Biodynamic excisional skin tension lines for surgical excisions: untangling the science

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ABSTRACT

OBJECTIVE There remains confusion between Langer's lines and wrinkle lines with respect to the optimal orientation of elliptical excisions on the trunk. This study sought to determine the directions of wound closure that would result in least wound tension after skin lesion excisions.

MATERIALS AND METHODS Some 1181 consecutive skin lesion excisions were investigated (age range 13–95 years, median 64 years) using a tensiometer to determine directions of least wound tension. These lines were mapped. Skin tension measurements were taken during the procedure and analysed. The clear majority of excisions were for skin cancer and the others were for cysts or dysplastic naevi. Lesions such as lipomas, which entail incisional rather than excisional surgery (i.e. where overlying skin was not excised) were excluded. All lesions were cut out in a circular fashion following tension measurements. Closure was undertaken in the direction of least tension (biodynamic excisional skin tension line) and this was illustrated. This process was repeated in all cases where body site and direction of closure was mapped. Statistical analyses were undertaken on a series on the scalp and lower limb.

RESULTS Biodynamic excisional skin tension lines have a clear directional preference: scalp–coronal direction, limbs—vertical orientation of ellipses and trunk – mostly horizontal except oblique at the shoulder and scapular regions.

DISCUSSION Skin cancer excisions often end up with poor cosmetic results, owing to inconsistency in identifying the correct excisional wound closure lines. This has not been helped by the (hitherto) lack of large in vivo biomechanical studies, and because incisional lines and excisional lines have not been considered separately in surgical practice. Orientating ellipses or wound closures using biodynamic excisional skin tension lines offers a guide to reducing wound tension and minimising wound complications or scarring after cutaneous surgery.

KEYWORDS

Skin – Skin tension – Langer's lines – Skin cancer – Excision

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Introduction

Skin lines used to plan incisions have been contentious, with differing descriptions.¹ Karl Langer, who originally investigated cleavage lines, studied cadavers that were punctured with a round-tipped awl (like an ice-pick) published a series of papers on 'cleavage lines' in 1861 that were not translated until 1978 by Gibson.² Cox, who recreated Langer's experiment in 1941, studied 28 cadavers and also marked out skin cleavage lines.³ Cleavage lines run in a sagittal direction on the scalp.

Kraissl considered wrinkles to be an adaptation to muscle contraction and he overlaid wrinkle lines over muscle anatomy illustrations to map out lines that he thought were ideal for surgical excisions.⁴ Borges noted that when one pinches oneself, wrinkles become larger when they form parallel to Langer's lines. Borges refined the technique of determining these 'relaxed skin tension' lines by stating that it was

important to note that, when pinching one's skin, one must consider both furrows and ridges because when contour lines are produced by muscle or joint action, one only notes furrows. Borges coined the term 'relaxed skin tension lines' (RSTL) and advised using these lines on the face for surgical excisions. However, on the trunk and limbs, Borges considered RSTL and wrinkle lines together.⁵ A small number of cadaver and clinical studies have therefore ended up guiding cutaneous surgery through history.

In the author's experience, incisional wounds such as orthopaedic joint replacement surgery wounds rarely develop hypertrophy or keloid scars whereas smaller and meticulously closed wounds after skin cancer excisions often develop complications at these same sites, even in experienced plastic surgical hands. Are skin lines for surgical egress (low load) biomechanically different from lines for surgical excisions (high load)? This hypothesis led to the development of a new computerised tensiometer to map

biodynamic excisional skin tension (BEST) lines.⁶ While many books depict skin tension and Langer’s lines differently, a commonly used depiction in textbooks was used as a reference point in this study (Fig 1) where this author sets out to map BEST lines for surgical excisions across the human body.

Materials and methods

The tensiometer used for this study has been described previously (Fig 2) and the statistical validity of the technique has already been published in previous papers.^{6,7} Being bidirectional and real time, this computerised device was not only able to assess any existing pre-tension on skin (that could give rise to errors while using the pinch technique) but was also able to accurately determine the line of closure under least tension for each excisional wound.⁶

A total of 1181 consecutive patients who presented with skin lesion excisions were investigated (age range 13–95 years, median 64 years; mean excision size 1.62 cm, range 0.4–4.5 cm). Skin lesions were excised in a circular fashion and the wounds were converted into an elliptical excision after noting the direction that would allow wound closure under least tension (Fig 2). These BEST lines were mapped. All procedures were performed by the same surgeon (the author) to ensure technical consistency.

Figure 1 Skin tension lines commonly depicted in textbooks. Originally published in Hockberger R, Marx J, Walls R. *Rosen’s Emergency Medicine: Concepts and clinical practice*. © Elsevier, 2002. Reprinted with permission)

This research was conducted in the context of a PhD study undertaken by this author investigating BEST lines. Ethics

Figure 2 Methodology of the biodynamic excisional skin tension line study

Figure 3 Biodynamic excisional skin tension lines mapped during study (anterior). Each line represents a different excision with no specific colour scheme

Figure 4 Biodynamic excisional skin tension lines mapped during study (posterior). Each line represents a different excision with no specific colour scheme

approvals (New Zealand HDEC Reference number 15/CEN/113; Australia: University of Queensland Institutional Human Ethics approval nnumber 2015001550) were obtained. All subjects gave written informed consent in accordance with the Declaration of Helsinki.

Each case underwent tensiometry before and during the procedure. The clear majority of excisions were for skin cancer and the others were for cysts or dysplastic naevi. Lesions such as lipomata, which entail incisional rather than excisional surgery (i.e. where overlying skin is not removed) were excluded. All excisions were full-thickness skin specimens and cancerous lesion removals usually involved excision of some underlying fat. All lesions were sent for histopathological examination and samples were measured after tissue shrinkage in formalin (range 0.4–4.5 cm, average size 1.62 cm).

The tensiometer was used to determine line of least tension and a map was made of BEST lines across the human body (Figs 3 and 4). As previous skin tension line diagrams found in the literature depict skin tension lines differently, especially on the scalp and lower limb, a comparison of wound tension and force required to close wounds on these areas were compared between different directions and statistical analysis was undertaken.

Results

The map of the site of each lesion and the direction of closure along BEST lines shows a clear preferential direction

(Figs 3 and 4) of BEST lines across the body (i.e. the lines to be followed to achieve closure under least tension). The composite body map of each excision shows that BEST lines have a distinct pattern on the body that is consistent with minimal age or sex variation. Skin tension studies in animals such as pigs found that, with age and fat deposition, Langer’s skin tension lines begin to change direction.⁸ This was not noted in this study of BEST lines. It was noted that shoulder and scapular movements result in significant ventral and dorsal pre-tension, which can give rise to erroneous calculations of skin tension using the skin-pinch method.

Tension measurements were recorded of sagittal, oblique and coronal directions on the scalp for 17 consecutive excisions (Table 1). A detailed statistical analysis, in this case two-sided paired t-tests, were applied and the skin tension (wound closing tension) compared in the coronal, sagittal and oblique planes. The coronal tension was noted to be significantly different (less) from both the sagittal and oblique tensions (two-sided paired t-test, unequal variances; *P* = 0.00075 and 0.000013, respectively) indicating that the BEST lines on the scalp run in the coronal direction.

Twenty-three circular lower-limb defects with diameters ranging from 1.5 cm to 4.5 cm were studied (Table 2). Closing wound tension was measured along the RSTL/wrinkle lines and the vertical planes because these were the two directions that had the two lowest tension measurements consistently compared with other directions.

A statistical analysis was undertaken of wrinkle/RSTL lines vs vertical BEST lines on the lower limb. Application

Table 1 Wound closing tension measured in different directions on the scalp.					
No.	Outward pre-tension	Coronal (transverse) force (N)/tension	Oblique force (N)/tension	Sagittal (vertical) force (N)/tension	Defect size (cm)
1	0.4	4.6	6.0	4.9	3
2	0.0	3.2	3.8	3.5	3
3	0.1	3.0	3.2	3.0	4
4	0.2	2.4	2.6	2.4	2
5	0.4	1.8	2.8	2.1	4
6	0.1	1.1	1.4	1.1	2.5
7	0.2	3.2	4.2	3.6	3
8	0.0	1.9	3.2	2.9	2.5
9	0.3	3.2	4.2	3.6	2
10	0.4	4.0	5.0	4.6	2.5
11	0.6	3.2	4.9	3.7	2
12	0.6	3.7	4.7	3.9	4
13	0.5	3.0	4.0	3.6	3
14	0.0	0.7	1.0	0.7	0.7
15	0.0	0.7	0.9	0.7	0.6
16	0.0	0.4	0.5	0.4	0.4
17	0.0	0.9	0.2	0.9	0.7

Table 2 Wound tension measurements comparing relaxed skin tension lines (RSTL)/wrinkle lines and vertical (biodynamic excisional skin tension, BEST) lines on the lower limb.

Incision no.	Age	Sex	Diagnosis	Lesion size (cm)	Tension (N) RSTL/wrinkle lines	Tension (N) BEST lines (vertical)
1	69	M	BCC	3.5	3.1	2.6
2	69	M	BCC	3.5	3.2	2.8
3	88	M	SCC	2.7	2.1	1.9
4	79	F	SCC	4	3.2	2.8
5	75	M	BCC	3.5	3.1	2.6
6	87	F	MM wider	4.5	3.1	2.6
7	86	F	SCC	2.0	1.7	1.4
8	75	M	BCC	4.0	3.2	2.8
9	75	M	BCC	3.4 (P)	2.5	2.3
10	69	F	KA	2.9	1.3	1.1
11	69	M	BCC	4.5	3.6	2.7
12	80	F	SCC	2.2 (P)	1.5	1.3
13	88	M	SCC	4.5	3.6	2.7
14	50	F	BCC	2.0	1.5	1.2
15	82	M	SCC	3.0	2.4	2.0
16	71	M	BCC	2.4	2.6	2.2
17	57	M	SCC	3.0	2.5	2.3
18	57	M	SCC	1.5 (P)	1.3	1.1
19	64	F	SCC	2.5	2.3	2.1
20	76	M	SCC	4.0	3.1	2.6
21	86	F	SCC	3.8	2.4	2.0
22	79	M	SCC	5.0	3.6	2.7
23	76	M	SCC	2.4	2.6	2.2

BCC, basal cell carcinoma; MM, malignant melanoma; P, lesion located posteriorly on the calf; SCC, squamous cell carcinoma

of the paired t-test, Student's t distribution: $t = 8.9154$, $df = 22$, $P = 9.338E-09$ (95% confidence interval) showed a statistical significant reduction in wound-closure tension using BEST lines when compared with wrinkle/RSTL on the lower limb. The statistical analyses of the scalp and lower limb sites are being presented in this article as these areas showed the most variance between skin tension lines or Langer's lines noted in textbooks (Fig 1). Because of the large sample size and publication limits of journal articles, the rest of the measurements on the trunk and face are not reported on here but will be the subject of a separate monograph on this topic. The direction of the BEST lines (for wound closure after excisional surgery) was mapped accurately in each case and is presented here (Figs 3 and 4). The lines were variably mapped in red, green, blue and black lines, with no specific colour scheme. Each line

Table 3 Site and numbers of excisions during which biodynamic excisional skin tension lines were mapped for this study.

Body site of excision	Lesions (n)
Trunk (chest/abdomen/back/groin)	376
Upper limb (arm/forearm/hand)	168
Lower limb (arm/forearm/hand)	166
Head (neck/scalp/upper back)	471

essentially depicts an individual excisional site and final wound orientation (Table 3).

Figure 5 Biodynamic excisional skin tension lines: a guide for excisional surgery

Discussion

This study demonstrates that BEST lines (i.e. lines that are most suitable for excisional surgery) do not conform to many previous depictions in textbooks. The lack of ‘science’ behind skin lines used for surgical excisions has been previously commented upon.⁹ While Langer’s lines run in a sagittal direction on the scalp, BEST lines run in a coronal direction; while RSTL/wrinkle lines run in a horizontal-oblique direction on the lower limb, BEST lines run in a vertical direction. Statistical analyses clearly show that using BEST lines allows for closure under least tension and these lines must be considered excisional lines (i.e. directions along

which an elliptical excision can be orientated). In contrast, Langer’s lines and wrinkle lines can be considered to be incisional lines as, below 8 mm diameter, both in this study and a previous paper, there was no directional preference noted.⁷

How did cleavage lines, often marked differently, end up as lines for surgical excision?⁹ Skin may be anisotropic, but it does exhibit orthotropy (i.e. a degree of symmetry with respect to two normal planes), which is due to the preferential orientation of collagen fibres,⁹ which explains the clear pattern that emerged in this study. It was the Swiss surgeon, Emile Kocher, who recommended using Langer’s lines for

surgical incisions and they became a routine part of surgical practice.⁹ Outside the face, RSTL and wrinkle lines have been considered together on the trunk and limbs, and many books describe cleavage lines differently creating confusion among surgeons.⁹

In this study, the mean diameter of the excision specimen was 1.62 cm (maximum diameter 4.5 cm) after tissue shrinkage and formalin fixation. Dauendorffer and colleagues reported that shrinkage of skin excision specimens occurs after surgical excision and prior to formalin fixation and they noted that width shrinkage was associated neither with the type of lesion (malignant or not, $P = 0.20$) nor with the location on the trunk ($P = 0.35$).¹⁰ Kerns suggests that patient age is significant and tissue shrinkage decreases 0.3% per year of increasing age, but body site was not significant.¹¹

Furthering the observation that incisional and excisional lines must be considered differently, other studies by this author have shown that incisional and excisional lines are different under multiphoton microscopy with respect to the interplay between collagen and elastin.¹² Where there was minimal tension (less than 1.5 N force typical of incisional surgery) elastin stretched and collagen buckled but when larger defects were created after excisions (such as after skin cancer excisions being studied here), multi-photon microscopic images revealed mostly collagen, suggesting that collagen stretched and elastin buckled.¹²

A simple zigzag excision has also been shown to reduce wound tension in keloid zones and that was also confirmed during this study.¹³ A limitation of this report is that, because of the large volume of cases, measurements of each lesion that was studied are not reported.

Conclusion

It is a well-known surgical dictum that if wounds are closed under tension, scars stretch and worsen according to the magnitude and direction of the forces acting on them.¹⁴ Previous skin tension studies included small numbers and there is a dearth of real-time measurements reported in the literature. This study was a large consecutive in vivo real-time clinical study that sheds light on the BEST lines that provide a guide for surgical excisions during cutaneous surgery.

Skin cancer excisions on the trunk often result with a poor cosmetic result, owing to inconsistency in identifying the correct excisional line. An improperly oriented excision may mean the difference between primary closure and a skin graft on the lower limb. BEST lines appear to have a remarkable anatomical consistency of pattern across the human body. Following BEST lines (Fig 5) can therefore be expected to reduce wound tension and improve both cosmetic results and surgical outcomes.

References

1. Carmichael SW. The tangled web of Langer's lines. *Clin Anat* 2014; **27**(2): 162–168.
2. Langer K. Zur Anatomie und Physiologie der Haut. 1) Ueber die Spaltbarkeit der Cutis; 2) Die Spannung der Cutis; 3) Ueber die Elasticita der Cutis; 4) Das Quellungsvermogen der Cutis. Sitzungsbericht der Mathematisch-naturwissenschaftlichen Classe der Kaiserlichen Academia der Wissenschaften, Wien, 1861. [English translation: Gibson T. On the anatomy and physiology of the skin. *Br J Plast Surg* 1978; **31**: 3–8, 93–106, 185–199, 273–278.
3. Cox HT. The cleavage lines of the skin. *Br J Surg* 1941; **29**: 234–240.
4. Kraissl CJ. The selection of appropriate lines for elective surgical incisions. *Plast Reconstr Surg* 1951; **8**(1): 1–28.
5. Borges AF. Relaxed skin tension lines (RSTL) versus other skin lines. *Plast Reconstr Surg* 1984; **73**: 144–150.
6. Paul SP, Matulich J, Charlton N. A New skin tensiometer device: computational analyses to understand biodynamic excisional skin tension lines. *Sci Rep* 2016; **6**: 30,117.
7. Paul SP. Revisiting Langer's lines, introducing BEST lines and studying the biomechanics of scalp skin. *Spectrum Dermatol* 2017; **2**: 8–11.
8. Rose EH, Vistnes LM, Ksander VA. Skin tension lines in the domestic pig. *Plast Reconstr Surg* 1976; **57**(6): 729–732.
9. Paul SP. Biodynamic excisional skin tension (BEST) lines: revisiting Langer's lines, skin biomechanics, current concepts in cutaneous surgery, and the (lack of) science behind skin lines used for surgical excisions. *J Dermatol Res* 2017; **2**(1): 77–87.
10. Dauendorffer JN, Bastuji-Garin S, Guéro S *et al*. Shrinkage of skin excision specimens: formalin fixation is not the culprit. *Br J Dermatol* 2009; **160**: 810–814.
11. Kerns MJ, Darst MA, Olsen TG *et al*. Shrinkage of cutaneous specimens: formalin or other factors involved? *J Cutan Pathol* 2008; **35**: 1,093–1,096.
12. Paul SP. Are incisional and excisional skin tension lines biomechanically different? understanding the interplay between elastin and collagen during surgical procedures. *Int J Biomed* 2017; **7**(2): 111–114.
13. Paul SP. The use of zigs and zags to reduce scarring over 'keloid triangles' during excisional surgery: biomechanics, review and recommendations. *Surg Sci* 2017; **8**: 240–255.
14. Sommerlad BC, Creasey JM. The stretched scar; a clinical and histological study. *Br J Plast Surg* 1978; **31**: 34–45.