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Instruments and Techniques

Thermal Conduction, Compression, and Electrical Current–An Evaluation of Major Parameters of Electrosurgical Vessel Sealing in a Porcine In Vitro Model

Christian W. Wallwiener, Cand Med*, Taufiek K. Rajab, MD, Wolfgang Zubke, MD, Keith B. Isaacson, MD, Markus Enderle, MD, Daniel Schäller, Dipl.-Ing, and Markus Wallwiener, MD

From the University Hospital rechts der Isar, Technical University of Munich, Munich, Germany (Cand Med C. Wallwiener); Universitaetsfrauenklinik Hospital, University of Tuebingen, Tuebingen, Germany (Drs. Rajab, Zubke, and M. Wallwiener); Minimally Invasive Gynecologic Surgery and Infertility, Newton Wellesley Hospital, Harvard Medical School, Boston, Massachusetts (Dr. Isaacson); and Research Institute, ERBE Electromedicine, Tuebingen, Germany (Dr. Enderle and Dipl-Ing Schäller).

ABSTRACT Bipolar vessel sealing is pivotal in laparoscopic hemostasis. However, major coaptive desiccation parameters have yet to be investigated in detail. The current investigation aims to study the impact of compressive pressure, thermal conduction, and electrical current effects on seal quality in a randomized, controlled experimental trial in an in vitro porcine model of vessel sealing. A total of 106 porcine vessels were sealed with either bipolar current or thermal conduction. Compressive pressure on the sealing site and maximum temperature were varied and monitored. Additionally, the longitudinal vessel tension was measured. The burst pressure of the resulting seal was determined as an indicator of seal quality. In bipolar coaptation, seal quality depends on the compressive pressure applied to the coagulation site in both arteries and veins. The optimal pressure interval was around 270mN/mm^2 for arteries and 200mN/mm^2 for veins. Deviation from these optimal pressures towards low and high extremes led to significantly fewer successful seals. We also found that both maximum coaptation temperature and vessel shrinking correlated with the seal quality. This correlation was reciprocal in arteries and veins. Thermal conduction alone was less successful than sealing by bipolar current. Therefore, compressive pressure during coaptation determines the seal quality. Upper and lower pressure boundaries for safe coaptation exist for both arteries and veins. Vessel sealing by thermal conduction without electrical current effects is possible but represents a less effective method for coaptation. These findings have implications for the rational design of new electrosurgical instruments. Journal of Minimally Invasive Gynecology (2008) 15, 605–610 © 2008 AAGL. All rights reserved.

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Laparoscopy was transformed from a diagnostic tool into a means for therapy by Kurt Semm, who performed the first laparoscopic appendectomy in 1983 [1]. Since then, laparoscopic operations have become routine. The clinical benefits of laparoscopy over laparotomy include shorter hospitalization, reduced pain, less blood loss, and decreased extent of

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Corresponding author: Cand. Med. Christian W. Wallwiener, University Hospital rechts der Isar, Technical University of Munich, Ismaninger Str. 22, 81675 München, Germany.
E-mail: cwallwiener@gmx.net

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adhesions [2]. This success has depended on continuous improvements in technology, with the introduction of electrosurgical vessel sealing probably being the most fundamental [3–5]. For many applications it is more efficient than alternative methods for ligation (e.g., suture, hemoclips, ultrasonic coagulation shears) [6,7].

Specific biothermomechanical parameters are key to the success of electrosurgical vessel sealing. In particular, the applied temperature and compressive pressure (CP) are thought to be pivotal factors [8,9]. In addition, tissue shrinking occurs during the sealing process. Very little detailed analyses of these parameters are available today. Moreover, it is not clear whether or not the applied high-frequency electrical current acts independently from the resulting increase in temperature.

The current study evaluates the influence of CP and temperature on electrosurgical vessel sealing in an in vitro setup. The relationship between achieving a good quality seal and mechanical vessel contraction was investigated. Finally, the effects of heat generated by purely thermal conduction as opposed to the high-frequency effects induced by electrical current are shown.

Methods

The study protocol was approved by our university research programs council and the European Academy of the European Society of Gynecological Endoscopy.

An experimental setup (Fig. 2) was designed that allowed standardized coaptation using either bipolar electrical current or purely thermal conduction without electrical current. The vertical CP during coaptation could be altered independently. All experiments were performed in an incubator at 36°C and 90% humidity to mimic physiologic conditions. For the sealing process, 2 pairs of jaws with rounded edges, simple surface geometry, and low thermal capacity were purposely built to include temperature probes (Nickel-Chrome-Elements Type K; Reckmann Measurement Technology, Hagen, Germany) 0.1 mm beneath the surface. One pair of jaws, made from polished stainless steel, was connected to a bipolar generator (Vio 300D; ERBE Electromedicine, Tuebingen, Germany). The generator was used with the clinically established pulsed biclamp mode (automatically modulated sine-wave signal form with a fundamental frequency of 350 kHz as previously described [10] and comparable with Valleylab's LigaSure [7] [Boulder, CO] and Gyrus' PlasmaKinetic [11] pulsed bipolar systems [Maple Grove, MN]) and autostop. The other pair of jaws was made from a silver-silicon compound (Wielandin GmbH, Pforzheim, Germany) to include a platinum microheater (Heraeus Sensor-Nite GmbH, Kleinostheim, Germany) for vessel sealing by purely thermal conduction. Here the coaptation process was stopped after all visual and acoustic signs of vaporization had ceased. Both pairs of jaws were built into a pressure device capable of impinging the vessel with a defined vertical CP. The jaws had a width of 6 mm, which defined the area of coagulation. The CP was applied through a metal bellow (Hydra-Metallbalg; Witzenmann GmbH, Pforzheim, Germany) filled with precision-controlled compressed air. A resistance strain gauge (ME-Messsystem GmbH, Henningsdorf, Germany) served as a force sensor to detect changes as small as 0.01 N.

A total of 106 porcine vessels (58 renal, femoral, and carotid arteries with a mean caliber of 5.1 mm [SD 1.3, CI 0.3] and 48 veins with a mean caliber of 4.8 mm [SD 1.5, CI 0.4) were harvested by the same investigator from 5 female Swabian-Hall pigs. The harvested vessels were randomized for the experiments. In all, 59 vessels were used to investigate the correlation between CP during bipolar electrocoaptation and seal quality (Table 1). The remaining 47 vessels were used to study vessel sealing by purely thermal conduction (Table 1). All vessels were carefully dissected from their connective tissues in situ and thoroughly flushed with a solution designed to protect transplants during transport, to remove any residual blood. The vessels then remained in a solution bath.

Immediately before sealing, the respective vessel was warmed in a 36°C saline bath and attached to the experimental apparatus by connectors (Luer-Lock; Volzer

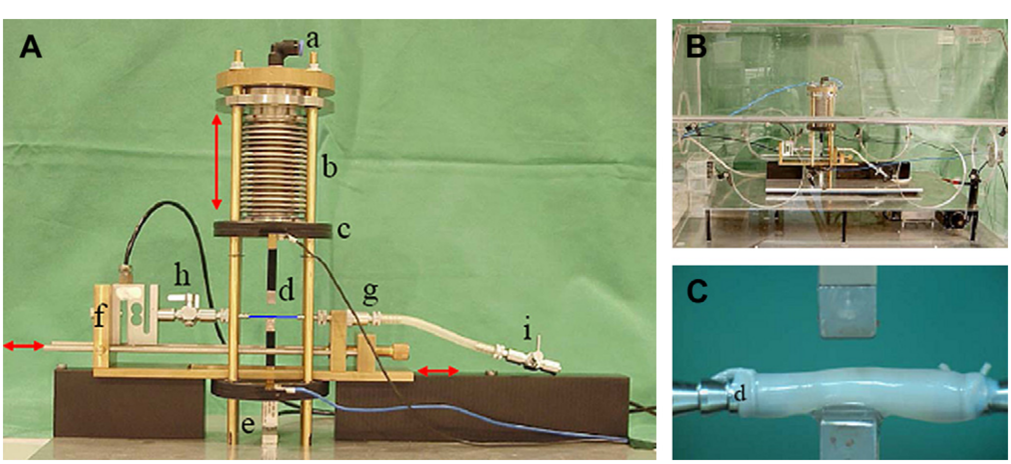

Fig. 1. Experimental setup with application of CP (A) and in incubator (B). Vessel in coaptation device (C).