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Effect of collagen and elastin content on the burst pressure of human blood vessel seals formed with a bipolar tissue sealing system

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ABSTRACT

Background: Bipolar devices are routinely used to seal blood vessels instead of sutures and clips. Recent work examining the impact of vascular proteins on bipolar seal performance found that collagen and elastin (CE) content within porcine arteries was a significant predictor of a vessel's burst pressure (VBPr). This study examined seal performance across a range of human blood vessels to investigate whether a similar relationship existed. In addition, we compared VBPr and CE content between porcine and human blood vessels. Our primary hypothesis is that higher collagen-to-elastin ratio will predict higher VBPr in human vasculature.

Methods: In six cadavers, 185 blood vessels from nine anatomic locations were sealed using a bipolar electrosurgical system. A linear mixed model framework was used to evaluate the impact of vessel diameter and CE content on VBPr.

Results: The effect of CE ratio on VBPr is modified by vessel size, with CE ratio having larger influence on VBPr in smaller diameter vessels. Seal burst pressure of vessels 2–5 mm in diameter was significantly associated with their CE content. Comparison of average VBPr between species revealed porcine carotid and iliac arteries (440–670 mmHg) to be the best vessel types for predicting the seal strength of most human blood vessels (420–570 mmHg) examined.

Conclusions: CE content significantly modified the seal strength of small to medium sized blood vessels but had limited impact on vessels >5 mm.

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1. Introduction

Bipolar electrosurgical devices are routinely used in open and laparoscopic surgical procedures to provide hemostasis to dissected tissue structures and blood vessels. Multiple

evaluations have been performed to assess the seal strength, quantified through burst pressure, of different bipolar tissue sealing systems; however, there are significant deviations in reported measurements [1–5]. In general, porcine arteries and veins are used as a model for human blood vessels due to their

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anatomic and physiological similarities. Some variation in the reported seal strength arises from the test method [6] or types of bipolar devices used, but when these factors are controlled, considerable differences remain. Further examination of published data found that the type of porcine blood vessel tested to evaluate seal strength differed by study and in some cases within a study.

Blood vessels from different anatomic locations have varying viscoelastic properties depending on their functional role [7,8]. The mechanical properties of blood vessels may be further influenced by genetics, age, lifestyle, and disease state [9–13]. Two primary components of vessel walls that have an important effect on the elasticity of blood vessels are elastin and collagen [14–16]. Prior work by this group examined the role of these structural proteins in porcine blood vessels and their influence on bipolar vessel seal strength [17]. A significant association between the ratio of collagen and elastin content (CE ratio) and seal strength as defined by vessel burst pressure (VBPr) was found when controlling for vessel diameter; specifically vessels with larger CE ratios demonstrated greater seal strength. Conversely, no association was detected between vessel diameter and seal strength when controlling for CE ratio.

Given the limited published data measuring the seal strength of human blood vessels [18] and the lack of data comparing seal strength measurements between human and porcine blood vessels, it remains unclear whether porcine arteries are the best model for predicting the strength of human vessel seals. The objective of this investigation was to determine the relationship between human cadaver VBPr and CE ratio and evaluate the suitability of porcine arteries as a model for human blood vessels. Our primary hypothesis was in human cadaver blood vessels, higher CE ratio is associated with increased VBPr and the strength of this relationship depends on vessel size. In keeping with Barlow's formula ($VBPr = 2 \times \text{Strength} \times \text{Wall Thickness/Diameter}$), we further hypothesized that the ratio of vessel wall thickness-to-diameter (WTD ratio) may also contribute to VBPr variability and impact the relationship between CE ratio and VBPr. Finally, we qualitatively evaluated the suitability of various porcine arteries as a model for predicting the bipolar seal strength of human vessels by comparing the average VBPr of human cadaver blood vessels observed in this study to those observed in prior studies of porcine arteries [17].

2. Methods

2.1. Human vessel collection and analysis of VBPr

Our research was performed on six cadaveric subjects with donor consent obtained through Science Care (Phoenix, AZ). One female and five male subjects ranging in age (40–61 y), body mass index (BMI; 14–28), smoking status (yes, 2; no, 4), and who expired from various causes were evaluated. Cadavers were stored for postmortem at 4°C until the time of dissection. Vessel harvesting from cadavers was performed within 3–11 d after death. Cadavers were dissected and nine types of vessels (carotid artery, deep femoral artery, femoral artery, iliac artery, inferior mesenteric artery, pulmonary

artery, pulmonary vein, renal artery, and splenic artery) were evaluated. Bipolar tissue sealing systems are regularly used to seal the inferior mesenteric artery, splenic artery, and pulmonary arteries and veins in surgery. Although clinical sealing of carotid, femoral, renal, and iliac arteries would rarely occur, these vessels were included to compare with previously published data on the porcine vessel testing model and provide a range of vessel diameters and CE ratios to further elucidate the relationship between size, CE, and VBPr.

Vessels segments were carefully dissected from surrounding connective and fatty tissue and their diameters were measured using white cotton string and a disposable ruler. Following diameter measurement, vessels were sealed *in situ* using a bipolar vessel-sealing system (LigaSure Atlas; Covidien, Boulder, CO). All seals were made with the standard two-bar setting on the ForceTriad generator system (Covidien) and one seal cycle per vessel was performed. After the vessel was sealed, the knife blade incorporated within the LigaSure Atlas device was activated creating two sealed segments. Before the dissection, one side of the seal was randomly selected for either burst test and collagen and elastin (CE) quantification or histologic examination. Sealed vessel segments including at least a 1-cm margin from the sealed tissue were removed from the cadaver for burst testing and histologic processing.

Sealed VBPr was determined using previously described methods [2,17]. Briefly, a blunt tip cannula was inserted into the open vessel lumen and an iris was clamped around the vessel to contain infused water within the vessel lumen. Deionized water was injected into the vessel at a rate of 100 mL/min until the seal burst. Burst pressure was recorded using a pressure meter (Fluke; Everett, WA). The maximum VBPr was recorded for each vessel tested.

2.2. Histologic analysis of vessel structure and CE content

Selected sealed vessel segments not subjected to burst testing were used for histologic analysis. After excision from the cadaver, the vessel samples were placed in 10% phosphate-buffered formalin for a minimum of 48 h before undergoing standard histologic processing. Samples were shipped to an independent histology laboratory (Premier Laboratory, LLC Boulder, CO) for sectioning, staining, and imaging. Histologic structure stains, hematoxylin and eosin and a modified Mason's trichrome stain [19], were used to qualitatively examine the seal area, vessel structure, and CE content. Vessel wall thickness measurements were performed on modified Mason's trichrome-stained samples.

2.3. Quantification of vessel CE content

After burst testing, vessel samples were placed into cryo tubes and stored in dry ice until they could be transferred to a –80°C freezer. Tissue sections were dissected from tissue adjacent to the seal. Care was taken during dissection to ensure all vessel layers were included in samples. Thawed tissue sections were weighed and transferred to microcentrifuge tubes for CE quantification. Total collagen was determined from tissue hydroxyproline content using the method described in

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