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Quantification of skin wound tension using a newly designed wound tensiometer

Erstellung von Wundspannungsgrenzwerten mit einem neu entwickelten Wundtensiometer

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ABSTRACT

Objective To (i) quantitatively measure wound tension in experimental skin wounds using a newly developed wound tensiometer and (ii) establish reference values for primary skin wound closure in medium- and large-breed dogs.

Study design Experimental cadaveric study.

Animal population Nineteen dogs of medium to large breeds (BW 20 to 40 kg).

Methods Elliptical skin wounds of different sizes were created on the chest and abdomen. The wounds were gradually enlarged. Experienced surgeons (ECVS diplomates or professors of small animal surgery) and inexperienced surgeons (1st year after graduation) independently assessed wound tension through manual manipulation and determined whether the wound could be closed without tension-relieving measures. In addition, wound tension was objectively quantified using a newly developed wound tensiometer.

Results The upper threshold for wound tension at which direct appositional wound closure was recommended by the experienced surgeons was 5.4 N, and the median minimal tension without recommendations for closure was 6.0 N. The data also demonstrate that wound tension and wound size do not necessarily correlate, and inexperienced surgeons need to develop a feel for wound tension.

Conclusion The intraoperative use of the wound tensiometer, in combination with established cut-off values, might facilitate decision-making regarding primary wound closure.

Clinical relevance The findings of this study provide evidence for the applicability of a wound tensiometer in guiding inexperienced surgeons in their choice of the skin wound closure method.

ZUSAMMENFASSUNG

Ziel (i) Report über die quantitative Messung der Wundspannung bei experimentellen Hautwunden unter Verwendung eines neu entwickelten Wundtensiometers und (ii) Entwicklung

von Referenzwerten für den primären Hautwundverschluss bei Hunden mittlerer und großer Rassen.

Studienaufbau Experimentelle Studie an Kadavern.

Tierpopulation Neunzehn Hunde mittelgroßer bis großer Rassen (KG 20 bis 40 kg).

Methoden Es wurden elliptische Hautwunden unterschiedlicher Größe an den Brust- und Bauchwänden der Hunde erzeugt. Erfahrene Chirurgen (ECVS-Diplomates oder Professoren für Kleintierchirurgie) sowie unerfahrene Chirurgen (im ersten Jahr nach Studienabschluss) beurteilten unabhängig voneinander die Wundspannung durch manuelle Manipulation und wurden gebeten zu entscheiden, ob die Wunde durch einen einfachen Wundverschluss ohne Verwendung von spannungsentlastenden Maßnahmen verschlossen werden sollte oder nicht. Im Vergleich dazu wurde die Wundspannung objektiv mit einem neu entwickelten Wundtensiometer quantifiziert.

Ergebnisse Der obere Grenzwert für die Hautwundspannung, bei dem ein direkter appositioneller Wundverschluss von den erfahrenen Chirurgen empfohlen wurde, lag bei 5,4 N und der Median der minimalen Spannung ohne Empfehlungen zum einfachen Wundverschluss bei 6,0 N. Zudem zeigen die Ergebnisse, dass Wundspannung und Wundgröße nicht unbedingt korrelieren und dass unerfahrene Chirurgen ein Gefühl für die Wundspannung entwickeln müssen.

Schlussfolgerung In Zukunft könnte die intraoperative Verwendung des Wundtensiometers in Kombination mit den ermittelten Cut-off-Werten die Entscheidungsfindung hinsichtlich des primären Wundverschlusses erleichtern.

Klinische Relevanz Die Ergebnisse dieser Studie liefern Belege für die Anwendbarkeit eines Wundtensiometers zur Unterstützung unerfahrener Chirurgen bei der Wahl der Methode zum Verschluss von Hautwunden.

Introduction

Halsted's 7 principles of surgery have been established for over 120 years [1], but objective data on wound tension are limited. Subjective assessment of wound tension by experienced surgeons remains the gold standard in small animal surgery, as there are no established methods for objective quantification or reference values for wound tension to guide the surgeon's decision whether to close the wound primarily without any tension-relieving procedures [2]. The detrimental impact of high wound tension on wound healing has led to the development of a variety of tension relieving techniques [3]. Although there is a negative correlation between wound tension and microcirculation in the skin adjacent to the suture line [4] no guidelines exist for determining the maximum safe tension for primary wound closure in dogs or cats.

Human studies have shown a wide range of acceptable wound tensions, making it difficult to establish practical reference ranges [5, 6]. Additionally, there is a lack of reliable and practical devices for objective quantification of wound tension, especially for routine clinical use [7]. In consequence, every inexperienced surgeon must go through a learning curve aimed at acquiring the manual skill to reliably assess wound tension during surgery and gain the necessary experience if a wound is suitable for primary closure based on subjective assessment of wound tension. Individual wound assessment gets complicated due to various factors that influence wound properties. These factors encompass various aspects, including the specific location of the wound and anatomical characteristics such as the elasticity of the skin, the quantity of subcutaneous tissue, and the hydration of the skin. Consequently, the individual nature of wound tension may lead to inadequate decision-making when relying solely on subjective evaluation, thus highlighting the need for a more objective approach.

To address these limitations, we developed a wound tensiometer for easy and fast intraoperative measurement of wound tension in dogs. This study aimed to compare the subjective assessment of wound tension between inexperienced and experienced surgeons and to establish thresholds for maximal wound tension in medium- and large-breed dogs. Because many surgeons tend to include wound size in their decision-making process for wound closure [7], we also examined the correlation between wound size and wound tension, hypothesizing that no predictable correlation exists.

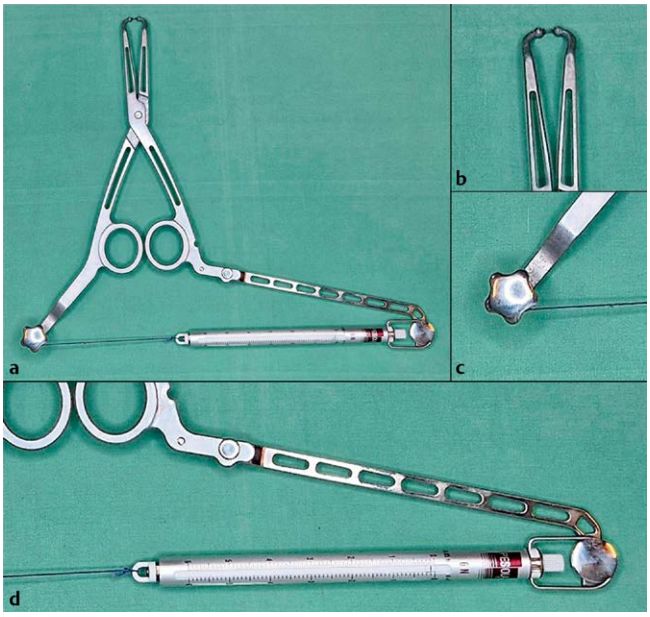
Materials and methods

The tensiometer

The tensiometer used in this study consists of 2 distinct components (▶ **Fig. 1**). First, a commercially available spring scale is employed, along with a specially designed hand instrument made of medical-grade steel, resembling an oversized towel clamp. The spring scale serves to connect the 2 branches of the tensiometer, counteracting the force exerted at the tip of the jaws during temporary wound adaptation. This arrangement reflects the force required to apposition the wound edges, which is equivalent to the measured wound tension. To ensure a secure and reliable grip on the wound edges without slippage, 2 small spheres measuring 1.5 mm in diameter are strategically placed distal to the pointed tips of the instrument (▶ **Fig. 1b**). Additionally, considering the lever action of the tensiometer's branches, the spring scale is adjusted to reflect the true force value at the tip of the instrument. Furthermore, the instrument is designed to be foldable, enabling a reduction in the space required during sterilization. Standard sterilization methods such as steam, gas, or plasma, can be employed for the sterilization process. These sterilization methods have undergone rigorous validation using a variety of instruments, and their efficacy has been presumed based on the specific materials used for the tensiometer.

The process for measuring wound tension involves the following steps (▶ **Fig. 2**):

a. Begin by inserting the tips of the tensiometer into the skin wound edges, positioning them approximately 2 to 3 mm from the skin margins. For optimal results, place the tensiometer at the widest point of the wound, where the maximum



▶ **Fig. 1 The wound tensiometer**. **a** The complete wound tensiometer. **b** Close-up view of the tip, showing 2 adjustment spheres for limiting the insertion depth of the tip into the skin. **c** The tension screw for applying tension to the device. **d** Foldable side arm designed to hold the spring scale. Source: F. Lackmann.

▶ **Abb. 1 Das Wundtensiometer**. **a** Das vollständige Wundtensiometer. **b** Vergrößerte Ansicht des vorderen Endes mit zwei Kugeln zur Begrenzung der Eindringtiefe der Spitze in die Haut. **c** Die Spannschraube zur Anwendung der Spannung am Gerät. **d** Klappbarer Seitenarm zur Befestigung der Federskala. Quelle: F. Lackmann.

tension is anticipated. Partially close the skin wound, ensuring that the spring scale is already taut.

b. Gradually increase the force applied to the spring scale by rotating the tension dial clockwise (indicated by the red arrow). This action progressively brings the skin wound closer together.
c. Continue shortening of the suture by turning the tension screw until the wound edges are appropriately aligned.
d. Obtain the final measurement of wound tension (indicated by the red arrow) in Newton (N).

Wound tension assessment

An initial experimental setup for ex vivo quantification of skin wound tension involved 8 medium to large breed dogs (BW 20 to 40 kg), including 1 Labrador Retriever, 1 Bernese Mountain Dog, 1 German Shepherd Dog, 1 Golden Retriever, 1 Boxer and 3 mixed breeds with normal body condition score (BCS). These dogs were euthanized for reasons unrelated to the study. The cadavers were stored at –20 °C and double-sealed in plastic bags to prevent desiccation, with storage durations varying up to 6 months. The cadavers were free of visible skin diseases and skin wounds on the trunk. For final processing, the bodies were thawed at room temperature for 48 hours.

In each of the 8 dogs, a total of 4 full-thickness skin wounds were randomly created, with 2 located in the lateral thoracic region and 2 in the lateral abdominal region (▶ **Fig. 3**). The wounds were generated by resecting elliptical skin areas of varying sizes, ranging from 4 × 10 cm to 15 × 25 cm (width x length). The longitudinal axis of the wound was aligned parallel to the tension lines, as reported by Deroy et al. [8]. The selection of random dimensions aimed to achieve a heterogeneous distribution of resulting wound sizes. Following the immediate creation of the wounds, 5 experienced surgeons (all ECVS diplomates and/or professors of small animal surgery) and 5 inexperienced surgeons assessed wound tension by palpation. They were blinded to any quantification of wound tension using the tensiometer. After evaluation, all surgeons were asked to assess the possibility of primary wound closure without any tension-relieving procedures. Subsequently, wound tension was objectively quantified using the tensiometer by averaging 3 consecutive measurements. Care was taken to ensure that no manipulation other than of the wound edges occurred between the subjective assessment by the surgeon and the subsequent objective quantification of the skin wound.

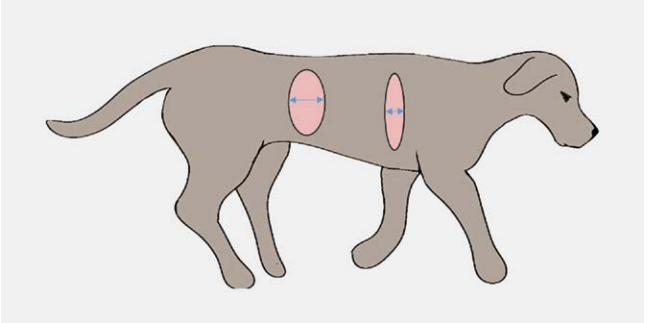
The second experimental setup aimed to replicate wound tension and associated wound size as realistically as possible. This setup exclusively utilized cadavers within 1 hour post-mortem. Eleven cadavers of medium to large breed dogs (BW 20 to 40 kg) were included, comprising 1 Labrador retriever, 1 Boxer, 2 Australian shepherds, 2 German shepherds, 1 Munsterlander, 1 Hanover hound, 1 English Bulldog and 2 mixed breeds with normal BCS. These dogs had been euthanized for reasons unrelated to the study, with no apparent or reported involvement of their integument. To prevent interference between adjacent wounds, only 1 elliptical full-thickness skin wound was created per side of the body, 1 in the thoracic and 1 in the abdominal region (▶ **Fig. 4**). Similar to the first experiment, the wounds were aligned according to the skin tension lines reported by Deroy et al. [8]. Initially, the wounds measured 5 × 10 cm (width x length). After preparing the skin wounds, a randomly selected experienced surgeon evaluated wound tension independently by palpation and determined whether the wound could be closed directly by apposition without employing tension-relieving procedures. The quantification of wound tension followed the procedure described in Experiment 1, with the surgeon blinded to both the reading and the exact size of the skin wound. Subsequently, the wound size was increased by 1 centimetre, and the surgeon conducted a subjective evaluation of the tension, followed by quantification of the skin tension and size. The size of the wound was defined as the distance between the wound edges at the widest point of the wound while maintaining a consistent height measurement. This procedure was repeated until the surgeon deemed the wound unsuitable for direct appositional closure, and a final recording of wound tension and wound size was taken.

Data Analysis

Descriptive statistics were conducted using commercial software (MedCalc v. 20.218, MedCalc Software Ltd, Belgium). The normal distribution assumption was assessed using the D'Agostino-Pearson omnibus test. Since the data did not follow a normal distribution, the median with an associated interquartile range of 75 % was

▶ **Fig. 2 Practical application of the tensiometer for measuring skin wound tension. a** The tips of the tensiometer are secured onto the edges of the skin wound, approximately 2 to 3 mm away from the skin margins. Typically, the tensiometer is positioned at the widest point of the wound where maximum tension is anticipated. Partially close the skin wound and ensure that the spring scale is already under tension. **b** Rotate the tension dial clockwise (indicated by the red arrow) to increase the force exerted on the spring scale, gradually bringing the skin wound edges closer together. **c** Continue shortening the suture by adjusting the tension dial until the wound edges are in proper alignment. **d** Take the measurement (indicated by the red arrow) of the final wound tension in Newton. Source: F. Lackmann.

▶ **Abb. 2 Praktische Anwendung des Tensiometers zur Messung der Hautwundspannung. a** Die Spitzen des Tensiometers werden in die Wundränder der Haut eingehakt, etwa 2 bis 3 mm von den Hauträndern entfernt. In der Regel wird das Tensiometer an der breitesten Stelle der Wunde platziert, wo die Wundspannung voraussichtlich am höchsten ist. Schließen Sie die Hautwunde teilweise und stellen Sie sicher, dass die Federskala bereits unter Spannung steht. **b** Drehen Sie das Spannrad im Uhrzeigersinn (roter Pfeil), um die Kraft auf die Federskala zu erhöhen und die Hautwunde allmählich zu schließen. **c** Fahren Sie fort, die Naht zu verkürzen, indem Sie das Spannrad drehen, bis die Wundränder aneinander liegen. **d** Lesen Sie die endgültige Wundspannung in Newton ab (siehe Pfeil). Quelle: F. Lackmann.



▶ **Fig. 3 Schematic representation of randomly created full-thickness skin wounds along the thoracic and abdominal body wall.** Wound size (indicated by blue arrows) was measured as the length between the wound edges at the widest point of the wound, perpendicular to the longitudinal axis of the wound. Two wounds were created on each side of the body. Source: F. Lackmann.

▶ **Abb. 3 Schematische Darstellung der nach dem Zufallsprinzip angelegten Hautwunden entlang der thorakalen und abdominalen Körperwand.** Die Wundgröße (durch blaue Pfeile gekennzeichnet) wurde als die Länge zwischen den Wundrändern an der breitesten Stelle der Wunde gemessen, senkrecht zur Längsachse der Wunde. Es wurden jeweils 2 Wunden pro Körperseite angelegt. Quelle: F. Lackmann.

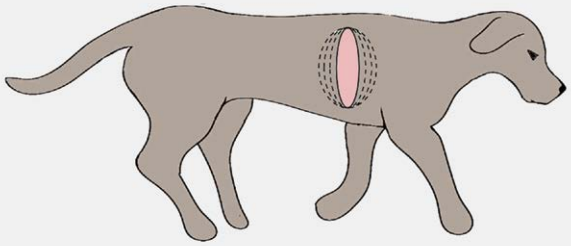
reported. Group-wise comparisons were performed using the Mann-Whitney U Test for unpaired data and the Wilcoxon test for paired data. Correlation analysis was conducted using Spearman's rank correlation coefficient. A significance level of $\alpha \leq 0.05$ was used for all tests.

Results

The repeatability of the tensiometer results was high, with a maximum deviation during the 3 consecutive measurements of 0.2 N. The accuracy of the tensiometer was verified on a test stand with calibrated weights. A 500 g weight was attached to the tensiometer and if the spring scale did not read 4.9 N, the spring tension was calibrated to that value.

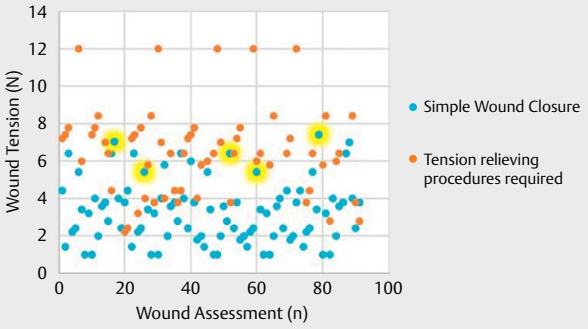
In the initial trial, inexperienced surgeons recommended direct wound apposition up to a maximum wound tension of 6.4 N (IQR: 5.4–7.1) (▶ **Fig. 5**; ▶ **Table 1**). They deemed wound tension to be excessive for direct appositional skin closure when it reached or exceeded 2.8 N (IQR: 2.65–4.35).

On the other hand, experienced surgeons suggested direct wound apposition up to a maximum wound tension of 5.4 N (IQR: 5.15–5.6) (▶ **Fig. 6**; ▶ **Table 1**), while they considered wound tension to be too high for direct appositional skin closure when the



▶ **Fig. 4 Schematic representation of the location and gradual enlargement of the thoracic wounds in trial 2.** The abdominal wound was always positioned on the contralateral body wall, to prevent any mechanical interaction between the 2 wounds. After the randomly selected experienced surgeon subjectively evaluated the skin wound tension and an independent observer quantified the wound size using the tensiometer, approximately 1 cm of skin was removed from both wound edges to enlarge the wound. Subsequent subjective evaluation and objective quantification of wound tension were performed again. This process was repeated until the surgeon subjectively assessed that primary closure of the wound without additional relaxation techniques was unfeasible. Source: F. Lackmann.

▶ **Abb. 4 Schematische Darstellung der Lage und graduellen Vergrößerung der Thoraxwunden in Versuch 2.** Die abdominale Wunde befand sich stets an der kontralateralen Körperwand, um jegliche mechanische Interaktion zwischen den beiden Wunden auszuschließen. Nachdem der zufällig ausgewählte erfahrene Chirurg die Hautwundspannung subjektiv bewertet und ein unabhängiger Beobachter die Wundgröße mit dem Tensiometer quantifiziert hatte, wurde etwa 1 cm Haut von beiden Wundrändern entfernt, um die Wunde zu vergrößern. Anschließend erfolgte erneut eine subjektive Bewertung und objektive Quantifizierung der Wundspannung. Dieser Vorgang wurde wiederholt, bis der Chirurg bei subjektiver Einschätzung den primären Verschluss der Wunde ohne zusätzliche Entspannungstechniken als nicht durchführbar einschätzte. Quelle: F. Lackmann.



▶ **Fig. 5 Relation between the subjective decision on wound closure and the objective quantification of skin wound tension by 5 inexperienced surgeons in 32 randomly created skin wounds (n = 152).** The blue dots represent the wound assessments in which the inexperienced surgeons proposed simple direct skin closure because wound tension was subjectively perceived to be low enough (n = 91). The orange dots represent the wounds where wound tension was perceived to be too high to simply close the wound without using a tension-relieving procedure (n = 61). The yellow highlighted dots represent the maximal wound tension measured for each surgeon for the wounds with simple wound closure. Source: F. Lackmann.

▶ **Abb. 5 Verhältnis zwischen der subjektiven Entscheidung über den Wundverschluss und der objektiven Quantifizierung der Hautwundspannung von 5 unerfahrenen Chirurgen bei 32 zufällig angelegten Hautwunden (n = 152).** Die blauen Punkte stellen die Wundbewertungen dar, bei denen die unerfahrenen Chirurgen einen einfachen direkten Hautverschluss vorschlugen, da die Wundspannung subjektiv als niedrig genug empfunden wurde (n = 91). Die orangefarbenen Punkte stellen die Wunden dar, bei denen die Wundspannung als zu hoch empfunden wurde, um die Wunde einfach zu schließen, ohne dass ein spannungsentlastendes Verfahren empfohlen wurde (n = 61). Die gelb markierten Punkte stellen die maximale Wundspannung für jeden Chirurgen dar, bei der ein einfache Wundverschluss empfohlen wurde. Quelle: F. Lackmann.

wound tension was equal to or greater than 6.0 N (IQR: 5.45–6.0). The difference between the lower and upper cut-off values was found to be significant in the inexperienced group ($p = 0.0422$), but not in the experienced surgeons ($p = 0.2528$).

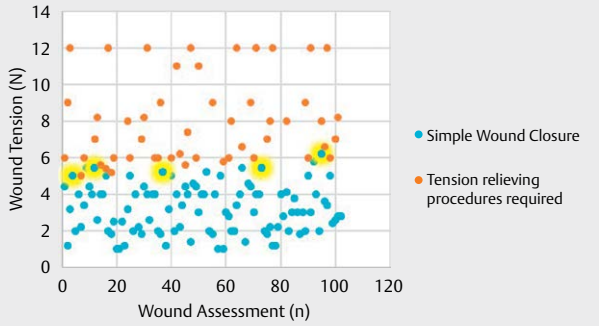
The comparison of data between inexperienced surgeons and experienced surgeons revealed no significant difference in maximum wound tension and minimum wound tension ($p = 0.0670$, $p = 0.0517$). However, considering that the minimum wound tension in the inexperienced surgeon group was lower than the maximum wound tension, the reference range for wound tension guiding the decision of whether or not to close the wound directly was established based on the data from the experienced surgeons only. According to this reference range, direct wound closure would be recommended for wound tensions up to 5.4 N, while it would be rejected for wound tensions exceeding 6.0 N.

When facing gradually enlarged skin wounds in fresh cadavers (experiment 2), experienced surgeons recommended direct wound closure for both thoracic and abdominal wounds up to a wound tension of 4.4 N (IQR: 3.325–4.0) and 4.0 N (IQR: 3.85–4.95), respectively, which was not significantly different from each other

▶ **Table 1** Median maximal and minimal wound tension recordings for experiments 1 and 2.

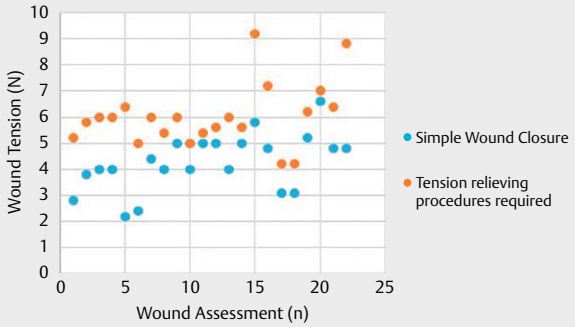
▶ **Tab. 1** Maximale und minimale Wundspannungsmesswerte aus Experiment 1 und 2.

	Max Novice surgeons	Min Novice surgeons	Max Experienced surgeons	Min Experienced surgeons
Experiment 1	6.4	2.8	5.4	6.0
Experiment 2 Thoracic	–	–	4.4	6.0
Experiment 2 Abddominal	–	–	4.0	5.6
Experiment 2 Pooled data	–	–	4.2	6.0



▶ **Fig. 6 Relation between the subjective decision on wound closure and the objective quantification of skin wound tension by 5 experienced surgeons (in 32 randomly created skin wounds n = 152).** The blue dots represent the wound assessments in which the experienced surgeons proposed simple direct skin closure because wound tension was subjectively perceived to be low enough (n = 101). The orange dots represent the wounds where wound tension was perceived to be too high to simply close the wound without using a tension-relieving procedure (n = 51). The yellow highlighted dots represent the maximal wound tension measured for each surgeon for the wounds with simple wound closure. Source: F. Lackmann.

▶ **Abb. 6 Verhältnis zwischen der subjektiven Entscheidung über den Wundverschluss und der objektiven Quantifizierung der Hautwundspannung von 5 erfahrenen Chirurgen bei 32 zufällig angelegten Hautwunden (n = 152).** Die blauen Punkte stellen die Wundbewertungen dar, bei denen die erfahrenen Chirurgen einen einfachen direkten Hautverschluss vorschlugen, weil die Wundspannung subjektiv als niedrig genug empfunden wurde (n = 101). Die orangefarbenen Punkte stellen die Wunden dar, bei denen die Wundspannung als zu hoch empfunden wurde, um die Wunde einfach zu schließen, ohne dass ein spannungsentlastendes Verfahren empfohlen wurde (n = 51). Die gelb markierten Punkte stellen die maximale Wundspannung für jeden Chirurgen dar, bei der ein einfacher Wundverschluss empfohlen wurde. Quelle: F. Lackmann.



▶ **Fig. 7 Relation between the subjective decision on wound closure and objective quantification of skin wound tension in gradually enlarged abdominal and thoracic skin wounds, with constant wound height and gradual widening of the wound, by 5 experienced surgeons in 11 dogs (n = 22).** The blue dots represent the wound assessments with the maximal wound tension in which the experienced surgeons proposed simple direct skin closure because tension was subjectively perceived to be low enough (n = 22). The orange dots represent the wounds where wound tension was perceived to be too high to simply close the wound, without using a tension-relieving procedure (n = 22). Source: F. Lackmann.

▶ **Abb. 7 Verhältnis zwischen der subjektiven Entscheidung über den Wundverschluss und der objektiven Quantifizierung der Hautwundspannung von 5 erfahrenen Chirurgen bei allmählich vergrößerten abdominalen und thorakalen Hautwunden bei konstanter Wundhöhe und gradueller Verbreiterung der Wunde (n = 22) an 11 verschiedenen Hunden.** Die blauen Punkte stellen die Wundbewertungen mit den maximalen Wundspannungen dar, bei denen die erfahrenen Chirurgen einen einfachen direkten Hautverschluss vorschlugen, da die Wundspannung subjektiv als niedrig genug empfunden wurde (n = 22). Die orangefarbenen Punkte stellen die Wunden dar, bei denen die Wundspannung als zu hoch empfunden wurde, um die Wunde einfach zu schließen, ohne dass ein spannungsentlastendes Verfahren angewandt wurde (n = 22). Quelle: F. Lackmann.

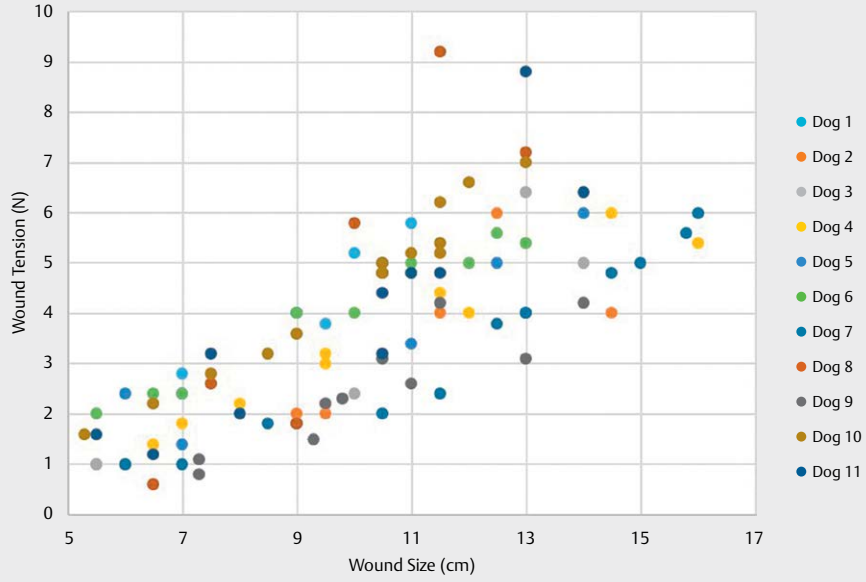
(p = 0.8945). Combining the data, direct wound closure was advised up to a maximal wound tension of 4.2 N (IQR: 3.8–5.0). The minimal wound tension for thoracic and abdominal wounds in which wound apposition was declined was 6.0 N (IQR: 5.55–6.35) and 5.6 N (IQR: 5.1–6.71), respectively, not being significantly different (p = 0.4469). Pooling the data, direct wound closure was not recommended with a minimal wound tension of ≥ 6.0 N (IQR: 5.4–6.4). Thus, the reference range for wound tension associated with direct wound apposition, derived from experiment 2, was determined to be between 4.2 N and 6.0 N (▶ **Fig. 7**; ▶ **Table 1**).

Experiment 2 also showed a strong correlation between wound size and wound tension (Spearman's coefficient of rank correlation = 0,819; CI: 0,741–0,875; p < 0.0001) (▶ **Fig. 8**).

Discussion

The objective quantification of wound tension in this ex vivo study of "simple" skin wound closure revealed 2 main findings: (1) inexperienced surgeons lack the ability to reliably assess wound tension, and (2) experienced surgeons would close skin wounds with tensions ranging from 4.2 to 5.4 N, without employing any tension-relieving technique.

The inexperienced surgeons exhibited an inconsistent perception of wound tension, as indicated by their perceived upper threshold being below the lower threshold. This lack of a reliable sense of wound tension undermines their decision-making process when determining whether to directly close a wound. Factors such as the location and dimensions of the wound may further contribute to this inconsistency. While wound size shows a strong correlation with wound tension and may initially seem like a suitable clinical parameter for estimating wound tension, the significant individual variations in tension among wounds of the same size and location, as observed in this study, demonstrate that size alone is not a reliable substitute for assessing wound tension. Size alone does not consider the individual variations and topographic differences in the elasticity and mobility of the skin and subcutaneous tissue. Therefore, it cannot be used as a substitute for assessing wound tension accurately. Relying primarily on the size of the wound to determine the type of skin closure will inevitably lead to excessive tension in the wound.



▶ **Fig. 8 Correlation of wound size and tension in 11 fresh cadavers with thoracic and abdominal skin wounds with consistent wound height measurements (n = 153)**. There is a strong correlation between wound size and wound tension (rho = 0,819; CI: 0,741–0,875; p < 0.0001), but there is also a high variation in wound tension for the same wound size. Source: F. Lackmann.

▶ **Abb. 8: Korrelation von Wundgröße und Wundspannung bei 11 frischen Kadavern mit thorakalen und abdominalen Hautwunden bei gleichbleibenden Wundhöhen (n = 153).** Es besteht eine starke Korrelation zwischen Wundgröße und Wundspannung (Rho = 0,819; CI: 0,741–0,875; p < 0,0001), aber es besteht ebenso eine große Variation der Wundspannung bei gleicher Wundgröße. Quelle: F. Lackmann.

The factors influencing wound dehiscence are likely multifactorial, and the precise impact of excessive wound tension in this process remains unproven [9]. To date, there is a lack of clinical studies demonstrating a clear correlation between wound tension and wound dehiscence. However, it is well-documented that wound closure under high tension can result in reduced local blood flow and increased scarring [4, 10]. Based on clinical experience, Halsted formulated his principles, which emphasized the importance of preventing excessive wound tension. These principles have been widely adopted by generations of surgeons and are included in relevant surgical textbooks [3].

Traditional assessment of wound tension in surgery involves manual palpation and traction of wound edges [11]. It necessitates manual training and clinical experience to establish a correlation between intraoperative perceived wound tension and postoperative wound healing issues associated with excessive tension during closure. To mitigate this frustrating and potentially harmful learning curve, this study aimed to develop a quantitative assessment of wound tension in a standard clinical setting. The newly designed tensiometer proved to be user-friendly, compatible with standard sterilization procedures, and demonstrated high precision and reliability. Surgeons facing uncertainty regarding wound tension during closure may find value in utilizing this objective measurement method to aid their decision on whether to proceed with simple wound closure. Using the maximum and minimum wound tensions recorded by the experienced surgeons in this study as references, a wound tension of 4.0 to 5.4 N, measured at the widest part of the skin wound, perpendicular to the tension lines, would lead an experienced surgeon to choose simple skin wound apposition. With a cut-off value of 5.6 to 6.0 N for the lower range of documented skin wound tension, at which experienced surgeons rejected simple appositional skin wound closure, a tension between 5.4 and 6.0 N might still be considered “safe” by an experienced surgeon. According to our study results, simple skin wound closure in wounds with tensions exceeding 6 N is not recommended. With that in mind, we have provided an objective means for inexperienced surgeons to acquire expert knowledge in the operating room without the need for physical peer supervision. While descriptions and images can provide inexperienced surgeons with numerous additional guidelines for performing surgical procedures, the assessment of skin wound tension continues to be a task that can only be conducted manually by experienced peers, requiring the physical presence of an experienced surgeon scrubbed in. Again, it is important to note that all our measurements have not yet undergone clinical validation. Instead, they serve as references for inexperienced surgeons until they can develop the same level of reliability as experienced surgeons in assessing skin wound tension.

The relatively large gap between the lower and upper cut-off values (4.0/5.4 to 6.0 N) in the group of experienced surgeons reflects, to some extent, the subjectivity and individuality inherent in their manual estimation of wound tension. However, it is also influenced by the specific experimental setup we employed. A more

extensive evaluation of a larger number of skin wounds with a finer distribution of sizes would likely have resulted in a narrower estimate for the "safe cut-off value" for simple skin wound closure as determined by experienced surgeons. Additionally, including a greater number of surgeons would have increased statistical power and potentially eliminated the type-II error observed when comparing cut-off values between inexperienced and experienced surgeons.

The lower cut-off value observed in the second cadaver study using fresh cadavers, compared to the slightly higher cut-off in the previously frozen cadavers, cannot be solely explained by differences in "wound tension." Wound tension, as a physical phenomenon, remains constant across tissues, but factors such as deformation and stiffness can vary significantly. Given the evident differences in skin elasticity and mobility between fresh and "old" cadavers, the surgeons' subjective perception of "wound tension" may be influenced by these artificial disparities. Therefore, we recommend adhering to the cut-off values derived from fresh cadavers to ensure consistency and accuracy in assessing wound tension.

The main limitation in applying the findings of this study to clinical practice lies in the absence of clinical data regarding measures of skin wound tension, the type of skin closure utilized, and wound healing outcomes. Various factors such as age, breed, underlying diseases, location and origin of the skin wound, medication, patient compliance, and owner compliance are likely to have additional influence [9]. While this study provides valuable guidance for inexperienced surgeons in making more informed decisions regarding skin wound closure using the tensiometer, clinical studies are necessary to assess and establish the relationship between the degree of wound tension and the incidence and nature of postoperative wound healing complications. It is important to note that just because an experienced surgeon determines that a wound can be safely closed without tension-relieving procedures, it does not guarantee that the current wound tension is optimal for uncomplicated wound healing. The provided reference values serve as an indication of what experienced surgeons would recommend, but these cut-off values need to be validated and further refined through the analysis of real clinical cases with appropriate follow-up.

Incorporating the use of the tensiometer in clinical practice can also assist surgeons in performing tension-relieving procedures. By conducting serial measurements of skin wound tension, surgeons can determine if there has been a satisfactory reduction in wound tension. Additionally, this device enables dynamic assessment of wound tension, which is particularly valuable in areas where tension levels are affected by limb positioning.

CONCLUSION FOR PRACTICE

Our study introduces a novel wound tensiometer for veterinary surgery, providing reference values for skin wound tension that experienced surgeons would deem appropriate for straightforward appositional skin closure. This tool serves as a valuable resource for inexperienced surgeons, offering guidance during the process of skin wound closure until they develop the expertise to independently assess wound tension and select the appropriate skin closure method. Incorporating a tensiometer into clinical practice may offer additional advantages for surgeons, particularly in tension-relieving procedures. Further in vivo studies and comparison of dehiscence rates will follow to advance the practical application of the tensiometer.

Conflict of interest

F. L. filed a patent for the tensiometer and the tensiometer will be commercial available. All other authors declare no conflict of interest related to this report.

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