Ultrasonic scalpel causes greater depth of soft tissue necrosis compared to monopolar electrocautery in a pig model

Homayounfar K\textsuperscript{1}, Meis J\textsuperscript{2}, Jung K\textsuperscript{3}, Klosterhalfen B\textsuperscript{4}, Sprenger T\textsuperscript{5}, Conradi LC\textsuperscript{6}, Langer C\textsuperscript{7}, Becker H\textsuperscript{8}

\textsuperscript{1}Department of General and Visceral Surgery, University Medical Center Goettingen, Georg-August-University, Robert-Koch-Strasse 40, 37075 Goettingen, Germany, email: khomayounfar@chirurgie-goettingen.de

\textsuperscript{2}Department of General and Visceral Surgery, University Medical Center Goettingen, Georg-August-University, Robert-Koch-Strasse 40, 37075 Goettingen, Germany, email: johanna.meis@stud.uni-goettingen.de

\textsuperscript{3}Department of Medical Statistics, University Medical Center Goettingen, Georg-August-University, Humboldtallee 32, 37075 Goettingen, Germany, email: klaus.jung@ams.med.uni-goettingen.de

\textsuperscript{4}Institute of Pathology, Roonstr. 30, 52351 Dueren, Germany, email: bernd.klosterhalfen@web.de

\textsuperscript{5}Department of General and Visceral Surgery, University Medical Center Goettingen, Georg-August-University, Robert-Koch-Strasse 40, 37075 Goettingen, Germany, email: tsprenger@chirurgie-goettingen.de

\textsuperscript{6}Department of General and Visceral Surgery, University Medical Center Goettingen, Georg-August-University, Robert-Koch-Strasse 40, 37075 Goettingen, Germany, email: lena.conradi@med.uni-goettingen.de

\textsuperscript{7}Department of General, Visceral, Thoracic and Minimal-invasive Surgery, Evangelic Hospital Goettingen-Weende, An der Lutter 24, 37075 Goettingen, Germany, email: allgemeinchirurgie@ekweende.de

\textsuperscript{8}Department of General and Visceral Surgery, University Medical Center Goettingen, Georg-August-University, Robert-Koch-Strasse 40, 37075 Goettingen, Germany, email: hbecker@chirurgie-goettingen.de
Correspondence:

Kia Homayounfar, MD
Department of General and Visceral Surgery
University Medical Center
Georg-August-University
Robert-Koch-Strasse 40
37075 Goettingen
Germany
Phone: +49-551-396736
Fax: +49-551-396106
Email: khomayounfar@chirurgie-goettingen.de
Abstract

Background

Ultrasonic scalpel (UC) and monopolar electrocautery (ME) are common tools for soft tissue dissection. However, morphological data on the related tissue alteration are discordant. We developed an automatic device for standardized sample excision and compared quality and depth of morphological changes caused by UC and ME in a pig model.

Methods

100 tissue samples (5×3 cm) of the abdominal wall were excised in 16 pigs. Excisions were randomly performed manually or by using the self-constructed automatic device. Quality of tissue alteration and depth of coagulation necrosis were examined histopathologically. Device (UC vs. ME) and mode (manually vs. automatic) effects were studied by two-way analysis of variance at a significance level of 5%.

Results

UC and ME induced qualitatively similar coagulation necroses. Mean depth of necrosis was 450.4 ± 457.8μm for manual UC and 553.5 ± 326.9μm for automatic UC versus 149.0 ± 74.3μm for manual ME and 257.6 ± 119.4μm for automatic ME. Coagulation necrosis was significantly deeper (p < 0.01) when UC was used compared to ME. The mode of excision (manual versus automatic) did not influence the depth of necrosis (p = 0.85). There was no significant interaction between dissection tool and mode of excision (p = 0.93).

Conclusion

Thermal injury caused by UC and ME results in qualitatively similar coagulation necrosis. The depth of necrosis is significantly greater in UC compared to ME.
Introduction

Soft tissue dissection is a major issue in all fields of surgery as it incorporates the risk of wound healing disorder, hematoma or seroma. These adverse events potentially cause additional interventions up to reoperation resulting not only in patients discomfort and prolonged hospital stay but also in persisting morbidity and higher health care costs [1]. The search for a dissection tool safer than standard monopolar electrocautery (ME) with its well known limitations in particular burns and carbonization, has led to the development of high-frequency ultrasonic dissection tools (UC). These instruments transform electrical power into ultrasonic waves of 55.5 kHz. The subsequently released thermal energy breaks up protein molecules leading to hemostasis and tissue dissection by cavitation and coaptation with good controllability of penetration depth [2]. UC has already been introduced into clinical routine in various subspecialties of surgery especially for laparoscopic procedures and numerous studies have evaluated its feasibility [3-7].

However, data on the extent of tissue alteration and its potential adverse effects are inconsistent. The discussion on UC has been raised again since recent studies identified a higher rate of sexual disorders after laparoscopic rectal resection compared to open procedures [8] whereto UC may contribute. Given that tissue alteration by UC has been shown to depend not only on power level setting but individual activation time and pressure [1,9], an experimental setup with a standardized tissue dissection technique without manual handling bias is needed to investigate the impact of UC on soft tissue morphology in comparison to standard ME. Therefore, we stepped back into an experimental pig model aiming to histopathologically evaluate the quality and extent of morphologic changes caused by UC and ME for soft tissue dissection using 2 types of dissection (manual and automated).
Material and Methods

Animal experiments were performed in 16 male 3-6 months-old pigs with a mean weight of 44.0 ± 4.7 kg. All animal care and experimental procedures were in accordance with German national legislation on animal protection. The animals were anesthetized using the following sedation, relaxation, and narcosis regimen: ketamine 10% with a dose of 0.25 mL/kg, xylazine 2% in a dose of 0.15 mL/kg, atropine sulfate 1% in a dose of 0.06 mL/kg. After endotracheal intubation anesthesia was continued with constant isoflurane (1.5–2 vol%) inhalation and oxygen (50 vol%) with a fresh gas flow rate of 1 L/min.

A software-controlled device was constructed for standardized automatic tissue dissection (Figure 1). After fixation at the operating table and insertion of the selected dissection tool, the device allowed identical excisions with fixed tissue contact times. Therefore, the dissector blade cut 5 cm in horizontal direction starting at an edge of the defined tissue sample and then moved forward for 1 cm redoing the same movements backwards until a 5x3 cm tissue sample was excised. In this study, we used the *Ultracision Harmonic Scalpel HSA07* (Ethicon Endo-Surgery, Inc, Nordestedt, Germany) on power level 5 for UC and the *Erbotom ICC 350* (ERBE Elektromedizin GmbH Tübingen, Germany) on 60 W (cutting) for ME. While manual excision was performed in all 16, the automatic device was used only in 9 animals after validation experiments (data not shown).

Using a template, 8 excisions were sketched on each pig’s abdominal wall. Then a double step randomization process defined the mode of excision (automatic versus manual) and the tissue dissection tool (UC versus ME) for each sample. Figure 2 illustrates the subsequent excision process. Vertical incisions were performed with a steel scalpel. Afterwards the tissue sample was excised in horizontal direction either by UC or ME, which exactly had to be done at the cutaneous-subcutaneous junction. Tissue samples were then fixed, dehydrated and paraffin embedded (*Leica TP1050 Tissue Processor, Leica EG 1140 Embedding Center, Leica Microsystems, Germany*). 3 micrometer cross sections of each sample were produced (*Sliding microtome, Leica Microsystems, Germany*) for Hematoxilin and eosin (HE) and Elastica van Gieson (EvG) staining. Light microscopy was performed by an experienced histopathologist (BK). 7 measure points were used to determine the median depth of necrosis in each sample. Preparation as well as histopathological and morphometric
examination of all specimens was performed at BMP Labor für Medizinische Materialprüfung GmbH, Aachen, Germany using standard operating procedures and an accredited quality management system.

Statistical Methods

The influence of the variables dissection mode (automatic versus manual) and dissection tool (ME versus UC) onto the depth of necrosis was evaluated using a two-way analysis of variance for repeated measures, including the interaction effect of the two factors as well. Effects were found to be significant if p-values were less than 0.05. All analyses were performed using the free software R (version 2.8, www.r-project.org).
Results

Histological findings

Conventional light microscopy using HE and EvG staining verified skin and subcutaneous tissue with a regularly structured epidermis of keratinized stratified squamous epithelium and stratum corneum with typical integumentary appendages in all 100 samples. The subcutaneous fat tissue consisted of univacuolar lipocytes as well as vessel-bearing connective tissue strings. Tissue samples of both, UC and ME showed qualitatively similar coagulation necroses at the resection plane which were pronounced in the fibrovascular connective tissue structures of the corium in relation to the subcutaneous fatty tissue. In addition, the consistence of the fatty tissue caused inaccuracy of depth extension determination. Therefore, further morphometric measurements of necrosis depth were restricted to that fibrovascular connective tissue layer. Figure 3 shows representative EvG staining results with deep red necrosis (a), more superficial necrosis with closure of a capillary (b) and deep necrosis with closure of a larger vessel (c) all caused by UC and necrosis with closure of small vessels caused by ME (d).

Morphometric measurements

Morphometric analyses could only be performed in 70 tissue samples with an exact horizontal resection plane at the cutaneous-subcutaneous junction (Figure 4). In the remaining 30 samples not suitable for analysis, excision was performed to deep in the fatty tissue. Table 1 displays the median depth of coagulation necrosis for all tissue samples. The mean depths (± standard deviation) of coagulation necrosis stratified by mode of excision and dissection tool are summarized in Table 2 and illustrated in Figure 5. Depth of necrosis was significantly greater when using UC in comparison to the ME (p < 0.01). Though depth of necrosis was also greater when using the automatic compared to the manual mode, this effect, however, was not significant (p = 0.85). Furthermore, there was no significant interaction between the mode of excision and the dissection tool (p = 0.93). That means the significant tool effect can be regarded to be of the same size under both modes.
Discussion

This study shows that both, UC and ME dissection technique lead to a similar histopathologic pattern of coagulation necrosis at the resection plane. However, the chosen dissection tool significantly affects the depth of this coagulation necrosis with UC generating a greater necrotic margin than ME when used for soft tissue dissection.

Few previous studies exist specifically on morphological changes of soft tissue caused by UC and ME. Addressing skin and subcutaneous soft tissue dissection in a pig model, Hambely et al. [10] reported significantly less extensive and more localized tissue damages with UC compared to ME. Focusing on quality in contrast to extent of tissue damage, Foschi et al. [11] identified coagulation necrosis to be the predominant thermal injury by scanning and transmission electron microscopy which is consistent with our results.

Examining the efficacy of UC for hemostasis, Diamantis et al. [12] have investigated the safety and efficacy of multiple dissection tools including UC and ME for dissection and coagulation of short gastric vessels in a New Zealand rabbit model. In contrast to our results, they reported a deeper tissue damage caused by ME compared to UC. However, they applied a different, more descriptive approach referring to histological layers but did provide neither exact measurement data nor statistical comparisons. By analyzing the efficacy of UC for the hemostasis of small-, medium- and large-sized arteries in pigs, Harold et al. [13] observed an increase in thermal injury concomitant to increased vessel size. This direct correlation between power level settings, activation time and thermal injury has been reported in more detail by Emam et al. shortly after [9].

These mentioned animal studies share a relevant limitation which is the missing description of morphometric measurement. Our data clearly indicate that both UC and ME do not cause a uniform necrotic zone at the resection margin (Figure 2), most likely not only because of dissection related but local factors like tissue quality and vessel density. This suggestion is supported by the findings of Hoenig et al. [14] They examined the thermal injury of laparosonic coagulating shears with either sharp or blunt tip compared to bipolar electrocautery in a porcine model and observed different extent of injury depending on the type of tissue dissected.
The special contribution of this animal study is that we tried to design an experimental setup that reduces handling related bias as much as possible. In particular, we implemented a randomization-process for sample retrieval, the comparative application of the automatic device versus manual dissection, the excision of 2 samples of each kind (A and B) per animal and multiple measurement points per sample for quantifying the depth of coagulation necrosis.

Facing our result of wider necrotic margin in UC, one might hypothesize that in terms of clinical relevance this might lead to more competent ligation of both, blood vessels and lymphatics. This is supported by Morino et al. [15] who investigated the safety and efficacy of UC compared to ME in laparoscopic colorectal surgery within a prospective randomized clinical trial. They found a significantly lower median intraoperative blood loss for UC. Schmidbauer et al. [16] also reported this convincing coagulating effect with minimal blood loss for UC for the field of liver resection. In contrast, clinical studies evaluating the postoperative seroma rate following breast cancer surgery could not confirm a significant benefit of UC on seroma formation [17,18].

In conclusion, our study confirms that both, UC and ME lead to coagulation necrosis at the resection plane. The depth of this coagulation necrosis is significantly greater when UC is used for soft tissue dissection compared to ME.

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Declaration of competing interests

The authors declare that they have no competing interests.
References


**Legends**

**Figure 1:** Self-constructed apparatus fixed at the operating table and loaded with ultrasonic scalpel. The instrument can be moved engine-driven into two directions (aluminium tracks).

**Figure 2:** Schematic illustration of tissue sample and excision planes with a) epidermal layer, b) corium, c) subcutaneous fatty tissue, d) vertical excision lines performed by steel scalpel, e) horizontal excision line performed by either ultrasonic scalpel 8UC) or monopolar electrocautery (ME).

**Figure 3:** Representative EvG staining results with deep red necrosis (a), more superficial necrosis with closure of a capillary (b) and deep necrosis with closure of a larger vessel (c) all caused by UC and necrosis with closure of small vessels caused by ME (d) (magnification a and d x200; c and d x 400).

**Figure 4:** Representative tissue section (HE staining) at x100 magnification displaying the morphometric measurement with 7 different measuring points.

**Figure 5:** Distribution of the depth of necrosis according to method and device.
Figure 5
Additional files provided with this submission:

Additional file 1: Table 1.doc, 55K
http://www.biomedcentral.com/imedia/1895518939623267/supp1.doc
Additional file 2: Table 2.doc, 29K
http://www.biomedcentral.com/imedia/2016760178623267/supp2.doc