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ORIGINAL ARTICLE

Total Mesorectal Excision—Does the Choice of Dissection Technique have an Impact on Pelvic Autonomic Nerve Preservation?

Daniel W. Kauff · Oliver Kempski · Sabine Huppert · Klaus P. Koch · Klaus P. Hoffmann · Hauke Lang · Werner Kneist

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Abstract
Background The aim of this experimental study was to assess the quality of pelvic autonomic nerve preservation of different dissection techniques.
Material and Methods Twelve pigs underwent low anterior rectal resection (LARR) with scissors, ultracision, monopolar diathermy, and waterjet, each in three animals. Assessment of pelvic autonomic nerve preservation was carried out by stimulation of the pelvic splanchnic nerves under electromyography of the internal anal sphincter (IAS). Neurostimulation was performed bilaterally after posterior dissection, after complete mesorectal dissection, and after rectal resection.
Results Stimulation resulted in significantly increased amplitudes of the time-based electromyographic signal of the IAS, confirming nerve preservation. The stimulation results after complete mesorectal dissection showed comparable median amplitude increases for dissection with scissors (10.34 μV (interquartile range [IQR], 5.58; 14.74)) and ultracision (9.79 μV (IQR, 7.63; 11.6)). Lower amplitude increases were observed for monopolar diathermy (4.47 μV (IQR, 2.52; 10.46)) and waterjet (0.61 μV (IQR, 0.07; 2.11)) (p=0.038). All animals undergoing dissection with scissors, ultracision, and monopolar diathermy had bilateral positive results. Of three animals undergoing LARR with waterjet, one had bilateral positive results. Two had unilateral negative results, indicating incomplete nerve preservation.
Conclusion Scissors, ultracision, and monopolar diathermy might have comparable nerve-sparing potentials and differed from waterjet.

Keywords Dissection techniques · TME · Pelvic autonomic nerve preservation · Rectal cancer · Internal anal sphincter

Introduction

Total mesorectal excision (TME) combined with pelvic autonomic nerve preservation enabled improvements in prognosis and, in particular, functional outcome and has become the standard surgical procedure for rectal cancer patients.[1,2] Although the concept is accepted worldwide, depending on the surgical department, different dissection techniques like monopolar diathermy, scissors, and more recent techniques such as ultracision and waterjet are being used. The surgical damage to the pelvic autonomic nerves was shown to contribute significantly to the quality of functional outcome.[3] However, there is no consensus about the role of the different dissection techniques in preserving autonomic nerves.

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D. W. Kauff · S. Huppert · H. Lang · W. Kneist (✉)
Department of General and Abdominal Surgery, University Medicine of the Johannes Gutenberg-University Mainz, Langenbeckstraße 1, 55131 Mainz, Germany
e-mail: werner.kneist@unimedizin-mainz.de

O. Kempski
Institute for Neurosurgical Pathophysiology, University Medicine of the Johannes Gutenberg-University Mainz, Mainz, Germany

K. P. Koch
Department of Engineering, University of Applied Sciences, Trier, Germany

K. P. Hoffmann
Fraunhofer Institute for Biomedical Engineering and University of Applied Sciences, St. Ingbert, Germany

Unfortunately, a comparison of surgical techniques for nerve-sparing TME has not been carried out so far.

In the last decade, further insights into the quality of nerve-sparing surgery have become available through the development of pelvic autonomic nerve monitoring using penile tumescence and intracavernous, intraurethral, or intravesical pressure measurement.[4] Recently, a new method for intraoperative neuromonitoring has been established in an animal model, enabling verification of functional nerve integrity under continuous electromyography of the internal anal sphincter (IAS).[5–7] Moreover, first clinical data demonstrated the feasibility of this method in rectal cancer patients. The technique has the potential to identify autonomic nerve damage intraoperatively and predicts neurogenic fecal incontinence after TME.[8]

Therefore, the present experimental study investigated the impact of the choice of dissection technique on the quality of the IAS electromyographic signal during low anterior rectal resection (LARR) in order to receive first hints on the nerve-sparing potential.

Material and Methods

Animals and Surgical Procedure

Twelve male pigs (German Landrace) weighing a median of 29 kg (range, 27–31 kg) underwent LARR performed by a colorectal surgeon. Mesorectal dissection was carried out with scissors, ultracision, monopolar diathermy, and waterjet, each in three animals (Fig. 1). According to a standardized procedure, it started posterior and moved forward right and left lateral and anterolateral. After finishing the anterior part, circumferential mesorectal dissection was completed. In all animals, low rectal resection was performed with scissors. The rectal stump was closed. Operations were carried out under general anesthesia with thiopental sodium (Trapanal®, 2.5 g/100 ml i.v.) 12–15 ml/h and piritramid (Dipidolor®, 45 mg/45 ml i.v.) 8–10 ml/h. For monitoring of vital parameters, electrocardiogram, arterial blood pressure, and body core temperature were observed continuously. Repeated blood gas measurements were done to ensure respiratory homeostasis. After the surgical procedure, the animals were sacrificed with an overdose of thiopental sodium and 40 ml KCl 7.45 % i.v. The experiments were performed according to the guidelines of the local authorities (Regional Board of Animal Welfare, Koblenz, Rhineland-Palatinate, Germany).

Dissection Techniques

Scissors

Sharp dissection was performed with dissecting scissors (Aesculap, Braun, Tuttlingen, Germany).

Ultracision

The ultracision system included a generator (Harmonic Generator 300®, Ethicon Endo-Surgery, Norderstedt, Germany), a handpiece (Harmonic Handpiece®, Ethicon Endo-

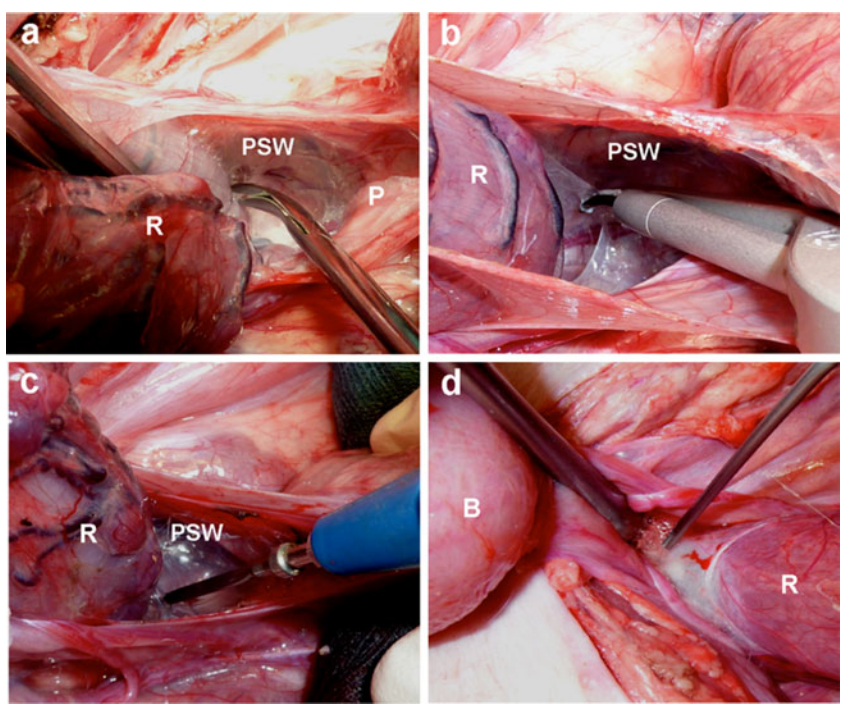


Fig. 1 Twelve male pigs undergoing mesorectal dissection with scissors (**a**), ultracision (**b**), monopolar diathermy (**c**), and waterjet (**d**), each in three animals. *R* rectum, *PSW* pelvic sidewall, *P* promontorium, *B* bladder

Surgery, Norderstedt, Germany), and a long coagulation scissors (Harmonic Focus 17 cm®, Ethicon Endo-Surgery, Norderstedt, Germany) for open surgery. The cutting speed was set to 3 at a frequency of 55.5 kHz.

Monopolar Diathermy (High-Frequency Radio Wave Electrosurgery)

The system consisted of an electrosurgical generator (Electrosurgical Unit, Erbe Elektromedizin GmbH, Tübingen, Germany) producing radio frequency current, a handpiece with an active electrode (electrosurgical pencil and spatula electrode, Erbe Elektromedizin, Tübingen, Germany), and a skin pad as a neutral electrode. The generator was set to coagulation mode.

Waterjet

The system consisted of a waterjet surgery unit (Erbejet 2®, Erbe Elektromedizin GmbH, Tübingen, Germany) and a handpiece with a 120-µm nozzle surrounded by a suction device (applicator bayonet with suction, Erbe Elektromedizin GmbH, Tübingen, Germany). Sterile isotonic saline was used as a separating medium. Pressure (range, 1–150 bar) and suction (range, 1–600 mbar) were adjustable and switched on/off by a foot pedal (Erbejet 2® one pedal foot switch with ReMode, Erbe Elektromedizin GmbH, Tübingen, Germany). Waterjet pressure was set to 50 bar and continuous suction to 200 mbar as described for rectal cancer surgery.[9]

Intraoperative Assessment of Pelvic Autonomic Nerve Function

Electromyography of the Internal Anal Sphincter

For identification of the IAS, the intersphincteric space was surgically exposed. Electromyography was performed with a bipolar needle electrode (Inomed Medizintechnik GmbH, Emmendingen, Germany) introduced into the IAS and a ground electrode placed at the left thigh. The setup was tested by impedance measurement, which verified the correct placement of the needle electrodes and ensured electrode function (range, 0.1–1.0 kΩ). The processed electromyographic activity of the IAS (amplitude in volts) was monitored continuously throughout the operation with a neuromonitoring system (NeMo®, Neuroexplorer® version 4.3, Inomed Medizintechnik GmbH, Emmendingen, Germany).[5–7]

Intraoperative Electric Stimulation of Pelvic Splanchnic Nerves

The earliest possible time for electric stimulation of the pelvic splanchnic nerves in this experimental setup was after the initial posterior mesorectal dissection. According to the standardized surgical procedure, stimulations were carried out after posterior dissection, after complete mesorectal dissection, and after rectal resection, using the neuromonitoring system with a handheld bipolar microfork probe (Inomed Medizintechnik GmbH, Emmendingen, Germany) (Fig. 2). Before the onset of neurostimulation, a further impedance measurement was performed in order to ensure that the system is set up correctly. Each step of the procedure was followed by three bilateral neurostimulations. In addition, macroscopic assessment of pelvic autonomic nerve preservation was documented.

At the end of the experiment, the nerves were severed at the level of the inferior hypogastric plexus by the performed dissection technique. This was followed by final stimulation of the pelvic splanchnic nerves.

In all animals, direct nerve stimulation consisted of pulse trains of 30 s with currents of 3 mA, frequency of 30 Hz, and monophasic rectangular pulses with pulse duration of 200 µs. The interval between two stimulations was at least 60 s.

Data Analysis and Statistics

Neurostimulation followed by sequential electromyographic amplitude increase of the IAS was considered as positive stimulation result. The signals were intraoperatively assessed by the surgeon and postoperatively analyzed in MATLAB® (Version 7.7.0.471, The MathWorks, Inc., Natick, MA, USA) in order to examine the amplitude increase during stimulation. Statistical analysis was carried out with SPSS® version 18.0 (Statistical Package for Social Sciences program, Chicago, IL, USA). The Wilcoxon's signed rank test was used for comparing the intraoperative electromyographic signals in their amplitude increase. Comparison between the stimulation results observed after

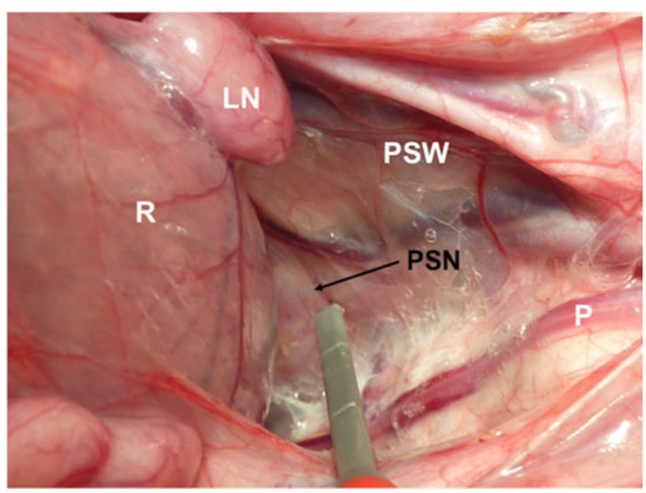


Fig. 2 Electric stimulation of the pelvic splanchnic nerves performed after posterior mesorectal dissection. *R* rectum, *PSW* pelvic sidewall, *LN* lymph node, *P* promontorium, *PSN* pelvic splanchnic nerves

Table 1 Summary of the amount of pelvic splanchnic nerve stimulations performed during all steps of LARR and comparison of median resting and evoked electromyographic amplitudes of the IAS for each dissection technique

Dissection technique	Pigs	Stimulations (*n*)	IAS amplitude		*p* value[a]
			Before stimulation (median (IQR) [μV])	During stimulation (median (IQR) [μV])	
Scissors	3	54	1.1 (0.7; 1.8)	8.5 (4.5; 15.0)	<0.001
Ultracision	3	54	0.8 (0.5; 1.2)	8.2 (5.1; 11.5)	<0.001
Monopolar diathermy	3	54	0.4 (0.2; 0.8)	4.0 (2.4; 8.5)	<0.001
Waterjet	3	54	0.9 (0.3; 2.2)	1.8 (0.8; 4.0)	<0.001

IAS internal anal sphincter, *IQR* interquartile range, *n* number

[a] Wilcoxon signed rank test

complete mesorectal dissection with the different surgical techniques was performed using analysis of variance (ANOVA). The stimulation results were expressed as the median and interquartile range (IQR). $p<0.05$ was considered statistically significant.

Results

In any case, the anesthetic milieu was stable. Vital signs including blood pressure, pulse, respiration, and blood oxygen saturation were within the normal range during the whole surgical procedure in all animals. Median dissection time was 10 min for complete mesorectal dissection with scissors, 15 min for ultracision, 11 min for monopolar diathermy, and 14 min for waterjet.

Stimulation of the pelvic splanchnic nerves resulted in significantly increased electromyographic amplitudes throughout the surgical procedures (Table 1). The pelvic autonomic nerves were macroscopically preserved in all investigated animals.

The IAS electromyographic amplitude increases after complete mesorectal dissection differed significantly among the applied surgical techniques ($p=0.038$) (Fig. 3). Comparable median amplitude increases were observed for dissection with scissors and ultracision. Lower amplitude increases were observed after mesorectal dissection with monopolar diathermy and lowest increases after waterjet-assisted dissection.

The median amplitude levels after complete mesorectal dissection demonstrated a decrease of 0.05 μV (0.5 %) for dissection with scissors, 0.32 μV (3.2 %) for ultracison, 0.51 μV (10.2 %) for monopolar diathermy, and 1.08 μV (63.9 %) compared to the recorded results observed after prior posterior dissection.

All investigated animals demonstrated bilateral positive stimulation results after the initial posterior mesorectal dissection. In animals undergoing mesorectal dissection with scissors, ultracision, and monopolar diathermy, stimulation results remained positive on both pelvic sides throughout the whole surgical procedure. Of animals undergoing LARR with waterjet, one had bilateral positive results at all steps of the operation. In one animal, negative results occurred on the left pelvic side after complete dissection, and in another one, the results became negative on the right pelvic side after rectal resection.

The comparison between all stimulation results after complete mesorectal dissection and after rectal resection demonstrated significantly lower amplitude levels after resection ($p=0.008$) (Fig. 4). Technique-specific severing of the intact pelvic autonomic nerves at the end of the experiments resulted in the absence of increased electromyographic amplitudes during neurostimulation (Fig. 5).

Discussion

Ultracision, monopolar diathermy, scissors, and waterjet are some of the utilized techniques for TME in the surgical

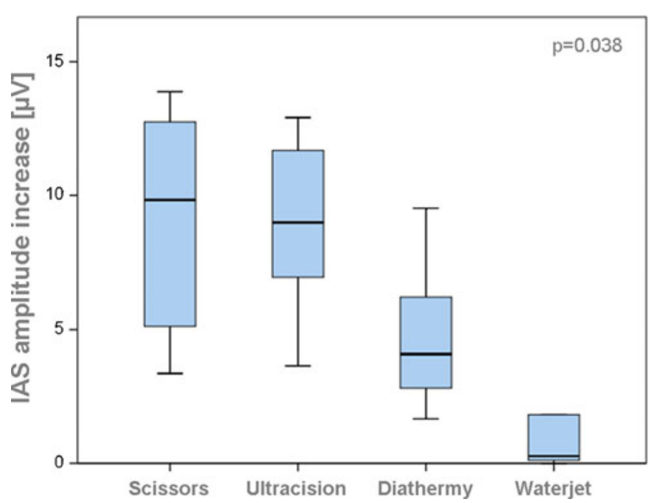


Fig. 3 Comparison between the stimulation-induced electromyographic amplitude increases of the IAS after complete mesorectal dissection with scissors, ultracision, monopolar diathermy, and waterjet (ANOVA)

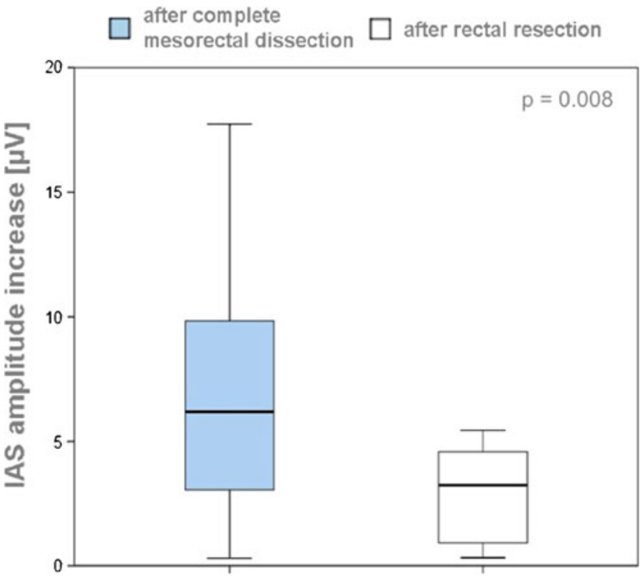


Fig. 4 Comparison of the stimulation-induced IAS electromyographic amplitude increases after complete mesorectal dissection and after rectal resection (Wilcoxon's signed rank test)

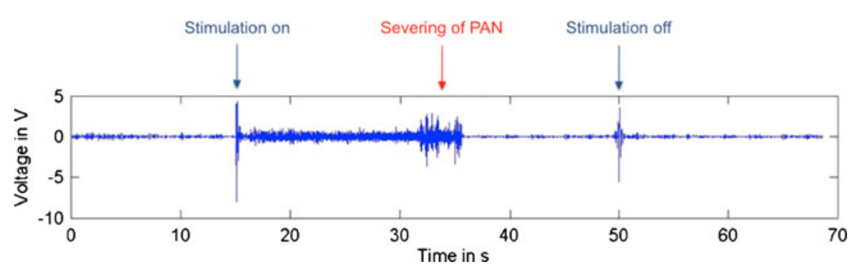
practice. The present study, to the best of the authors' knowledge, is the first aiming to compare the nerve-sparing potential of these different surgical techniques during mesorectal dissection.

Ultracision relies on an acoustic transformation system of piezoelectric elements transforming electrical energy into mechanical energy. The cutting and coagulating effect through mechanical vibration enables protein denaturation by destroying the hydrogen bonds and generates heat at temperatures up to 150 °C in the vibrating tissue. The heat generated by monopolar diathermy may reach up to 400 °C, resulting in increased lateral thermal spread and conduction of energy.[10] In monopolar diathermy, the current is conducted from the active electrode through the tissues to the neutral electrode. Thermal tissue damage far from the plane of dissection was found to be higher in electrosurgery,[11] which may have contributed to the observed decreased IAS electromyographic amplitudes after mesorectal dissection with monopolar diathermy. Carlander et al. compared in an experimental study with 37 anesthetized rats the risk of sciatic nerve impairment for electrosurgery and ultracision based on the evoked electromyographic potential of the biceps femoris.[12] Similar to the results of the present study, dissection with diathermy resulted in lower amplitude increases during neurostimulation. TME performed with dissecting scissors led to electromyographic amplitude decreases comparable to those observed after mesorectal dissection with ultracision (0.5 vs. 3.2 %). Ultracision, monopolar diathermy, and scissors did result in bilateral positive stimulation results throughout the whole surgical procedure, which indicated complete pelvic autonomic nerve preservation. Therefore, all these surgical techniques might have a comparable nerve-sparing potential during mesorectal dissection.

The waterjet technique enables dissection without thermal tissue damage.[13] Data from a clinical trial showed that neurogenic bladder occurred in 10 out of 49 rectal cancer patients after waterjet-assisted TME. Three of these patients developed persistent neurogenic bladder.[9] Another study focused on urodynamic outcome and could not reliably exclude a partial neurogenic functional disorder in 3 of 25 patients. No patient had a complete neurogenic bladder at a median follow-up of 5 months.[14] A more recent retrospective study with 105 patients demonstrated that postoperative neurogenic bladder with requirement of catheterization occurred in 1.9 %.[15] These clinical studies concluded that mesorectal dissection with waterjet enabled optimal radicality and pelvic autonomic nerve preservation.

Nevertheless, in the present study, the stimulation-induced amplitude increases after waterjet dissection were lower than after assisted dissection with scissors, ultracision, and monopolar diathermy. Moreover, only waterjet dissection was combined with unilateral negative stimulation results, indicating that damage to the fine network of autonomic nerve fibers (diameters ranging from <150 to >300 µm)[16] did occur, even though pelvic autonomic nerve preservation was macroscopically assessed as complete. As suggested by previous studies, which used waterjet dissection for TME in rectal cancer patients,[9,14] the applied pressure in the current study was set to 50 bar. Andratschke et al. concluded in a recent investigation that neither the size of the jet (120 or 150 µm) nor pressures of 40 to 60 or 80 bar play a significant role for nerve function.[17] The authors stated that nerve damage was mainly caused by the preparation technique, especially by the variable angles of incidence (tangential vs. vertical) to the direction of the nerves, and the application time. However, Tschan et al. applied

Fig. 5 Sharp severing of intact pelvic autonomic nerves at the end of the experiment resulted in the absence of increased electromyographic amplitudes of the IAS during pelvic splanchnic nerve stimulation. *PAN* pelvic autonomic nerves



waterjet dissection with even lower pressures ranging from 20 to 80 bar on the sciatic nerve of rats and reported that functional damage was observed at 40 bar or higher.[18] From that point of view, the results of the present study and the study of Andratschke et al. were observed under used pressures above the apparently save threshold of 30 bar. Our data, therefore, underline that pressures used so far in waterjet surgery of the mesorectum[9,14] may be too high and risk damage to nerve structures.

Furthermore, it is conceivable that the waterjet volume flow affects nerve function as it disperses the endoneurium, which makes the nervous tissue appear to be bloated. This is in accordance with the results of Wanner et al. who investigated waterjet dissection in fatty tissue and observed a water uptake of the cut tissue.[19] Whether direct pressure damage, angle of incidence, reactive microcirculatory disturbances, or water uptake of tissue contributed to the observed lower IAS electromyographic amplitudes and negative stimulation results cannot be conclusively answered by this pilot study.

Overall, the present data of all investigated animals demonstrated that the positive stimulation results after rectal resection were lower in their amplitude increases than the results after mesorectal dissection. The reason for this could be the performed circumferential rectal myotomy disrupting the intramural intrinsic IAS innervation.[20] The absence of increased electromyographic amplitudes in one animal during rectal myotomy indicated that partial nerve damage did occur. It is conceivable that manual pulling of the rectum for resection may lead to the displacement of the autonomic nerves from the pelvic sidewall with subsequent increased risk of nerve damage during resection.[21] Direct trauma to the IAS could be excluded as rectal resection was performed at an adequate distance.

The study is limited to the exploration of mesorectal dissection with scissors, ultracision, monopolar diathermy, and waterjet. It lacks randomization and investigated a small group of animals. Further studies should be performed with larger numbers of animals and include mesorectal dissection with bipolar scissors, ligasure, laparoscopic, and robotic surgical techniques as well as waterjet pressures below 50 bar.

Conclusion

The presented data demonstrated that the neurostimulation-induced increases of the IAS electromyographic signal during mesorectal dissection differed among all investigated surgical techniques. Scissors, ultracision, and monopolar diathermy could be considered as equivalent with regard to the observed positive stimulation results. According to this experimental setup, they might be more favorable than waterjet. The study reported first hints on the nerve-sparing potential of different surgical techniques for mesorectal dissection. Although the current results are encouraging, controlled randomized studies with larger numbers of animals and studies dealing with the clinical situation are required before definite conclusions can be drawn.

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