA and RITA can be seen from the same distance; however, visualization of the RITA is better because the lateral approach is only conducted through the left side. Therefore, the conduit length—particularly for RITA—can be longer using the subxiphoid approach than using the lateral thoracic approach. From the operator's view on the console, the BITAs were observed to be parallel and linear; imparting the appearance of being parallel strips of fluorescence on a long, straight tunnel.[14] In the lateral approach, because ITA is observed laterally, branching on the opposite side is difficult to confirm. However, in the subxiphoid approach, branches extend to the right and left sides and can therefore be relatively easily identified. This view enables the operator to locate small branches more easily than in the lateral thoracic approach, enabling them to be quickly cauterized or clipped. In addition, branch treatment is safe and secure due to improved access to the proximal portion and branches of the conduit.

Long graft harvesting, using a robotic thoracic approach has been reported in a clinical case.[18] In this instance, the harvesting also started at the first rib and continued to the bifurcation of the ITA and subclavian artery. However, questions remain as to whether or not there is any significant difference in the length of the harvested conduit with the results obtained via the current subxiphoid approach.

As previously reported by Subramanian et al. (2005), the gastroepiploic artery can also be harvested and anastomosed in the same operative field during the subxiphoid approach.[17] The number of branches anastomosed during robot-assisted CABG has been reported to be an average of 2.2 to 2.6 branches.[1,19] Using linear harvesting by the subxiphoid approach, longer lengths of the RITA may possibly be detached and raise the possibility of CABG and multivessel CABG.

There are limitations to this study that warrant mention. Firstly, the use of carcasses instead of a live porcine model. The harvesting time comparisons are not realistic without the compounding problems associated with a live experiment. There is no bleeding, no lungs in the way, no heart beating. Comparing harvesting times may not be realistic given the lack of bleeding, lungs in the way, and beating heart in the present study. In clinical practice [14], harvesting of RITA via the lateral approach is conducted from the left thoracic cavity beyond the mediastinum, rendering central side separation to the bifurcation of the subclavian artery technically difficult, and harvested RITAs tend to be shorter. We therefore attempted to identify a better method for harvesting longer RITA. We believe that, rather than comparing harvesting times, the present report should emphasize that longer

RITA are likely to be harvested via the subxiphoid approach because there is no differences between the right and left side visual fields.

A subxiphoid approach involving a lifting sternal method was introduced in references 20 and 21. In our study, the mediastinum was lifted in the same manner as in references 14, 20, and 21. One of our co-authors was an author in paper 20. This method provides an excellent view and increases the limited working space for thoracoscopic maneuvers [21,22].

A clinical surgery case report described an instance where the subxiphoid approach was actually performed in a human in a related facility [14]. Dr. N. Ishikawa, co-author of the current paper, took part in that surgery. The excellent view available with the subxiphoid approach facilitates safe surgery, even with bleeding, lungs in the way, or a beating heart. We therefore believe that the use of carcasses in the present study did not significantly affect the results.

The second limitations of this experiment revolved around the use of the robotic system that was used. Although we used the standard model of the standard da Vinci™, a more advanced da Vinci S™ system is available, which is more compact and has more flexible arms. The use of this advanced system may increase the ease of use of this method.

The third limitation was requiring additional ports for anastomoses. However, the incision made for harvesting ITA can be used as a port for the stabilizer. On considering the merits of harvesting ITA, we regard the incision useful.

Finally, new surgical approaches usually contain a steep learning curve,[10] which may also be the case with the robot-assisted subxiphoid approach.

In conclusion, the robot-assisted subxiphoid approach appears to be an effective method of performing minimally invasive myocardial revascularization in patients with multivessel disease. This approach may be an evolutionary step towards enabling surgeons to perform less invasive multivessel CABG.

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Figure 1. **Phase I: Dry-lab model**

Baseline setting : A 30° angle-up camera was used.

a. Distance between instrument ports（10 cm or 6 cm）

b. Vertical distance between the camera port and the instrument ports（1 cm or 0 cm）

Figure 2. **Phase I: Dry-lab model :**

Analysis of the horizontal and vertical movement area (polygonal area) of the arm.

Figure 3. **Positioning of the robotic system and camera and instrument ports for the subxiphoid, linear harvesting technique.**

A: The surgical cart is placed at the head of the table. The instrument ports were placed symmetrically to the right and left of the subxiphoid incision, under direct vision through the camera.

B: The chest wall is lifted and working space is created.

Figure 4. **Operator's view, on the console, during the subxiphoid approach.**

A, The ITA trunk and branches. B, Branching of the subclavian artery from the ITA. C, Free ITA grafts.

*ITA, internal thoracic artery.

Video 1. **Operator's view, on the console, during the subxiphoid approach, using linear harvesting technique.**

Figure 5. **Phase I: Dry-lab model.**

The range of motion in the vertical direction was 183.3 cm^2 for Group 1, 181.9 cm^2 for Group 2, 182.9 cm^2 for Group 3, and 178.8 cm^2 for Group 4. The range of motion in the horizontal direction was 287.3 cm^2 for Group 1, 276.3 cm^2 for Group 2, 417.4 cm^2 for Group 3, and 405.2 cm^2 for Group 4.

Table 1. **Phase II** : Experimental results from the harvesting of the internal thoracic arteries.

Objectives: A new method was developed to harvest bilateral internal thoracic artery grafts using a subxiphoid approach, using robotic assistance. This study compared the potential utility of the subxiphoid method with the lateral thoracic approach.

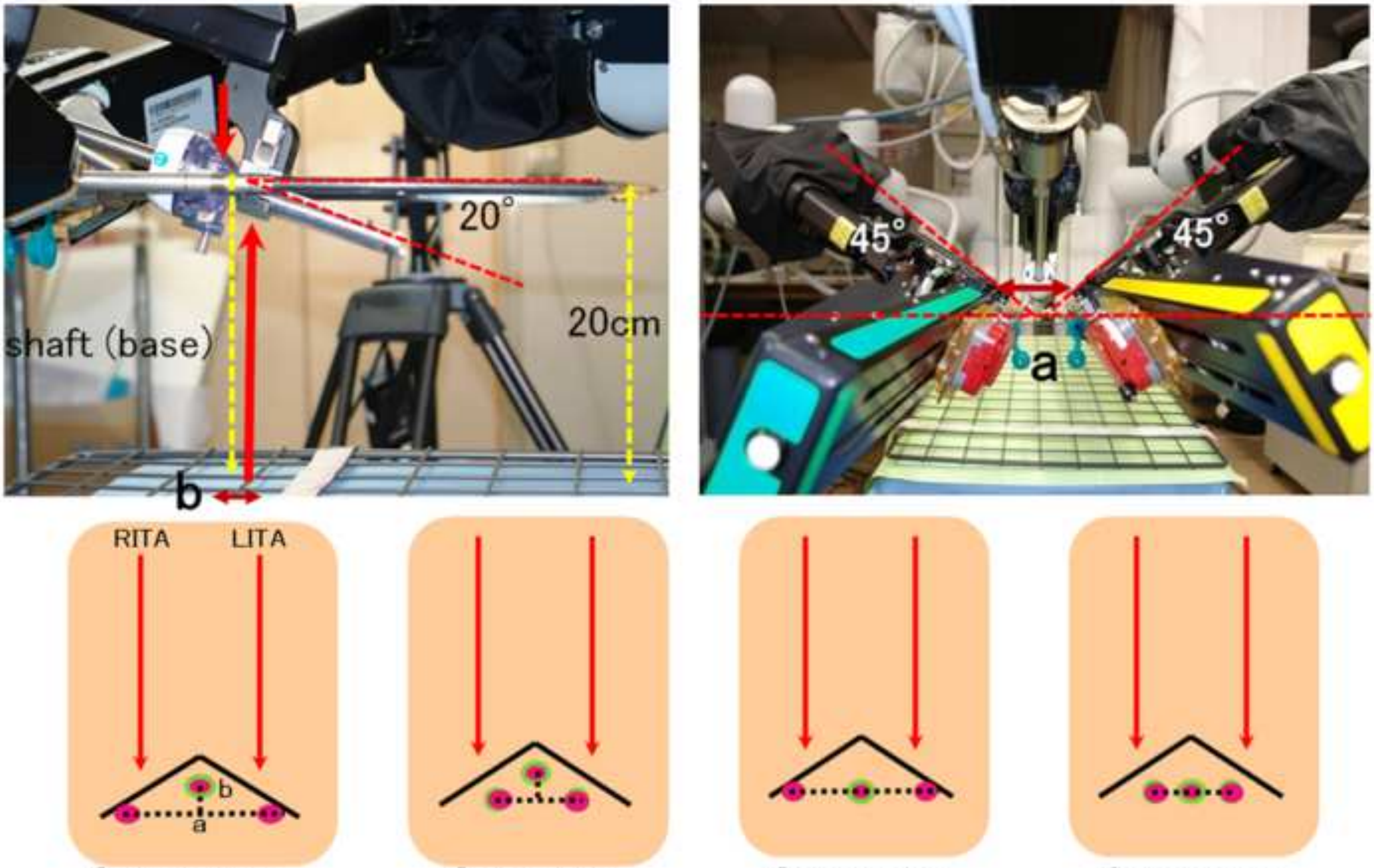
Methods: The first part of the study examined the optimal placement of the instrument ports to maximize the robotic arm`s range of motion. The second part of the study examined the two approaches for harvesting bilateral internal thoracic arteries from pig carcasses. The lengths of the obtained grafts and the time to conduct each procedure were compared using the Mann-Whitney *U*-test.

Results: The preliminary study suggested that optimal positioning of the instrument ports was achieved by placing the right and left instrument ports far apart and linearly arranging all the ports. Using this configuration, the subxiphoid approach yielded left internal thoracic artery that were 11.7 ± 1.90 cm long, compared with 9.17 ± 0.74 cm using the conventional approach (P = 0.0131); the right internal thoracic arteries (11.8 ± 1.69 cm) obtained via the subxiphoid approach were significantly longer than those obtained by the conventional approach (8.88 ± 0.58 cm). The time to harvest the right internal thoracic arteries (34.7 ± 8.14 min) was significantly shorter using the subxiphoid approach, compared to the conventional approach (52.3 ± 8.21 min).

Conclusions: Because of the maximized lengths of the grafts and the duration of the procedure, the robot-assisted subxiphoid approach may be an effective method of performing minimally invasive, myocardial revascularization in patients with multivessel disease.

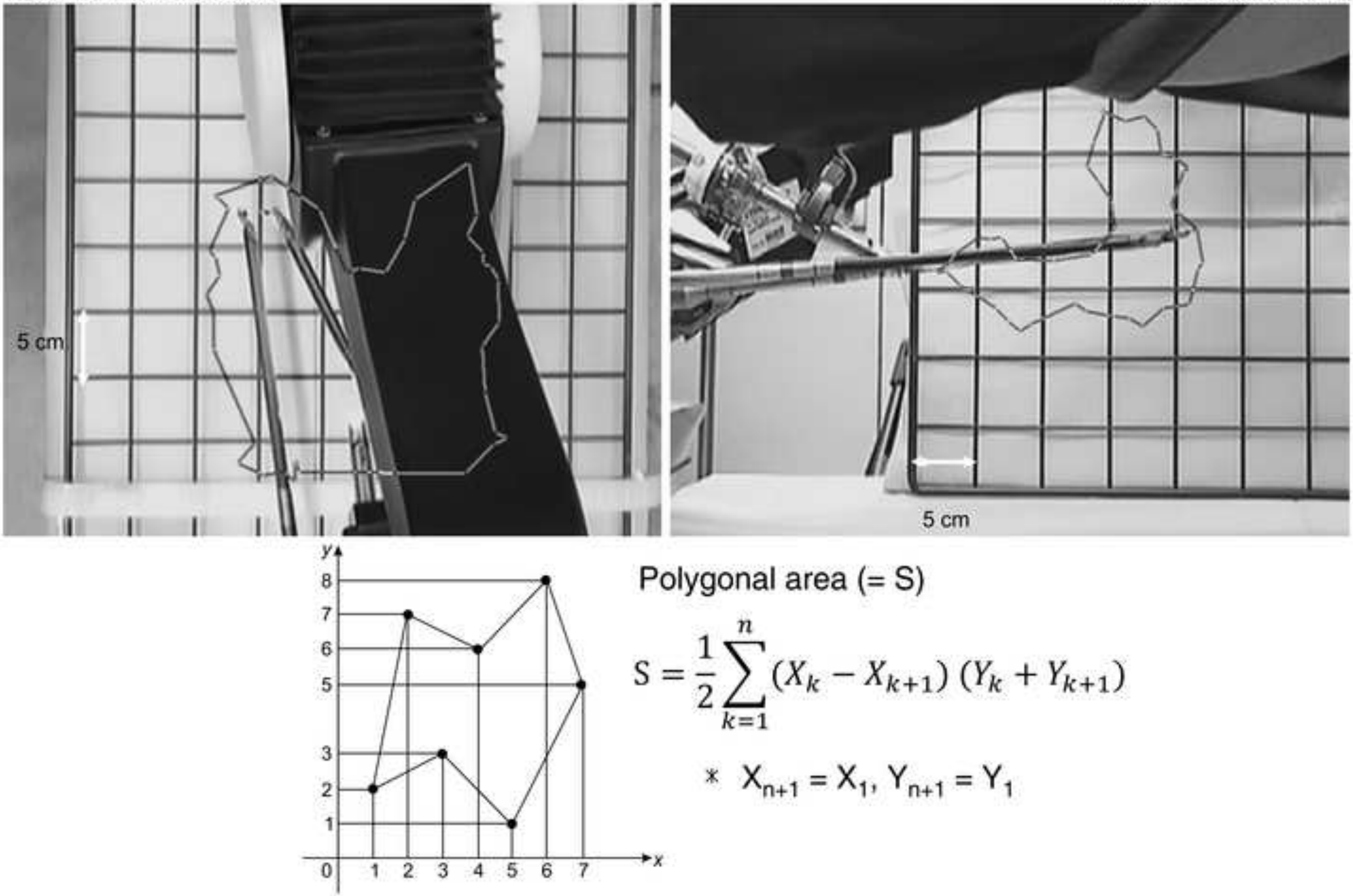
MINIABSTRACT:

A robot-assisted subxiphoid approach to harvesting bilateral internal thoracic arteries was developed and tested on pig carcasses. The new method maximized the lengths of the grafts and shortened the procedure. The new approach may be an effective method for performing minimally invasive myocardial revascularization in patients with multivessel disease.



① a.10cm b.1cm ② a.6cm b.1cm ③ a.10cm b.0cm ④ a.6cm b.0cm

Figure 2



Horizontal movement area

Vertical movement area

Polygonal area (= S)

$$S = \frac{1}{2}\sum_{k=1}^{n}(X_k - X_{k+1})(Y_k + Y_{k+1})$$

$* \ X_{n+1} = X_1, Y_{n+1} = Y_1$

Figure 3

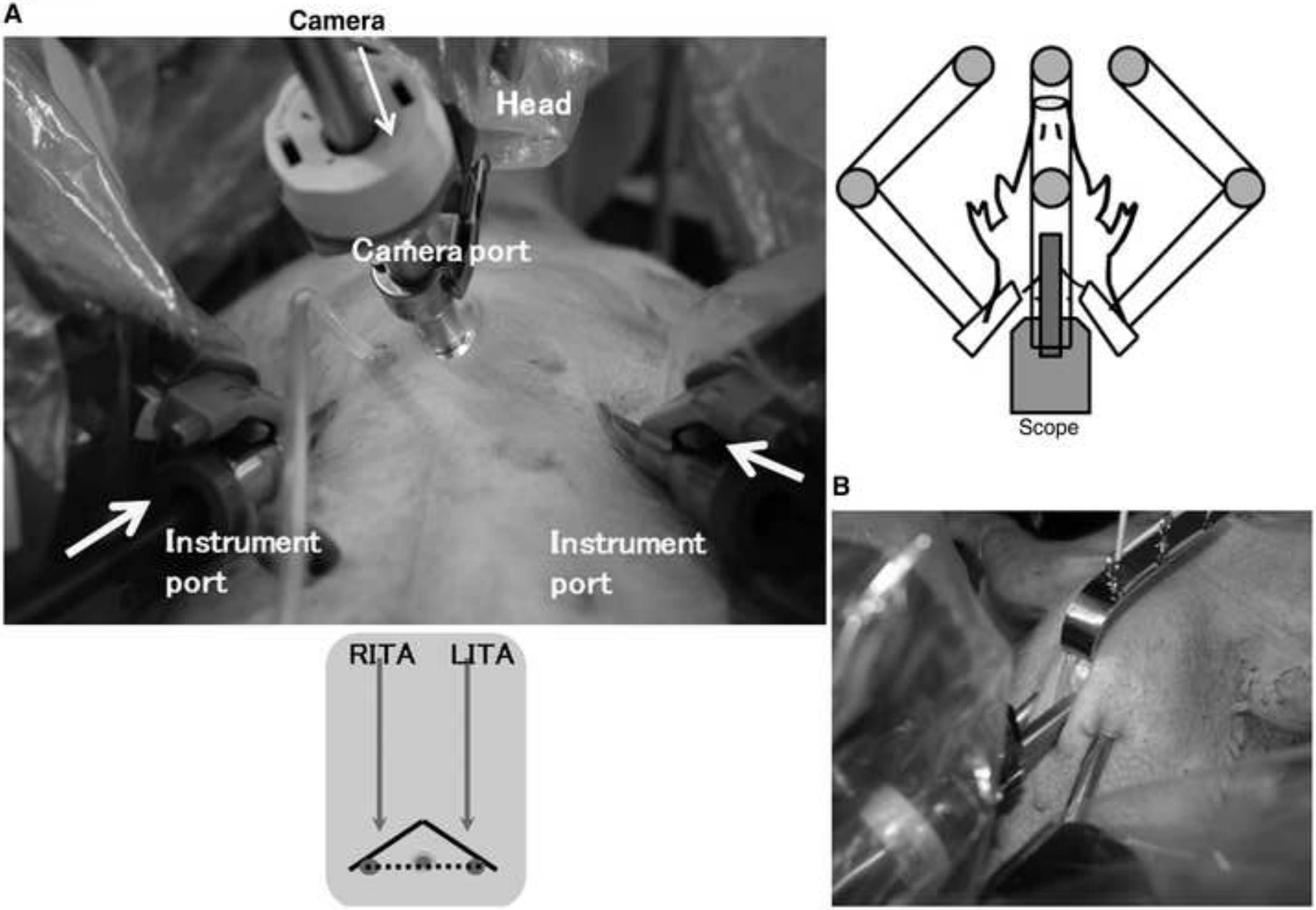

A
Camera
Head
Camera port
Instrument port
Instrument port
RITA
LITA
Scope
B

Figure 4

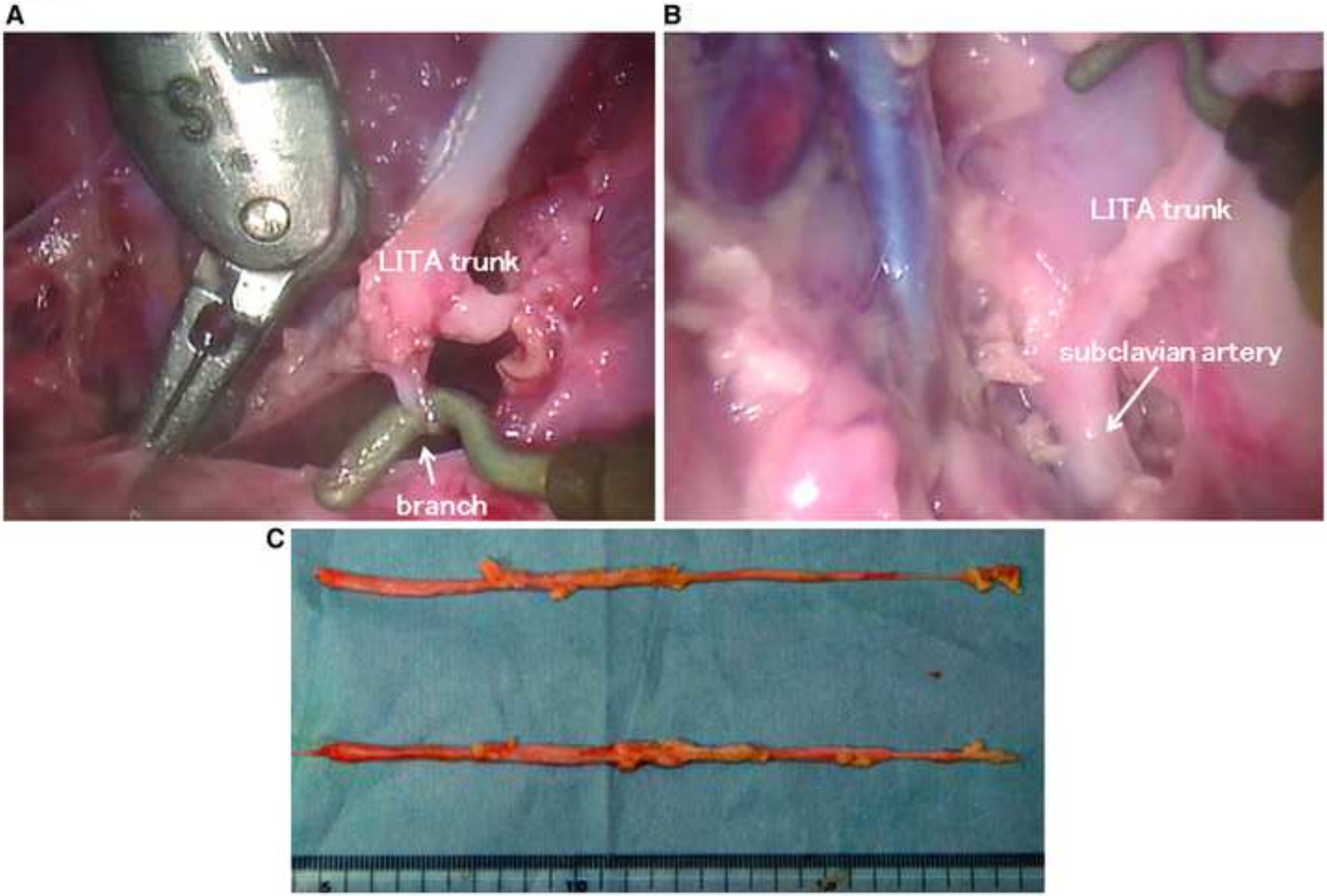
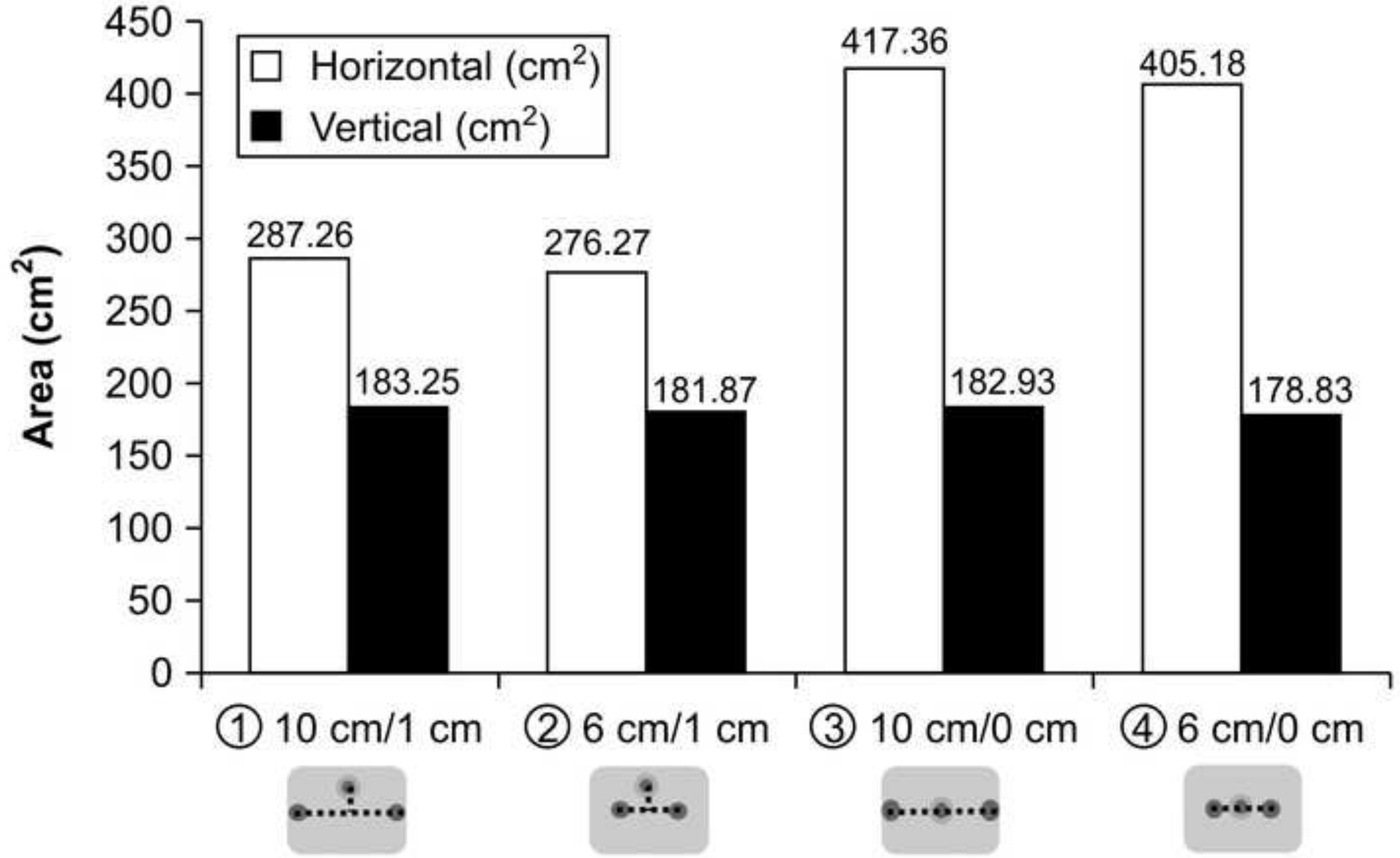


Figure 5


Area (cm²)
450
400
350
300
250
200
150
100
50
0
☐ Horizontal (cm²)
■ Vertical (cm²)
287.26
183.25
276.27
181.87
417.36
182.93
405.18
178.83
① 10 cm/1 cm
② 6 cm/1 cm
③ 10 cm/0 cm
④ 6 cm/0 cm

	Subxiphoid approach	Lateral thoracic approach	*P value(<0.05)*
Pigs	*N* = 6	*N* = 6	
Length of harvested LITA	11.7 ± 1.90 cm	9.17 ± 0.74 cm	0.013
Length of harvested RITA	11.8 ± 1.69 cm	8.88 ± 0.58 cm	0.0082
(Free conduit length)			
Time for harvesting LITA	39.7 ± 13.2 min	43.3 ± 13.7 min	*N.S*
Time for harvesting RITA	34.7 ± 8.14 min	52.3 ± 8.21 min	0.013

LITA, left internal thoracic artery; RITA, right internal thoracic artery

Videoclip

Click here to download Videoclip: Video1.wmv