



Limb replantation with two robots: a feasibility study in a pig model

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Limb replantation with two robots: a feasibility study in a pig model

Running title: Limb replantation with two robots

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Abstract

The aim of this study is to assess the feasibility of limb replantations and transplantations by telesurgery.

The material consisted in a *Large White* pig and two surgical robots (Da Vinci S® telemanipulators). The procedure consisted in a trans-humeral cross-section of the left thoracic limb, which was secondarily replanted.

Results showed good vascular permeability, while the operator's physiological tremor was suppressed.

Our results seem to demonstrate that telesurgery could improve limb replantation and transplantation management, especially regarding operating gesture precision.

Key words: pig – microsurgery - replantation - robot - telesurgery - transplantation

Introduction

The concept of telesurgery developed in the 1990's is defined as any remote computer-assisted surgical intervention [1]. The first intervention in telesurgery, a transatlantic laparoscopic cholecystectomy, was performed in 2001 [2]. Telesurgery, which is performed with a surgical robot controlled by the surgeon, has two theoretical advantages: the remote operation on the one hand and a better surgical gesture on the other hand. The second advantage only is currently used in elective surgery in numerous specialties such as digestive, urologic, gynecologic or cardiac surgery [3]. The feasibility of telesurgery has been demonstrated with experimental microsurgery [4-7].

In this context, the objective of this work is to demonstrate the feasibility of limb replantation and transplantation by telesurgery. That is, from a qualitative point of view by gearing down movement and thus suppressing physiological tremor, but also from a quantitative point of view by using two surgical robots occupying lesser space in the operating field than in conventional microsurgery, thus allowing two microsurgeons to work at a time.

Material and methods

Operating staff included six persons, three surgeons, an anaesthetic nurse, a scrub nurse and a technician trained in robotics.

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3 Among the three surgeons, there were one senior surgeon and two residents,
4 taking turns on the two robot's consoles. The anaesthetic nurse was competent in
5 veterinary anaesthesia. The scrub nurse underwent a short training in
6 telemanipulation. The robotics-trained technician helped fitting out the two robots.
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15 Material included a *Large White* pig (weight: 51 kg), standard surgical
16 instruments for bone surgery, two surgical robots designed for soft tissue surgery.
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20 Standard surgical instruments included an oscillatory power saw, a surgical
21 motor for drilling, a metal plate designed for blocking screws (Allians®, Newclip™),
22 and a fluoroscope (XiScan4400®, FMCONTROL™).
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27 The two robots were DaVinciS® models (Intuitive Surgical, Inc.™) made up of
28 three subunits: a mobile cart, an imaging cart, and a console for the surgeon to
29 remote-control the articulated arms of the surgical robot. The mobile cart consisted of
30 four articulated robotic arms, three for holding the surgical instruments and one
31 bearing the optical device covering the operating field. Each arm is made up of
32 several joints allowing three-dimensional movement of both the optical device and
33 the instruments. The instruments consisted in dissecting forceps and straight Potts
34 scissors, with a movement reduction ratio of 1:5. The fourth arm had an optical
35 device allowing three dimensional vision with a 25 times magnifying power.
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51 The surgical procedure consisted of two steps, the humeral cross-section and
52 the replantation of the left forelimb. It was done in accordance with international rules
53 on veterinary experimental surgery and with French laws on animal protection.
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56 Anaesthesia was performed by continuous administration of sevoflurane halogenous
57 gas (Sevorane®) by means of a tracheal mask. The animal lied on its back on the
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3 operating table, each limb strapped to the table by Velcro® scratches in an abducted
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5 position. The entire procedure was videotaped.
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9 Amputation of the forelimb was done without the surgical robot. It included
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11 three steps: soft tissue dissection, preparation for osteosynthesis and cross-section
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13 of the humerus. A longitudinal incision was performed on both lateral and medial
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15 aspects of the brachial region to allow proper dissection of vascular, nervous,
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17 muscular and tendinous elements. Preparation of the osteosynthesis started with the
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19 plate being screwed to the medial aspect of the humerus. Good positioning of both
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21 the plate and the screws was verified with fluoroscopic imaging. The plate was then
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23 removed after this control, so as to show the screw holes, and a midshaft humeral
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25 osteotomy was performed with the oscillating power saw. Before totalizing of the
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27 amputation (figure 1), every vessel and nerve was cut and both ends of each element
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29 was marked out with a vascular clamp (Biover®, Arex™)
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35 Replantation of the forelimb included three successive steps: humeral
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37 osteosynthesis, soft tissue repair and result assessment. Osteosynthesis was done
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39 without the surgical robots. The plate was applied on the medial aspect of the
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41 humerus with six 3.5mm screws into the holes drilled during the amputation. Repair
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43 of the soft tissues was performed using both surgical robots facing themselves (figure
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45 2), in order to spare space in the operating field for the eight arms to move without
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47 any conflict on both sides of the forelimb. These eight arms bore two optical devices
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49 and six surgical instruments. The two consoles were installed side by side three
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51 meters away from the operating field (figure 3). Each surgeon remote-controlled his
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53 own robot to perform soft tissue repair of one of the two lateral or medial sides of the
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55 humeral region. However this splitting in halves of the operating field wasn't in any
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57 way rigid as the two operators frequently coordinated their movements on a single
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3 task, for instance cutting sutures after having performed a microsurgical
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5 anastomosis. The operators took turns on the consoles regularly in order to get some
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7 rest. Two nerves (median and ulnar nerves), two arteries (humeral and a branch
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9 arteries) and two veins (cephalic and basilica veins) were repaired by separate
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11 stitches of 10/0 nylon suture. Muscles and tendons on the one hand and skin on the
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13 other hand were respectively repaired by Kessler stitches of 3/0 nylon sutures and
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15 separate stitches of 4/0 nylon sutures. Result assessment consisted in measuring
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17 quantitatively the duration of each surgical step on the videotape, and verifying
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19 qualitatively the correct position of both the plate and the screws with fluoroscopic
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21 imaging, the efficacy of patency tests on each vascular repair before skin closure and
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23 last of all the vascular success of the replantation by performing a blood letting of the
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25 distal segment of the forelimb at 10, 30 and 60 minutes after skin closure. The animal
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27 was sacrificed at the end of the procedure by a lethal injection of potassium chloride.
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39 Results

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44 We wanted to assess with our results not only the vascular success of the
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46 replantation but also all the gesture and ergonomic adaptations the operators had to
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48 overcome in order to master telemicrosurgical techniques.
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53 On a quantitative basis, total duration of the procedure was 7 hours including
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55 one hour for installation and anaesthesia, one hour for the amputation step, four
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57 hours for the replantation step and one hour between skin closure and the animal's
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59 sacrifice. Installation time lasted 25 minutes and total ischaemia duration was one
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3 hour and forty minutes between section of the last artery and performance of a
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5 patency test on the first artery repaired.
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9 On a qualitative basis, patency tests -done with telemicrosurgical forceps-
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11 were all positive immediately after vascular anastomosis and just before skin closure
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13 (figure 4). Although the robot does not allow tactile proprioceptive feedback, no
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15 secondary vascular lesions were to be noted during both knot tightening and
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17 performance of the patency tests. Visual feedback made up for proprioceptive
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19 feedback. Vascular success of the replantation was assessed by the venous
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21 bleeding after having performance of a blood letting at the tip of the limb at 10, 30
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23 and 60 minutes after skin closure (figure 5). We observed slight venous engorgement
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25 of the replanted forelimb. As far as gesture was concerned, physiological tremor was
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27 totally removed during the operative steps in which the robots were involved.
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29 Concerning ergonomics, there were no conflicts between the two surgical robots to
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31 be noticed during the arms' movements. Both operators, comfortably seated, not only
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33 often coordinated their movements to perform certain tasks, but also could take turns
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35 on the consoles regularly.
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47 Discussion

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52 Physiological tremor is a well-known phenomenon in conventional
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54 microsurgery. Telesurgery allows suppression of this tremor by gearing down
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56 operative gesture [3]. The more precise is the gesture, the more it is geared down.
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58 Some authors demonstrated that telesurgery shortened dramatically the
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60 microsurgical learning curve [8, 9].

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6 Simultaneous cooperation of two surgical robots is to our knowledge the first
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8 description reported during a single surgical procedure. In our study, configuring the
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10 two robots so two operators can work at a time significantly reduced ischaemia
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12 duration. Indeed the only moment when two operators can work together on a
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14 replantation or a transplantation is during the debridement of both amputated ends.
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16 Conventional surgical repair of soft tissues requires a large operating field if one
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18 takes into account the size of the operator's hands and the surgical microscope's
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20 size. On the contrary the distal size of the eight articulated arms of the robots in the
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22 same operating field was much smaller because of their modest length and high
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24 mobility.
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32 We must underline some limits of our study. First of all for ethical and practical
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34 reasons, the pig had to be sacrificed one hour after the end of the procedure. Which
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36 did not allow us to assess furthermore vascular permeability. However, this limit does
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38 not challenge the anastomosis quality, especially as the slight post-operative venous
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40 engorgement proved good arterial permeability.
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44 The second limit is the important economical investment necessitated by both
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46 acquisition and maintenance of a surgical robot, not to mention the cost of two
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48 robots. Many surgical teams nonetheless invested in such a technology in many
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50 different surgical fields [10, 11]. The cost is outbalanced to their advice by lesser peri-
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52 operative bleeding, operating gesture enhancement, reduction in scarring size, and a
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54 shorter hospital stay before discharge for the patient [12, 13]. As far as microsurgery
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56 is concerned, we would like to underline the fact that assets on behalf of
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58 telemicrosurgery are quite different. Microsurgical procedures necessarily call for a
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3 wide operating field to correctly expose all the different wounded elements. For us,
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5 the major telemicrosurgical asset is a decrease in operating time.
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8 The third limit is the lack to date of osteosynthesis ancillary instruments
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10 designed to fit the robot's arms. One has to keep in mind that the DaVinciS®
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12 telemanipulator was not designed for orthopaedic surgery in the first place. There is a
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14 need to convince all the industrial partners to promote research and development in
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16 this specific surgical field.
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20 Last but not least, our experience is limited to a single case, and we cannot
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22 conclude to any reproducibility of our results.
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27 As a conclusion, by highlighting this first and unique experimental replantation
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29 of a pig forelimb with two surgical robots to date, numerous practical application
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31 perspectives seem to be possible in telemicrosurgery.
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References

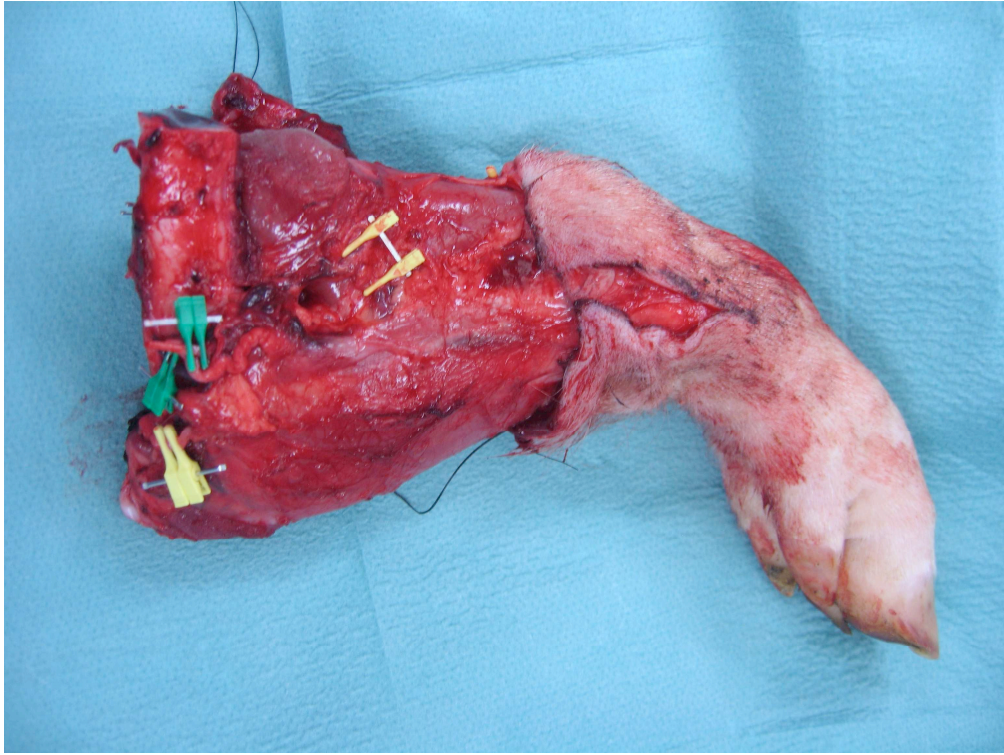
1. Pande R, Patle Y. The telecommunication revolution in the medical field: present applications and future perspective. *Curr Surg* 2003;6:636-640.
2. Marescaux J, Leroy J, Gagner M, Rubino F, Mutter D, Vix M. Transatlantic robot-assisted telesurgery. *Nature* 2001;413:379–380.
3. Cohn LH. Futures directions in cardiac surgery. *Am Heart Hosp J* 2006;4:174-178.
4. Katz R, Rosson G, Taylor J, Singh N. Robotics in microsurgery: use of a surgical robot to perform a free flap in a pig. *Microsurg* 2005;25: 566-569.
5. Van der Hulst R, Sawor J, Bouvy N. Microvascular anastomosis: is there a role for robotic surgery? *J Plast Reconstr aesthet Surg* 2007;60:101-102.
6. Taleb C, Nectoux E, Liverneaux P. Telemicrosurgery: a feasibility study in a rat model. *Chir Main* 2008;28:104-108.
7. Nectoux E, Taleb C, Liverneaux P. Nerve repair in telemicrosurgery: an experimental study. *J Reconstruc Microsurg* (in press).
8. Blavier A, Gaudissart Q, Cadière GB, Nyssen AS. Perceptual and instrumental impacts of robotic laparoscopy on surgical performance. *Surg Endosc* 2007;65:80-91.
9. Zorn KC. Robotic radical prostatectomy learning curve of a fellowship-trained laparoscopic surgeon. *J Endourol* 2007;21:441-447.
10. Peplinski R, Rhodes R. Economic aspects of starting a Da Vinci robotic surgery program. In: *Robotic Urology*, H John & P Wiklund (Eds.). Springer Berlin Heidelberg 2008 pp:253-261.

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3 11. Stephenson E, Sankholkar S, Ducko C, Damiano R. Robotically assisted
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11 12. Smith A, Smith J, Jayne DG. Telerobotics: surgery for the 21st century.
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15 13. Nelson B. Comparison of length of hospital stay between radical retropubic
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Figures legend

1. Amputation patch of a pig left upper limb at the humeral stage. There are some vascular clamps marking the vasculo-nervous elements.
2. Telesurgery work station. There are two consoles on the right, which enable each operator to control the articulated arms of the mobile cart (middle of the figure). The pig is installed on the operation table between the two mobile carts. Each operator is sitting in front of his console with his head on a support between two IR sensors. He can also use a binocular viewing system, which gives him a three-dimensional vision of the operative field. His hands control the movements of the arm of the mobile cart through levers linked to surgical instruments by electronic circuits. These circuits are transmitted by servomotors. The surgical staff can watch the operation through monitors showing the operative field.
3. Telesurgery operative area. After humerus osteosynthesis, two surgical robots are used for the telesurgical time. In the middle of the figure, we can see six telemanipulated arms: two arms are carrying cameras; the others are carrying telemicrosurgery instruments.
4. Telesurgery operative area. Patency test done with telemicrosurgical forceps was positive after vascular anastomosis.
5. Operative view at the end of replantation. We can see a bleeding of the distal fragment replanted through a bloodletting. This demonstrates the success of the intervention.

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1. Amputation patch of a pig left upper limb at the humeral stage. There are some vascular clamps marking the vasculo-nervous elements.
812x609mm (96 x 96 DPI)

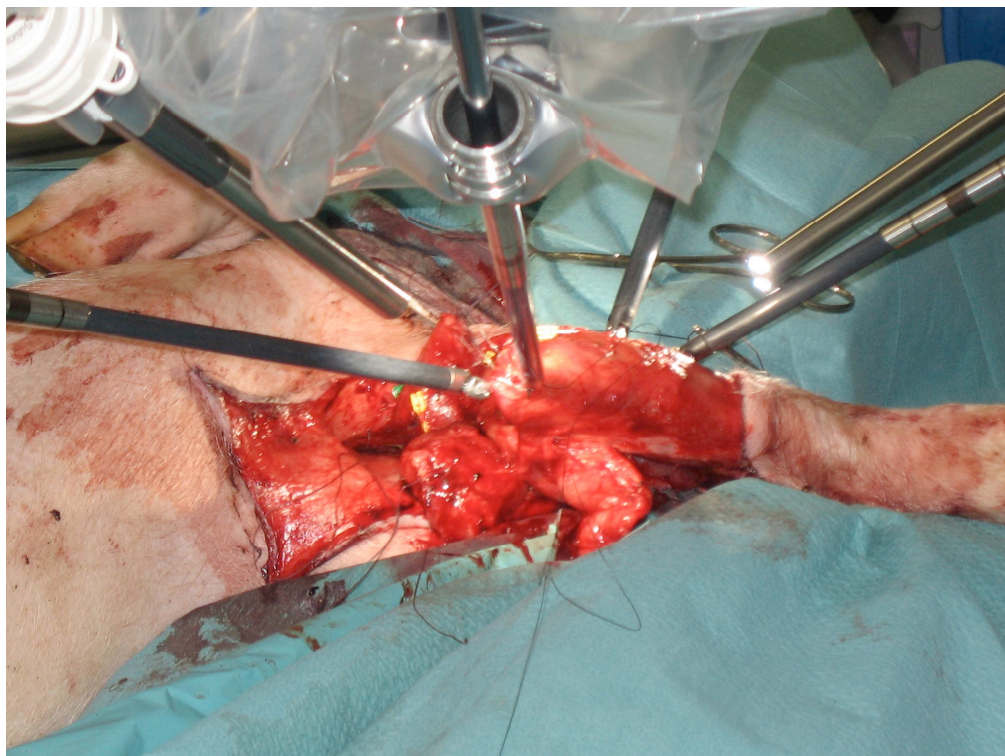
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2. Telesurgery workstation. There are two consoles on the right, which enable each operator to control the articulated arms of the mobile cart (middle of the figure). The pig is installed on the operation table between the two mobile carts. Each operator is sitting in front of his console with his head on a support between two IR sensors. He can also use a binocular viewing system, which gives him a three-dimensional vision of the operative field. His hands control the movements of the arm of the mobile cart through levers linked to surgical instruments by electronic circuits. These circuits are transmitted by servo-motors. The surgical staff can watch the operation through monitors showing the operative field.

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3. Telesurgery operative area. After humerus osteosynthesis, two surgical robots are used for the telesurgical time. In the middle of the figure, we can see six telemanipulated arms: two arms are carrying cameras; the others are carrying telemicrosurgery instruments.

812x609mm (96 x 96 DPI)

view



Telesurgery operative area. Patency test done with telemicrosurgical forceps was positive after vascular anastomosis.
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Operative view at the end of replantation. We can see a bleeding of the distal fragment replanted through a bloodletting. This demonstrates the success of the intervention.
812x609mm (96 x 96 DPI)

Review