Robotic intercostal nerve harvest: a feasibility study in a pig model

Hideaki Miyamoto, MD, Thomas Serradori, MD, Yoji Mikami, MD, PhD, Jesse Selber, MD, Nicola Santelmo, MD, Sybille Facca, MD, PhD, and Philippe Liverneaux, MD, PhD

Department of Hand Surgery, University Hospital of Strasbourg, FMTS, Illkirch, France; Department of Orthopaedic Surgery, University of Tokyo, Tokyo, Japan; General and Digestive Department, University Hospital of Nancy, Nancy, France; Department of Orthopaedic Surgery, Yokohama Rosai Hospital, Yokohama, Japan; MD Anderson Center, Houston, Texas; and Department of Thoracic Surgery, University Hospital of Strasbourg, FMTS, Strasbourg, France

The aim of this study was to report the feasibility of robotic intercostal nerve harvest in a pig model. A surgical robot, the da Vinci Model S system, was installed after the creation of 3 ports in the pig's left chest. The posterior edges of the fourth, fifth, and sixth intercostal nerves were isolated at the level of the anterior axillary line. The anterior edges of the nerves were transected at the rib cartilage zone. Three intercostal nerve harvesting procedures, requiring an average of 33 minutes, were successfully performed in 3 pigs without major complications.

The advantages of robotic microsurgery for intercostal nerve harvest include elimination of physiological tremor, free movement of joint-equipped robotic arms, and amplification of the surgeon's hand motion by as much as 5 times. Robot-assisted neurolysis may be clinically useful for intercostal nerve harvest for brachial plexus reconstruction.

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We have designed the robotic intercostal nerve harvest procedure in 3 stages: setup of the robot, approaches with 3 ports, and intercostal nerve dissection. The da Vinci surgical robot (Model S, Intuitive Surgical, Inc.) was set up (Fig. 1). We placed 3 ports, each 2 cm in diameter, in the left side of the pig’s chest (Fig. 2). The camera allowed 3D vision and progressive magnification up to ×25. The movements of the instruments were multiplied by 5 times (superfine position). After the video camera was introduced into the first port, forceps and scissors were introduced under direct vision (Fig. 3A). The video camera arm was equipped with a carbon dioxide insufflation system at a pressure of 4 mm Hg to maintain the operative field and control bleeding. The posterior edges of the fourth, fifth, and sixth intercostal nerves were isolated by microsurgical forceps, microscissors, and a hydrodissector (Erbejet) to the anterior axillary line (Fig. 3B). Venous bleeding was coagulated (Fig. 3C). The anterior edges of the 3 intercostal nerves were transected using robotic microscissors at the rib cartilage zone (Fig. 3D).

An assistant thoracic surgeon arranged the setting and replacement of robotic arms. All robotic intercostal nerve harvests were performed (Video 1) by the same microsurgeon.

VIDEO 1. Clip showing steps in robotic intercostal nerve harvest in a pig model. Copyright Philippe Liverneaux. Published with permission. Click here to view with Media Player. Click here to view with Quicktime.

Results

The time to set up the robot and place the 3 ports averaged 33 minutes (40, 30, and 30 minutes). The surgical time for harvesting the fourth, fifth, and sixth intercostal nerves in the console averaged 40 minutes (45, 35, and 40 minutes). The total time needed for the procedure was 1 hour and 13 minutes. The intercostal nerve harvests were successfully performed under appropriate carbon dioxide insufflation without having to convert the procedures to the conventional open approach. The ribs and major intrathoracic organs appeared intact. No intercostal nerve was accidentally transected. The total amount of bleeding during the operation averaged less than 20 ml.

Discussion

Refinement of open intercostal nerve transfer procedures and the development of advanced microsurgical techniques for restoration of elbow flexion following brachial plexus injuries have improved the outcomes of nerve transplantation procedures.11,15,22,24,34 The drawbacks of the conventional open approach for harvesting intercostal nerves include relatively long skin incisions,34 undesirable pleural damage,10 wound infection,10 and thoracic cage deformity.26 Complication rates increase as the number of intercostal nerves harvested increases.10 Kawabata et al. investigated mild growth retardation of ribs corresponding to the site of donor intercostal nerves, although no thoracic cage deformity was detected clinically.9 Leaving the periosteum of the ribs intact during dissection of the intercostal nerves is crucial if thoracic cage deformity is to be avoided.26

To resolve these drawbacks, the intercostal nerve harvesting process has been advanced using video-assisted thoracoscopy.2,19,21 In 2006, Mikami et al. successfully performed 12 intercostal nerve neurolysis procedures in 3 mini-pig models.11,19 One of 12 nerves was inadvertently transected during neurolysis. The average time for nerve harvesting was 30–60 minutes for each nerve.2,19 In 3 clinical cases described by Mikami and colleagues in 2008,20 4 thoracoscopic ports for harvesting 2 intercostal nerves were used. All patients recovered useful biceps function (Medical Research Council Grade 3+/5). One of these 3 clinical cases had to be converted to a conventional open nerve harvesting procedure due to accidental nerve transection. The total operation time in the first clinical case was 9 hours.20 Video-assisted thoracic surgery was also

FIG. 1. Photograph showing a pig placed in the lateral decubitus position and prepared for robotic intercostal nerve harvest. The robot is placed above the pig’s shoulder. The visualization system is in front of the animal and the surgeon console is behind it. Figure is available in color online only.

FIG. 2. Skin is marked to show the location of ports for the robotic arms. The first port was placed in the sixth intercostal space in the midaxillary line for the video camera arm (cannula); the second and third ports were placed 5 cm anterior and posterior to the first port at the level of the seventh intercostal space (stars). These two ports were used for robotic arms. Figure is available in color online only.
applied to harvesting a full-length phrenic nerve to allow direct nerve transfer to the biceps. Although existing endoscopic instruments are available for harvesting intercostal nerves, there are some incompatibilities related to the instruments’ size and the restricted maneuverability of the tips of the instruments.

The most important advantages of robotic microsurgery (telemicrosurgery) for intercostal nerve harvest are motion scaling up to 5 times, elimination of physiologic tremor, and free movement of joint-equipped robotic arms, which can improve manipulation. Several publications have compared surgeon performance using robotic microsurgery to conventional freehand microsurgery. Results were similar in the repair of anastomosis: operative time was shorter with conventional freehand microsurgery, but surgery-related comfort was superior with the telemanipulator. The surgical robot has been applied in 3 different types of procedure: 1) brachial plexus reconstruction using the Oberlin procedure; 2) nerve transfer to the deltoid muscle using the nerve to the long head of the triceps; and 3) supraclavicular brachial plexus procedures. As with other reported robot-assisted thoracic surgeries, robotic intercostal nerve harvesting may contribute to postoperative pain reduction, shorter hospitalization, earlier return to usual activities, lower complication rates, and better quality of life outcomes. After harvesting by robot-assisted thoracoscopy, intercostal nerves can be directed to the axilla subcutaneously and can be anastomosed to whichever nerve is needed to reanimate a particular muscle (biceps, triceps, etc.). Based on 3 clinical cases of ours, the length of harvested nerve allows direct repair of the recipient nerve (an interpositional graft is not required).

Potential complications associated with robotic intercostal nerve harvest include pneumothorax, atelectasis due to single-lung ventilation, and iatrogenic intrathoracic injuries. Most of the current literature on postoperative respiratory complications after intercostal nerve harvest showed minimal or no clinical effect on respiratory function. Chalidapong et al. reported that objective pulmonary function was reduced for 2 weeks and normalized within 3 months. Single-lung ventilation has usually been suggested for video-assisted thoracoscopic surgery to retain the working field and facilitate the surgery. Some authors have investigated the use of double-lung ventilation in thoracoscopic surgery and found that it was safe and provided appropriate exposure while decreasing cost, operative time, and undesirable complications in comparison with single-lung ventilation. Our procedure requires a chest tube, unlike the open technique, which, although taking more time and requiring a larger incision, rarely needs a chest tube. Another disadvantage of robotics, which must be weighed against its benefits, is the cost of acquisition, maintenance, and operation of the system.

In our animal experiment, we were able to establish an adequate surgical view and working field under double-lung ventilation. The absence of sensory feedback has been criticized as a fault of surgical robots. However, sensory feedback is not mandatory in conventional microsurgical procedures. We had no difficulty in using the robot to...
harvest the intercostals nerves without sensory feedback. For clinical cases, to avoid iatrogenic intrathoracic injuries, the surgeon must perform the robotic-assisted nerve harvest under supervision by an experienced thoracic surgeon and be prepared to convert to the conventional open procedure.

Conclusions

Three intercostal nerve harvests in 3 pigs each were performed using a robot. We conclude that intercostal nerve harvest in an animal model is feasible using the surgical robot. Robot-assisted neurolysis appears to be safe and may be useful for intercostal nerve harvest in clinical cases for brachial plexus reconstruction.

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**Author Contributions**
Conception and design: Liverneaux, Santelmo. Acquisition of data: Liverneaux, Miyamoto, Serradori, Facca. Analysis and interpretation of data: Liverneaux, Miyamoto, Facca. Drafting the article: Liverneaux, Miyamoto. Critically revising the article: Liverneaux, Mikami, Selber. Reviewed submitted version of manuscript: Liverneaux. Approved the final version of the manuscript on behalf of all authors: Liverneaux. Statistical analysis: Liverneaux, Miyamoto. Administrative/technical/material support: Liverneaux. Study supervision: Liverneaux.

**Supplemental Information**
**Videos**


**Correspondence**
Philippe Liverneaux, Hôpitaux Universitaires de Strasbourg, 10 avenue Achille Baumann, Illkirch 67403, France. email: liverneaux.philippe@orange.fr.