Surg Endosc (2011) 25:1741–1746
DOI 10.1007/s00464-010-1305-6

ORIGINAL ARTICLES

Transoral endoscopic neck surgery: feasibility and safety in a porcine model based on the example of thymectomy

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Received: 23 March 2010 / Accepted: 21 July 2010 / Published online: 24 August 2010

Abstract
Background In anatomical studies and cadaver dissections, we developed an endoscopic transoral access to the anterior neck region to reduce surgical access trauma. Through a sublingual trocar and two additional trocars in the vestibule of the oral cavity, the pretracheal and thyroid region was reached with standard laparoscopic instruments.
Methods We conducted an experimental trial in five pigs under general anesthesia to estimate the safety and feasibility of the method; via this approach, the thymus was partially resected. Perioperative antibiotics were administered but analgesics were not given in the postoperative course. Oral intake and behavior were observed during the following 2 days. After necropsy, examination of the access route took place by means of dissections. The tissue surrounding the working trocar was histologically examined.
Results The pretracheal region could be reached without a problem and the procedure was performed almost "bloodlessly" in an anatomically defined layer. The intervention time decreased successively. Postoperative awakening was uneventful. Regular oral food intake was observed after 2–3 h. Pain reactions were not registered during the entire postoperative phase. After dissection, all relations appeared inconspicuous (no infections, fresh/old hematoma). Two local encapsulated seromas were observed. Histologically, only a mild tissue reaction was noted.
Conclusion In this study, the endoscopic transoral approach to minimally invasive neck surgery seemed safe and feasible. Minimally invasive endoscopic procedures in the anterior neck region could be a possible application of this new approach.

Keywords Transoral · Endoscopic · Minimally invasive · Neck surgery · Animal study · Natural orifice surgery

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The evolution of laparoscopic surgery in recent years, sophisticated instrument design, and the ground-breaking new possibilities of endoscopic imaging have led to a substantial increase in the use of these techniques in all areas of surgery. Today, endoscopic approaches are being developed and explored in nearly all surgical disciplines.

In recent years, an increasing number of endoscopic procedures have been described for use in neck surgery. Using minimally invasive procedures, various interventions have been carried out: these include thyroid and parathyroid surgery in animal experiments [1–4] and clinical applications in humans [5–8]. The removal of the submandibular gland via an endoscopic approach has been investigated in animal experiments [9–11] and in studies of human cadavers [11–14]. The technique has already been applied to patients suffering from chronic sialolithiasis [11]. Vascular surgery of the carotid artery has been described in animal experiments [15]. In addition to the endoscopic removal of cervical cysts in patients [16], dissection of the vagal nerve and endoscopic cervical liposuction have already been performed [17]. Neck dissections in animal experiments [18, 19], cadaver studies [20], and applications in humans [21, 22] complete the picture. All of these endoscopic surgeries are accompanied by skin incisions and therefore have to be classified as transcervical approaches.

The attempt to reduce surgical access trauma in thyroid surgery has led to various endoscopic techniques. One innovation, introduced in 1996, was to make the skin incision in the lateral neck and use minimally invasive techniques and instruments for hemithyroidectomy [23]. At the same time, endoscopic parathyroid surgery was introduced [1, 24, 25].

Yeung [26] was the first to describe a minimized incision length for thyroid surgery in 1998. Miccoli et al. [27] standardized the technique for the transcollar approach with the use of endoscopic techniques [minimally invasive video-assisted thyroidectomy (MIVAT)] and worked with an incision length of 15–20 mm. The limiting factor in this approach is the size of the resected specimen [28]. Dysphagia due to scarring, especially in the platysmal muscle layer, may be problematic following the procedure.

Other groups changed the incision site to less visible sites, in line with the cosmetic demands of patients. Thoracic, axillary, and breast approaches were used [6, 28–31]. Calling these approaches "minimally invasive" is questionable since vast amounts of subcutaneous tissue have to be dissected to reach the pathological site.

A new paradigm is now changing the vision of surgical procedures for the future: approaches that utilize the natural orifices of the human body to reach the areas of interest with minimal access trauma—so-called "natural orifice surgery" (NOS) [32]. In 2008, Witzel et al. [33] presented an NOS approach for thyroidectomy. To minimize surgical trauma, they utilized an experimental transoral access route to the thyroid gland by means of single-port access via an axilloscope. This approach so far has not developed past the first experimental stage and was, in fact, a hybrid approach because additional 3.5-mm skin incisions 15 mm below the level of the larynx were necessary.

Inspired by the work of Witzel and his colleagues, we developed an endoscopic transoral and minimally invasive approach for surgical procedures to the anterior neck region using a three-point access, sublingually and bilaterally, in the vestibule of the mouth [34]. This approach allows direct entry to anatomically defined surgical spaces and therefore avoids possible postoperative sequelae like dysphagia following scarring of the muscle layers of the neck.

The transoral endoscopic approach had been successfully established in anatomical studies [35] and the first successful application in human cadavers followed in May 2008 [36]. In this approach, a purely endoscopic technique was used to access the anterior neck region without further skin incisions (Fig. 1). Based on these preclinical experiments, questions arose as to whether the target region could be reached in a living patient and if a "bloodless" operation could be performed in the space created. In addition, the postoperative course with respect to infections, dysphagia, and oral food intake was of interest. We therefore evaluated the technique in a short-time-survival animal trial.

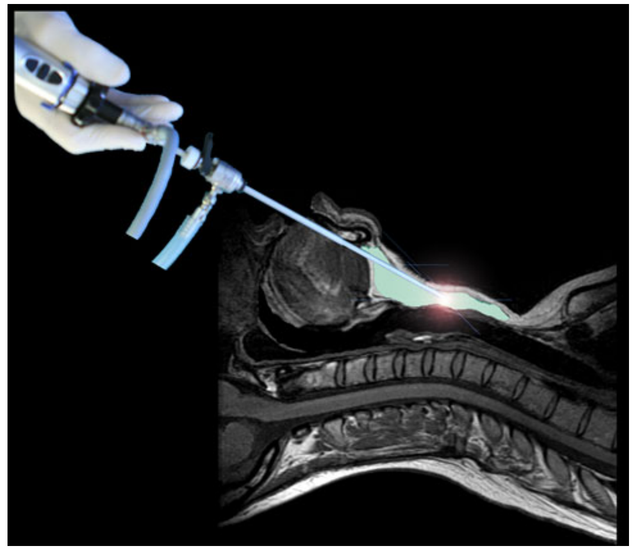

Fig. 1 Image of an endoscopic minimally invasive transoral approach for surgical procedures in the anterior neck region

Material and methods

Permission to perform this experimental trial was obtained from the Regional Administrative Authority Frankfurt/Oder, Germany (Landesamt für Verbraucherschutz, Landwirtschaft und Flurneuordnung, Frankfurt/Oder, Germany, genehmigte Tierversuchsanzeige 23-2347-8-13-2008, 28.08.2008).

Five male pigs (race: country pig-large white-piatrain) were used to evaluate the feasibility and safety of the minimally invasive endoscopic approach to the anterior neck region through the floor of the mouth. Intravenous anesthesia was induced with ketamine, midazolam, and azaperone, and pancuronium as a relaxant. After oral intubation, intravenous prophylactic in the form of a single shot of 1500 mg cefuroxime was applied and breathing was controlled with a standard ventilation system (Evita XL, Dräger, Lübeck, Germany). Standard laparoscopic instruments (Ø 2.7 mm) as well as specially built trocars (Ø 3.0 mm, Karl Storz GmbH, Tuttlingen, Germany) were used.

The anatomy of the pig with respect to structure and alignment of the suprahyoid muscles, as well as the superficial layers of the pretracheal muscles, is identical to that of humans. The thymus in pigs lies below these structures. There is another layer of bilateral muscles dorsal to the pig's thymus (pretracheal muscles), and below this is the pig's rather small thyroid gland (up to 5.0 ml in 4-month-old pigs) [37–39]. We decided to resect parts of the thymus in the operative procedure to the anterior neck region. The thymus of the animals has a vascular supply, thus ensuring a realistic surgical setup during the operation.

After use of skin and mucosal disinfectant (Sterillium©, Bode-Chemie, Hamburg, Germany, and Softasept N©, Braun, Melsungen, Germany) a midline incision was made sublingually between the papillae of Wharton's ducts, revealing the muscles of the floor of the mouth. These were divided into the median raphe and the trocar was inserted into the subplatysmal layer in front of the thyroid cartilage. After endoscopic control, CO_2 was insufflated at 6 mmHg. The CO_2 formed a tent in the anterior neck region through "gas dissection." After mucosal incision in the vestibule on both sides, the next step was to loosen the periost from the mandible. Following this, both working trocars were inserted subplatysmally and moved toward the layer of the thymus (Fig. 2). After the midline opening of the pretracheal muscles, the thymus was displayed, loosened on both sides, and parts of it were resected with an electric surgical knife (Erbe, Tübingen, Germany, type and mode of action: VIO 300D, Effect 3, swift-coag, 50–90 W). Harvesting of the specimen was attempted through the sublingual channel. Finally, the incisions were closed with absorbable sutures (Vicryl© 3/0, Ethicon, Norderstedt, Germany).

Fig. 2 View of the surgical procedure—all trocars in place

The animals woke up breathing spontaneously and were brought back into their sty after 3 h. For the next 2 days, all animals were observed to establish pain reactions and oral feeding. Possible pain reactions were estimated based on their social behavior in the sty; normally, the animals fight with each other, especially during feeding. If the pigs experience pain, they press their trunks against a wall as this phantom pain detracts from other pain.

On the third postoperative day, all animals were anesthetized and the incision sites in the oral cavity were checked. The animals were subsequently euthanized with 20 ml intravenous T61 (1 ml includes 5 mg tetracainehydrochloride, 50 mg mebezoniumhydrochloride, and 200 mg embutramide; Intervet Company, Unterschleißheim, Germany). A complete dissection of the floor of mouth and the anterior cervical region, including the surgical field, was performed to reveal infections, hematomas, or other collateral damage.

Results

We evaluated the feasibility and safety of the minimally invasive endoscopic approach to neck surgery through the oral cavity, without any other skin incisions, in an animal trial. Details of each pig are given in Table 1. In each case, the anterior neck could be reached endoscopically without a problem. There was no bleeding that required surgical intervention. A midline incision of the pretracheal muscle layer revealed the thymus. The latter was mobilized and the adjacent vessels were cauterized with monopolar scissors (Fig. 3). This would not fulfill the needs of humans when sealing vessels; a harmonic scalpel (e.g., Ultracision, Ethicon Endosurgery, Norderstedt/Germany) would have to be used in humans. Next, parts of the thymus were resected. We were able to resect ¼ to ½ of the gland in different regions (caudal and cranial) on both sides. The resected parts had an average volume of 28.7 cm^3 (Table 1). Intraoperative bleeding did not exceed 10 ml.

Table 1 Cut-suture time, details of the animals, and size and volume of the resected specimen

	Cut-suture time (min)	Time to reach TG (min)	Weight (kg)	Age (months)	Resected specimen (cm)	Resected volume (cm^3)
Trial 1	173	19	40	4	7.2 × 5.45 × 0.8	31.4
Trial 2	108	60	45	4	8.8 × 3.7 × 0.6	19.5
Trial 3	75	27	40	4	6.5 × 4.1 × 1.5	40.0
Trial 4	62	18	42	4	4.7 × 2.4 × 1.3	14.7
Trial 5	41	10	39	4	8.8 × 3.6 × 0.8	37.8
					4.8 × 3.7 × 0.7	
Average	92	27	41	4		28.7

TG thymus gland

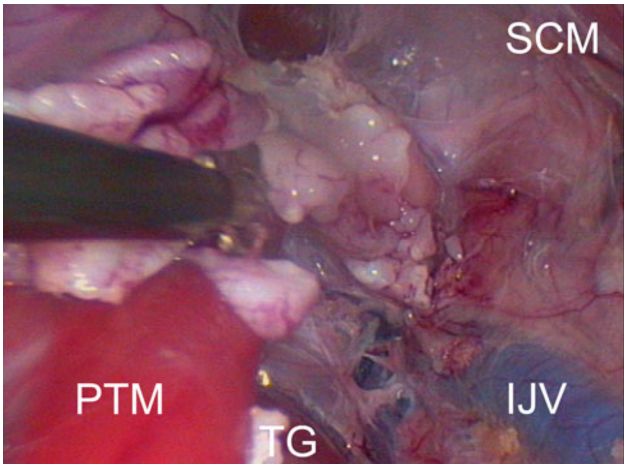

Fig. 3 Endoscopic view of the transoral approach. *SCM* sternocleidomastoid muscle, *PTM* pretracheal muscle, *IJV* internal jugular vein, *TG* thyroid gland under PTM

The time between cut and suture and the time to reach the thymus layer, with all trocars and working instruments in place, decreased in each new trial (Table 1).

All pigs breathed spontaneously after the surgical procedure and could be extubated without complications. They recovered fast and no acute postoperative bleeding occurred. After 4–5 h, all animals started oral food intake without signs of pain. For the following 2 days the animals were held in their sty and were fed standard pig food and water. There were no irregularities, no notable signs of pain (i.e., they displayed normal social behavior; none of the pigs pressed their trunks against the wall). Signs of local infections in the neck tissues were not noted.

On the third postoperative day, all animals underwent a second anesthesia induction to examine the incision, paying special attention to local infections or wound breakdown, comparing the findings to the direct postoperative finding: none of the pigs showed any such conditions. There were no locoregional infections or other unusual findings. The animals were euthanized with 20 ml T61 and the submandibular and anterior cervical regions were dissected. After resection of the skin and platysma, the subcutaneous tissue where the trocars were placed could be examined. There was no fresh bleeding, hematomas, or infection. In cases 1 and 2, we found a minimal prelaryngeal edema. This did not result in any breathing disorders during the postoperative course in these animals. The access path of the trocars could be identified (Fig. 4A).

After opening the pretracheal strap muscles in the midline in case 3, a seroma (50 ml) was revealed, and in case 5, an offensive hematoseroma (10 ml) became visible. These were attributed to the use of the monopolar cautery and the special conditions of the porcine model. The rest of the thymus could be seen in the pretracheal space. No other bleeding or infections were observed. In three cases (1, 4, 5), minor injuries to the infralaryngeal strap muscles, which had not affected the animals in their postoperative behavior, were noticed. They were covered with fibrin deposits. All these minor injuries to the strap muscles (maximum size of 5 × 15 mm) were located in the cranial portion of the muscles around the insertion site of the lateral working trocars where the muscles are attached to the thyroid cartilage of the larynx. These had been caused by the placement of the lateral working trocars.

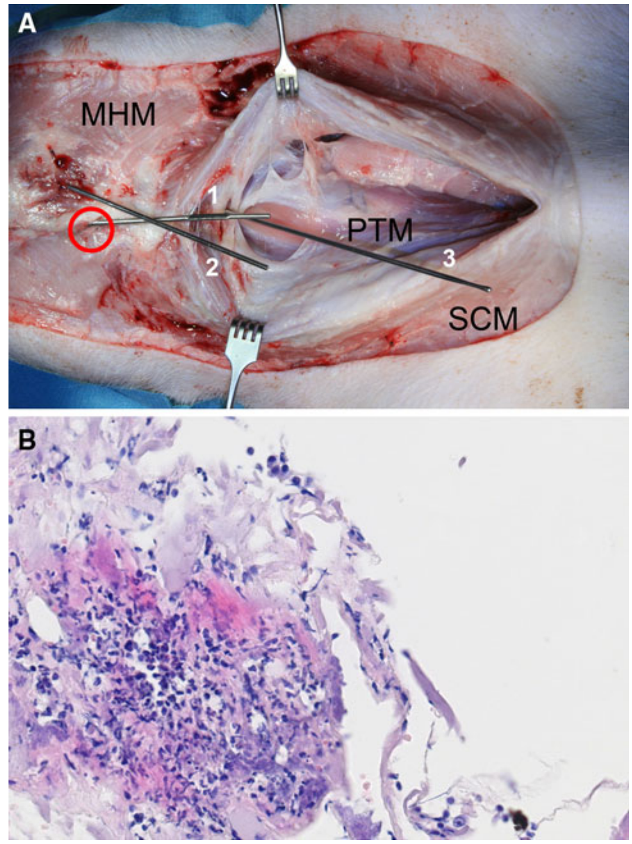

Fig. 4 **A** Dissection view with probes in place of the original trocars: *red circle*, histology taken; *SCM* sternocleidomastoid muscle, *MHM* mylohyoid muscle, divided in the midline, *PTM* pretracheal muscle; *1* and *2*, channels of the working trocars; *3*, channel of the trocar for the endoscope. **B** Histology (H&E staining)

Histological examination of biopsies of the submandibular region around the trocar showed minimal inflammation (Fig. 4B). Irregular tissue, measuring maximally 1.2 cm in diameter, was described by the pathologist as showing minimal microscopically infected fat tissue. Ectatic venous and arterial vessels and small venous flaps and small amounts of necrotic tissue in the marginal zone could be seen.

Discussion

The minimally invasive video-assisted thyroidectomy could reduce the amount of necessary dissection [26, 27], but it still requires dissection of skin, subcutaneous layers, and the cervical platysma. This may cause dysphagia due to scarring of the readapted muscle layers. With the aim of moving the incision from the visible cervical regions to satisfy the higher cosmetic demands of patients, endoscopic techniques were adopted and modified for thyroid resection. This led to various extracervical approaches [6, 25, 28–31]. More extensive dissection of subcutaneous layers was necessary, thereby increasing the risk of hematomas or severe scarring. These techniques also require the wide opening of the platysma above the thyroid gland, which can lead to extensive scarring. Due to this extensive dissection in extracervical endoscopic approaches, one should refer to these procedures as maximally rather than minimally invasive.

The concept of natural orifice surgery (NOS) changed the surgeon's perspective: natural openings of the body are used by interdisciplinary teams to reach the target area directly. The aim is to reduce surgical access trauma, collateral damage, and complications, and to achieve faster recovery for the patient [32, 40].

Witzel et al. [33] were the first to adopt the concept of using a single-port approach in the ventral floor of mouth with an axilloscope to resect the thyroid gland in an animal trial. This technique was a hybrid since it required an additional skin incision in the laryngeal area. Karakas et al. [39] began another attempt in this direction by placing the axilloscope in the lateral sublingual floor to obtain single-port access to the thyroid gland. By passing the larynx laterally, they could reach the gland, dissect the upper pole vessels, and identify the recurrent laryngeal nerve. A major disadvantage of this technique is the need to work through the scope which results in limited triangulation of the working instruments. Lateral approaches near the larynx also limit the procedure in a hemithyroidectomy. At the very least, the use of a scope limits the volume and size of the resected specimen as described in other endoscopic techniques [41].

We have developed an endoscopic sublingual and bivestibular approach (3-point) to reach the anterior neck region as an NOS technique in preclinical cadaver studies [32, 36]. Our animal trial with short-time survival was able to prove the feasibility and safety of this new method, even though it was applied to only five animals. In all cases the pretracheal working space in the anterior neck region could be reached. The created working space in the anterior neck region was big enough to work safely under endoscopic vision. Triangulation of instruments was satisfying and "sword fighting" caused no problems. We were able to reach both sides of the anterior neck region easily. Hemorrhaging was not observed in either the intraoperative or the postoperative course. We did not observe any locoregional infections, specifically in the soft tissues of the anterior neck. In two cases, localized and encapsulated seromas were detected. This was attributed mainly to the use of electrosurgery and has also been observed in other animal experiments [1, 3]. In human application of endoscopic techniques, such seromas have never been documented [5–8] and therefore these are probably a problem specific to the experimental animal model. Care has to be taken when positioning the lateral working trocars since lacerations of the strap muscles was observed. These were minimal and did not cause any problems in the postoperative course, notably with respect to swallowing.

Existing experimental data on endoscopic surgery of the anterior neck region had not reflected on the postoperative course and the behavior of the animals after surgery; all of these experiments were final experiments ending with necropsy after surgery was completed [33, 39]. In our series, a postoperative course of 3 days addressed the questions of postoperative pain and food intake. Postoperative behavior in terms of pain, foot intake, and social behavior in the sty was normal. Dissection after 3 days showed no signs of hematomas or local infections at the trocar entry sites. The thymus region could clearly be seen. Localized encapsulated seromas were present in two animals at the resection site. Procedure time was reduced with every new procedure.

Harvesting of the resected specimen is still an unsolved problem. In this animal trial, harvesting was possible only in small volumes (up to 4.0 ml). Larger specimens could not be harvested due to the ligaments in the prelaryngeal region of this animal model. In human application, this could be a limiting factor for this technique.

In conclusion, with this minimally invasive endoscopic approach via a transoral route (Fig. 1), we could establish a new approach in endoscopic neck surgery within natural orifice surgery. Preclinical studies and this animal trial have shown that it is feasible and safe in animal trials. Possible advantages (faster recovery) and fewer complications (e.g., postoperative pain, dysphagia) are likely, but can be estimated only after human application. Of course, the operation leaves no visible scars. Problems might occur in the harvesting of the resected specimen and particular attention must be paid to possible infections of the neck tissues during human application.

Acknowledgments The author thanks Karl Storz GmbH & Co. KG, Tuttlingen, Germany, for its support of this study by supplying the instruments and video technique. The New European Surgical Academy (NESA), Berlin, Germany, contributed financial support.

Disclosures Thomas Wilhelm has no conflicts of interest or financial ties to disclose.

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