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A novel tension relief technique to aid the primary closure of traumatic equine wounds under excessive tension

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AUTHOR CONTRIBUTIONS

Francesco Comino, assistant surgeon, analysed the data and prepared the manuscript. Patrick J. Pollock and Ian Fulton primary surgeons and contributed to the manuscript. Charlotte Hewitt-Dedman assistant surgeon and help in the data analysis. Ian Handel analysed the data and contributed to the manuscript. Dylan Gorvy, primary surgeon, developed the idea for the technique, analysed the data and contributed to manuscript preparation. All authors approved the final version.

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CONFLICT OF INTEREST

The authors declare no conflicts of interest related to this report.

ETHICAL ANIMAL RESEARCH

Research ethics committee oversight not required by this journal: retrospective analysis of clinical data.

INFORMED CONSENT

Explicit owners informed consent for the inclusion of animals in this study was not stated ~~or not applicabl~~e.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request: Open sharing exemption granted by editor for this descriptive retrospective clinical report.

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KEYWORDS: Horse,Wound,Primary closure,Convalescence

Background: To achieve an excellent functional and cosmetic result, prim~~a~~ry closure is preferred over leaving wounds to heal by secondary intention. However, traumatic wounds are often under excessive tension during wound closure and incorrect suture technique can compromise microcirculation, leading to skin necrosis and impaired wound healing.

Objective: To describe an inexpensive and effective tension relief technique that helps the successful primary closure of a variety of equine wounds at high risk of dehiscence.

Study design: Retrospective case series.

Methods: All wounds that were managed with the Tension Tile System (TTS) at four Equine Hospitals between March 2017 and May 2021 were evaluated. The wounds were classified according to various criteria including anatomical location, time elapsed prior to surgery, depth of wound, and post-surgical use of immobilisation. Outcome criteria was based on the success of primary intention healing. The duration of convalescence (weeks) after surgery was also recorded.

Results: During the study period, the TTS was used in 191/860 (22%) wounds repaired under general anaesthesia or standing sedation. Overall, primary intention healing (Group A) was achieved in 132 ~~out~~ of 191 cases (69%, CI 62%-75%), with partial dehiscence (Group B) in a further 30/191 cases (16%, CI 11%-22%). Severe dehiscence (Group C) was recorded in 29/191 cases (15%, CI 11%-21%). The median convalescence time was 4 weeks (Range 3-15, IQR 4-6) in Group A.

Main limitations: Retrospective nature of the study and subjective outcome assessment. The technique was applied to wounds under significant tension; however, this was based on a subjective assessment by the surgeons involved.

Conclusions: The Tension Tile System is an economical and effective technique for challenging equine wounds under tension, in a variety of anatomical locations.

1.INTRODUCTION

In order to achieve an excellent functional and cosmetic result, every attempt should be made to close wounds primarily. Second-intention healing is a protracted process, and at a high risk of complications such as chronic inflammation, the development of exuberant granulation tissue, poor wound contraction and slow epithelialization. This is of particular relevance to the distal limb.[1] In addition, the thin epithelial cell layer that accompanies second intention healing makes these wounds far more susceptible to trauma compared to normal skin, particularly in areas of high mobility.[2] However, primary intention healing can be challenging to achieve and in a large retrospective study, complete primary healing after closure of traumatic wounds was successful in only 26% of horses and 41% of ponies.[3]

Traumatic equine wounds are often under excessive tension either during or following closure. This can result in circulatory compromise, skin necrosis, and wound dehiscence. The tension on the skin margins can be defined as static or dynamic. Static tension refers to the tension lines of the skin at rest and it is important to consider during closure or debridement. This is especially relevant for wounds with a skin defect or that have undergone significant contraction prior to closure. Dynamic tension is generated during movement and is particularly important for wounds over or near an area of high mobility or those oriented perpendicular to lines of skin tension.[4-6] Depending on the location, wounds can have a combination of both static and dynamic tension.

Multiple suture techniques have been described to decrease the tension required for wound apposition, however, under high tension, these do not prevent sutures cutting through the skin.[7] Quills or stents can be incorporated into the sutures, however, in our experience they do not adequately distribute the pressure and avoid the risk of focal skin necrosis.

A recent study by Dannemiller et al., demonstrated the importance of a wide surface area in contact with the skin to prevent pressure related damage in the dolphin. In addition, in human surgery, tension relieving devices with a large contact area are used to decrease this risk.[8-10]

Skin is a heterogenous viscoelastic tissue that is capable of further extension beyond its initial elasticity with the application of a stretching over time. These inherent properties, called mechanical creep and complemented by stress relaxation, can be harnessed to aid wound closure.[9-12] There are several commercial tension relieving systems available for use in human surgery, however these are expensive and have not been validated or their use well established for equine wounds.[9,13-14] The TopClosure system has been reported in a small equine case series, however, the outcome was poor, in agreement with our own personal experience.[15]

In the following retrospective case series, we describe a modified form of an inexpensive and effective tension relief technique, called the Tension Tile System (TTS). This is designed to take advantage of the mechanical properties of the skin and has been used successfully in a small case series of human wounds.[16] Using this system, we were successfully able to close a wide variety of equine wounds under high static tension or anticipated dynamic tension.

2. MATERIALS AND METHODS

2.1 Case selection

Clinical and surgical patient records were reviewed for all horses that presented with traumatic wound to four referral Equine Hospitals in Sweden, the UK, and Australia between March 2017 and December 2021. Wounds managed with the TTS were selected and evaluated. All surgical procedures were performed by registered specialist surgeons, either an ECVS diplomate or a registered surgery specialist of the ANZCVS, were included.

Patients were excluded if the data in the medical record were not detailed enough to categorize the wound and fully evaluate the outcome.

2.2 Classification of cases

A total of 191 patients fulfilled the inclusion criteria. The following data was recorded: Age (median and interquartile range), breed (Warmblood, Standardbred, Thoroughbred and other) and whether a horse or pony (< or =148cm). Using a modified classification system after Wilmink et al. (2002), the wounds were categorized according to the following criteria: anatomical location (distal limb, carpus, tarsus, proximal limb, body and head/neck), time elapsed prior to surgery (0-24 hours, 2-7 days, 8-21 days, > or = 22 days), depth of wound at the deepest point (skin, subcutis, muscle, bone), complicating factors (open synovial cavity, traumatised tendon, exposed bone, none), and post-surgical use of immobilisation (categorised as yes or no).[3]

The application of a cast, bandage cast, splint, or full Robert Jones Bandage were considered rigid immobilisation.[17]

Distal or proximal limb wounds were defined as a wound located distal or proximal to the carpus or tarsus respectively.

2.3 Treatment protocol

All patients received pre-operative flunixin meglumine (Finadyne; 1.1 mg/kg bwt i.v.;MSD Animal Health Sweden) and sodium benzylpenicillin (Geepenil, 12 mg/kg bwt i.v.; Orion Pharma Animal Health). Gentamicin (Gentaject, 6.6 mg/kg bwt i.v.; Ceva Animal Health) was also administered if a synovial structure or bone was involved. Following clipping and sterile surgical preparation, wounds were debrided by sharp surgical dissection and if available, with the use of the Versajet™ hydrosurgery system (Smith and Nephew, UK), to remove contamination and necrotic tissue.[18]

2.4 Tension Tile (TT) Surgical Technique

The plastic backing of a standard sterile suture pack (0 USP polyamide, Ethilon, Ethicon US) was used as an attachment plate (Tension Tile, TT). A sterile foam dressing with silicon adhesive (Mepilex, Mölnlycke Healthcare, Sweden) was cut to shape, and affixed to the tile to reduce skin pressure (Fig. 1 A,B). The TTs were attached to the skin with four 0 USP polyamide sutures on either side of the wound, such that the leading edge of the plate was approximately 5 -10 mm from the wound margin (Fig. 2 A,B,C). In cases where there was a high degree of tension or when the plate was bent to achieve better contact with the skin, an additional one or two sutures (0 USP polyamide) were placed on the long side away from the wound edge. Next, three horizontal mattress sutures were pre-placed, using 2 USP polyamide sutures. The sutures were passed through the TT and the skin on either side of the wound margin (Fig. 2B). The wound edges were then apposed with 1 USP and 0 USP polyamide using a combination of a horizontal mattress and simple interrupted suture pattern (Fig. 2C). Intra-operative skin stretching was maintained using a modified 135 mm fragment forceps (ref. no. 001208M, Veterinary Instrumentation UK), and given the acronym GTA "Gorvy Tissue Approximator". Compared with a standard Backhaus towel clamp, the increased length of the ratchet enabled differing degrees of tension to be applied without overlapping the wound margins (Fig. S1 A,B,C).

Finally, the pre-placed horizontal sutures were tied, transmitting all the shearing force to the TT, in turn distributing it to a large healthy skin surface area (Fig. 3A,3B). If the wound was located over a tendon, to avoid trauma from the subcutaneous suture material, the pre-placed 2 USP polyamide sutures were passed through the TT and the skin, using an interrupted cushings pattern, crossing the wound margins over the plate (Figure 3C). When this technique was used, normally only two sutures could be placed, due to limited space.

When appropriate, a drain was inserted prior to wound apposition. If possible, an active suction drain (Redon drain, Primed, Germany) was preferred to a passive drain.

The duration of postoperative NSAIDs was based on the type of wound and clinical status of the patient, but usually for no more than three days. As a routine, antimicrobials were administered for three days or until the drain was removed. This was extended in cases with complicating factors such as bone or synovial structure involvement.

2.5 Outcome criteria

Using a modified grading system after Wilmink et al., wounds were classified based on the success of primary intention healing at two weeks after surgery, the standard time for suture and TT removal (Fig.4 A,B; Fig.S2 A,B,C; Fig.S3 A,B,C).[3]

The wounds were assessed subjectively by one of the surgeons (DG,PP,IF) and two residents (FC,CHD) using photographs of the wound and/or the description in the clinical report. The wounds were divided into three groups: Group A - no dehiscence, Group B - partial dehiscence (>0% and 40% of wound length), and Group C - severe dehiscence (>40% - complete).

Duration of convalescence (weeks) after surgery was also recorded. Convalescence was defined as the time needed before return to work or unrestricted turnout.

2.6 ~~Statistical methods~~Data analysis

Data were recorded in Microsoft Excel and imported into the R statistical system (R Core Team (2022). R: A language and environment for statistical computing. R Foundation for StatisticalComputing,Vienna,Austria. URL https://www.R-project.org/.) for organization, explorationand statistical analysis. Data were managed and plotted using functions from the tidyverse[19] and janitor packages (Sam Firke (2021). Janitor: Simple Tools for Examining and Cleaning. R version 2.1.0. https://CRAN.R-project.org/package=janitor). Success rates for specific subgroups were reported as proportions with 95% confidence intervals using Clopper/Pearson methodology.

3. RESULTS

During the study period (March 2017 to December 2021), 860 wounds were repaired under general anaesthesia. Of these, 191 (22%) were repaired with the Tension Tile System and met the criteria for inclusion in the study (Table 1).

The age of patients ranged from three months to 23 years old (median 6 years; interquartile range 7). The Swedish Warmblood was the most common breed represented (n=74, 38%), followed by the Standardbred (n=33, 17%), pony breeds (n=26, 14%) and Thoroughbred (n=22, 12%). A variety of other breeds accounted for the remainder of animals treated, including the Quarter Horse and Arabian. Overall, primary intention healing with zero dehiscence (Group A) was achieved in 132 out of the 191 cases (69%, CI 62%-75%). Partial dehiscence (Group B) occurred in a further 30 cases (16%, CI 11%-22%) and severe dehiscence (Group C) in 29 (15%, CI 11%-21) cases. The predominant causes of failure in Group C were infection or ongoing tissue necrosis (Table 1). The outcome for the three surgeons is shown in Table 1, with primary closure achieved by the first surgeon in 71% of the wounds (CI 63.1%-78%), the second surgeon in 89% (CI 51.8%-99.7%) and the third surgeon 52% (CI 31.9-71.3).

The success of primary healing in ponies was 88% (CI 69.8-97.6) and in horses 66.1% (CI 68.3-73.2) (Table 1).

Distribution and outcome of wounds at different locations are reported in Table 1. Primary intention healing was achieved in 75% (CI 59.7%-86.8%) on the proximal limb wounds, 74% (CI 51.6%-89.8%) on the carpus, 71 % (CI 41.9%-91.6%), on the body 67% (CI 52.1%-79.2%) on the distal limb, 65% (CI 51.4%-77.8%) on the tarsus and 50% (CI 51.4%-77.8%) on the head/neck.

In Group A, 48% of patients presented within 24 hours of injury and primary closure was achieved in 67% of these wounds (CI 56.8-76.8). A further 40% presented between two days and three weeks following trauma and in 12% of cases, the wounds were greater than 22 days old prior to presentation. In 10% of chronic cases (more than two days old), unsuccessful closure had already been attempted once or twice prior to presentation.

Successful delayed primary closure was achieved in 65% of the wounds between 2-7 days (CI 49.5-77.8), in 76% between 8-21 days (CI 56.5-89.7), and 77% in wounds presented after 22 days or more (CI 54.6-92.2) (Table 1).

In 90/191 (47%) of cases, the wounds were complicated by the presence of an open synovial cavity, the involvement of a tendon, or exposed bone (Table1). Primary healing was achieved in 76% of wounds involving an open synovial cavity (CI 54.9-90.6), 75% of wounds associated with tendon trauma and 67.6% of wounds with exposed bone (CI 50.2-82).

Immobilisation was used after surgery in 114/191 (60%) of cases, with the distribution and outcome reported in Table 2.

The median convalescence time was 4 weeks (Range 3-15, IQR 4-6) in Group A, 7 weeks (Range 4-16, IQR 4-10.5) in Group B and 10 weeks (Range 5-16, IQR 8-12) in Group C. In 12 cases (6%), animals were euthanized; two of these for reasons unrelated to the wound and the remainder due to ongoing necrosis/infection (Table 1).

4.DISCUSSION

Optimal primary intention healing, in terms of cosmetic and functional outcome, is achieved when surgical incisions are made with the tension lines of the skin taken into consideration, thereby resulting in a tension free or near tension free closure. Unfortunately, traumatic equine wounds are often under tension when attempting primary closure. This is due to poor wound orientation, skin contraction after injury, or traumatic skin loss either at the time of injury or from necessary debridement to remove contaminated or necrotic tissue. The successful surgical management of these wounds is related to the ability to release tension from the wound margins, so that the sutures do not compromise the microcirculation. Therefore, choosing the correct technique is paramount to achieve primary healing.

Our results demonstrate the effectiveness of the Tension Tile System (TTS) in a wide range of anatomical locations, enabling the successful healing by primary intention of wounds that were previously thought impossible to close. Primary intention healing was achieved in 69% of wounds overall, which is a marked improvement compared to a previous report where the equivalent overall success was only 28%. [3] All surgeons were able to use the technique effectively with a high degree of success. The proportion of wounds with zero dehiscence varied among surgeons, however the lowest success rate was 51%, almost double compared to previously reported data.[3] Multiple factors can affect the healing process and for this reason the difference between surgeons could be related to a learning curve for the technique or factors not surgically related. In addition, the very restrictive and subjective grading system played an important role in the evaluation of dehiscence and may have influenced the results.

The success rate in ponies was higher compared to horses, in agreement with previous findings.[3]

However further investigation is needed before a definitive conclusion can be made regarding possible differences in primary wound healing.

Primary intention healing was achieved irrespective of the depth of the wound, complicating factors or time elapsed prior to surgery. Meticulous preparation and application of the TTS enabled the successful delayed primary closure of wounds.

Contamination, necrotic tissue, traumatised skin and unhealthy granulation tissue must be removed in both acute and chronic wounds, using a combination of surgical sharp and/or mechanical debridement. Unfortunately, this often results in increased distance between the wound margins. However, the increased capacity to control tension using the TTS allows surgeons to debride the wound more effectively without compromising the ability to attempt primary closure. This is particularly important with traumatic wounds associated with complicating factors, such as tendon trauma, joint involvement, or exposed bone. In these cases, primary healing is critical, since secondary intention healing may lead to an increase in the convalescence time and associated costs of treatment. In particular, where a tendon is involved, continuous movement will impede the healing due to the formation of different planes of granulation tissue.[2]

Partial degloving injuries are very challenging, as these wounds are often characterised by a combination of high tension and poor-quality skin margins. The application of the TTS enables tension management with an excellent distribution of pressure over a large skin surface area compared to traditional tension relief techniques; theoretically decreasing the risk of pressure necrosis or sutures cutting through the skin. The plates were left in place for 2 weeks, the standard time for suture removal, with no evidence of skin necrosis.

In this study, the use of rigid immobilisation was subjectively decided by the surgeon, taking into consideration the degree of ‘dynamic tension’ anticipated. The Tension Tile System works predominantly against ‘static tension’, by taking advantage of mechanical creep and stress relaxation, but can counteract dynamic tension to a certain extent. However, the post-surgical dynamic tension on the skin, generated during movement, can overload the system. For wounds with potentially high dynamic tension, the authors advise the use of immobilisation in addition to the TTS. This combination can create a perfect synergy to counteract all the tension forces generated. However, a prospective randomized study needs to be performed to assess the advantage of immobilization in addition to the TTS.

Failure to achieve complete primary closure was associated with an increased convalescence time. This finding is in accordance with a previous study that reviewed healing of traumatic wounds associated with extensor tendon lacerations, where a significant association between primary healing and the return to soundness of the patient was reported.[20] Achieving complete primary healing in a short time permitted horses to start rehabilitation earlier, which could have a positive effect. An extended convalescence period, with the horse restricted to a box or small paddock, may lead to a loss of athletic condition and increased risk of behavioral problems. Time spent in convalescence can be costly and delays using the horse for its intended purpose.

The main limitations of this study are related to its retrospective nature, the possibility of selection bias and the subjective assessment of the outcome. Many approaches have been proposed to assess wound healing, varying from a simple measurement with tape or caliper to more complex methods using digital cameras or a three-dimensional measurement device.[21-23] However, these latter methods are expensive and not validated for primary closure. In this study, the authors elected for a subjective and very stringent method for evaluating wound dehiscence. Any gap between the wound edges was considered a partial dehiscence and a thin dehiscence along the entire length of the wound was considered a complete failure. Although this method led to difficulties in wound evaluation between observers, it was similar to the only previous published grading system used in equine wounds and the use of such strict criteria helped to avoid bias in the evaluation and an overestimation of the success rate.[3]

A future prospective randomized study would be the natural next step to objectively evaluate the Tension Tile System in comparison with other techniques. In addition, the use of an objective grading system based on numeric measurement should be considered for better evaluation and reproducibility.

In conclusion, the Tension Tile System provides an economical and effective alternative to traditional or commercial tension relief systems. It helps the successful closure of challenging equine wounds under tension in a variety of anatomical locations.

Table 1: Observed outcome of primary closure following application of the Tension Tile System (success or failure) for each variable.

		Dehiscence					
		None		Partial		Complete	
		0%		10-40%		>40%	
	Total	n	%	n	%	n	%
	191	132	69	30	16	29	15
Surgeons/surgical centre							
~~Dylan Gorvy~~No. 1	155	110	71	20	13	25	16
~~Ian Fulton~~No. 2	9	8	89	1	11	0	0
~~Patrick Pollock~~No. 3	27	14	52	9	33	4	15
Breed							
Horse	165	109	66	30	18	26	16
Pony	26	23	88	0	0	3	12
Wound Location							
Distal limb	51	34	67	8	16	9	18
Carpus	23	17	74	5	22	1	4
Tarsus	55	36	65	12	22	7	13
Proximal limb	44	33	75	2	5	9	20
Body	14	10	71	2	14	2	14
Head/neck	4	2	50	1	25	1	25
Duration							
0-24 hours	92	62	67	16	17	14	15
2-7 days	48	31	65	9	19	8	17

8-21 days	29	22	76	3	10	4	14
22 days or more	22	17	77	2	9	3	14
Wound Depth							
Skin/subcutis	82	53	65	16	20	13	16
Muscle/Tendon	55	38	69	8	15	9	16
Exposed bone	54	41	76	6	11	7	13
Complicating Factors							
None	100	66	66	20	20	14	14
Open synovial cavity	26	19	73	3	12	4	15
Tendon trauma	28	21	75	2	7	5	18
Exposed bone	37	25	68	5	14	7	19
Convalescence							
3-4 weeks	86	77	90	9	10	0	0
5-8 weeks	63	46	73	8	13	9	14
9-16 weeks	31	6	19	11	35	14	45
Euthanased	11	3	27	2	18	6	55

Table 2: Observed outcome for wounds with or without immobilisation

			Dehiscence		
			None	**Partial**	**Complete**
			0%	10-40%	>40%
Wound Location	**Immobilisation**	%	n	n	n
Distal limb	yes	65	21	6	6
	no	35	13	2	3
Carpus	yes	83	15	3	1
	no	17	2	2	0
Tarsus	yes	73	28	8	4
	no	27	8	4	3
Proximal limb	yes	50	15	2	5
	no	50	18	4	0
Body	yes	0			
	no	100	10	2	2
Head/neck	Yes	0			
	no	100	2	1	1

Figure Legends

Fig.1: A. Materials required for the Tension Tile System (TTS); B. plastic backing of standard suture packs, foam dressing, and polyamide sutures (0, 1 and 2 USP)

Fig.2: A. Application of the Tension Tile System to the skin with 0 USP polyamide; B. Tension Tiles attached, and pre-placed horizontal mattress sutures of 2 USP polyamide inserted; C. The wound edges are then apposed with a combination of horizontal and simple interrupted sutures of 0 or 1 USP polyamide.

Fig.3: A. Pre-placed USP 2 polyamide horizontal mattress sutures tied, releasing the tension on the suture line; B. TTS applied to a large wound on the lateral side of the distal metatarsus; C. Variation of the technique when the wound is located over a tendon by the USP 2 polyamide suture in a Cushing pattern.

Fig.4: A. Large wound on the lateral side of the distal metatarsus showed with TTS figure 3B B. The same wound after sutures removal at 2 weeks from surgery.

Fig.S1: Comparison of the “GTA” ratchet (A) with a standard Backhaus towel clamp (B); “GTA” applied during the application of the TTS (C)

Fig.S2: A. Large wound over the cranial stifle B. Wound sutured with the help of the TTS C. Wound at sutures removal 2 weeks after surgery.

Fig.S3: A. Large degloving wound cranial and lateral side of the forearm B. Wound sutured with the help of the TTS C. Wound after sutures removal 2 weeks after surgery.

REFERENCES

1. Wilmink JM, Stolk PWTH, Van Weeren PR, Barneveld A Differences in second-intention wound healing between horses and ponies: macroscopic aspects. Equine Vet J. 1999; 31(1):53-60
2. Kamus L, Theoret C Choosing the Best Approach to Wound Management and Closure. Vet Clin Equine 2018; 34:499-509
3. Wilmink JM, Van Herten J, Van Weeren PR, Barneveld A Retrospective study of primary intention healing and sequestrum formation in horses compared to ponies under clinical circumstances. Equine Vet J. 2002; 34(3):270-273
4. Wakury H, Sakuma Y, Mutoh KI, Watanabe S Cleavage Line Patterns of the Skin in the Horse. Okajimas Folia Anat. Jpn 1990; 67(5): 351-364
5. Provost PJ, Bailey JV Principles of Plastic and Reconstructive Surgery. In: Auer JA, Stick JA, Kümmerle JM, Prange T, eds. *Equine Surgery* 5th ed. Elsevier; 2019: 367-381
6. Alexander T. T Anatomy of Wound Repair. In: Alexander T.T, eds. Wounds and Lacerations 4th ed. W.B. Saunders;2012:10-14
7. Celeste C Selection of Suture Materials, Suture Patterns, and Drains for Wound Closure. In: Theoret C, Schumacher J, eds. Equine Wound Management 3rd ed. Wiley Blackwell; 2017: 173-199
8. Dannemiller NG, Hendrickson DA In vitro evaluation and in vivo use of a novel surgical stent to minimize suture pressure necrosis. Vet Surg 2020; 49:741-747
9. Topaz M, Carmel NN, Silberman A, Li MS, Li YZ The TopClosure® 3S System, for skin stretching and a secure wound closure. Eur J Plast Surg 2012; 35:533-543
10. Rana H, Suri M The Tension wound closure device system, for skin closure of excessive tension wounds. Int. J. Med. Health Res. 2017; 3(8):69-72

11. Stashak TS Principles and Techniques for Reconstructive Surgery. In: Theoret C, Schumacher J, eds. Equine Wound Management 3rd ed. Wiley Blackwell; 2017: 200- 324
12. Topaz M, Carmel NN, Topaz G, Li M, Li YZ Stress–Relaxation and Tension Relief System for Immediate Primary Closure of Large and Huge Soft Tissue Defects: An Old–New Concept. Medicine 2014; 93(28):1-6
13. Hirshowitz B, Lindenbaum E Sure-Closure skin stretching system. Plast Reconstr Surg 1999; 103(1):332-3.
14. Barnea Y, Gur E, Amir A, et al. Our experience with Wisebands: a new skin and soft-tissue stretch device. Plast Reconstr Surg 2004; 113(3):862-9.
15. Kelmer G, Cypher E, Schumacher J Simple techniques to decrease tension on sutured wounds of horses. Equine vet. Educ. 2021; 34(2):67-72
16. Choudhary S, Mantry R, Arora P, Jain R, Habib O, Gupta S ´Tension Tile System´(TTS): a simple innovative wound closure device. Eur J Plast Surg. 2015; 38:315-318
17. Bischofberger AS. Drains, Bandages, and external Coaptation. In: Auer JA, Stick JA, Kümmerle JM, Prange T, eds. Equine Surgery 5th ed. Elsevier; 2019: 280-300
18. Skärlina EM, Wilmink JM, Fall N, Gorvy DA Effectiveness of conventional and hydrosurgical debridement methods in reducing Staphylococcus aureus inoculation of equine muscle in vitro. Equine Vet J. 2015; 47:218-222
19. Wickham H, et al. Welcome to the tidyverse. Journal of Open Source Software 2019;4(43):1686, https://doi.org/10.21105/joss.01686
20. Mespoulhès-Rivière C, Martens A, Bogaert L, Wilderjans H Factors affecting outcome of extensor tendon lacerations in the distal limb of horses. Vet Comp Orthop Traumatol. 2008; 21:358-364
21. Pavlovčič U, Jezeršek M Handheld 3-dimensional wound measuring system. Skin Res Technol. 2018; 24:326-333

22. Jorgensen LB, Skov-Jeppesen SM, Halekoh U, et al. Validation of three-dimensional wound measurements using a novel 3D-WAM camera. Wound Rep Reg. 2018; 26:456-462

23. Ferreira F, Pires IM, Ponciano V, et al. Experimental Study on Wound Area Measurement with Mobile Devices. Sensors 2021; 21(17):5762