Skin tension or skin compression? Small circular wounds are likely to shrink, not gape

James A. Bush a,b,*, Mark W.J. Ferguson a,c, Tracey Mason a, D. Angus McGrouther b

a Renovo Group plc, The Manchester Incubator Building, 48 Grafton Street, Manchester M13 9XX, UK
b Plastic and Reconstructive Surgery Research, The University of Manchester, Stopford Building, Oxford Road, Manchester M13 9PT, UK
c Faculty of Life Sciences, University of Manchester, Stopford Building, Oxford Road, Manchester M13 9PT, UK

Received 5 October 2006; accepted 6 June 2007

Summary The final appearance of a scar may be influenced by tension or mechanical factors [Borges AF. Scar prognosis of wounds. Br J Plast Surg 1960;13:47–54; Arem AJ, Madden JW. Effects of stress on healing wounds. J Surg Res 1976;20:93–102; Burgess LP, Morin GV, Rand M, et al. Wound healing. Relationship of wound closing tension to scar width in rats. Arch Otolarngol Head Neck Surg 1990;116:798–802; Meyer M, McGrouther DA. A study relating wound tension to scar morphology in the pre-ternal scar using Langer’s technique. Br J Plast Surg 1991;44:291–4] Karl Langer suggested that information could be gained about the tension inherent in skin, in all directions, by observing the wound edge retraction that occurred after making circular skin incisions [Langer K. On the anatomy and physiology of the skin II. Skin tension. Br J Plast Surg 1978;31:93–106]. Circular wounds may be used to demonstrate the orientation of the dominant axis of ‘tension’ in the skin but is this always a tensile stress as opposed to a compressive stress? This is the second article in a series documenting the mechanical properties of circular punch biopsy wounds. The aim of this study was to make detailed observations of the dimensional distortions of circular wounds on the face and neck, from which deductions could be made with regard to mechanical stress.

One hundred and seventy-five benign head and neck lesions were excised from 72 volunteers using circular dermal punch biopsies. The distortions of the resulting wounds were observed to be elliptical in most cases. Measurements were taken of the maximum and minimum diameters of the wound and expressed as ratios of the size of the punch biopsy used for excision. The change in area from the area of the punch biopsy to that of the wound was also calculated.
The maximum diameter of the wound was smaller than the diameter of the punch biopsy in 40.6% of cases, the minimum diameter of the wound was smaller in 97.7% of cases and the area of the wound was smaller than that of the punch biopsy in 90.3%. These dimensional changes varied between sites (\( P = 0.0005, \ P = 0.0001 \) and \( P < 0.0001 \), respectively).

We conclude that the reported rhomboidal or lattice structure [Ridge MD, Wright V. The directional effects of skin. A bioengineering study of skin with particular reference to Langer’s Lines. J Invest Dermatol 1966;46:341–6] of skin has individual components which are under tensile force due to elastic retraction. Wounds smaller than the rhomboidal unit will reduce in area, due to the intact tensional forces in the individual dermal components, giving an appearance of the skin overall being under compression. Larger wounds, disrupting more of the lattice structure, will gape.

© 2007 British Association of Plastic, Reconstructive and Aesthetic Surgeons. Published by Elsevier Ltd. All rights reserved.

The literature suggests that tension or mechanical factors may be important in determining the final appearance of a scar.\(^{1-4}\) Karl Langer performed a series of human cadaveric studies in which he first observed the orientation of the linear clefts produced by stab wounds with a round bodied awl (Langer’s lines of cleavage),\(^7\) and later, the retraction of wound edges that occurred after making circular incisions.\(^5\) Langer suggested that, assuming there were no limitations on the elastic recoil of skin, the tension inherent in skin could be investigated by observing the wound edge retraction that occurred on skin incision.\(^1\) Langer also realised that by making a circular incision information could be gained about skin tension in all directions. With uniform tension in all directions wounds would remain circular whereas, in the absence of uniform tension, wounds would be distorted in a particular direction.\(^5\) He observed that circular wounds always gaped in the same direction as his lines of cleavage and, by microscopic examination of skin sections, found that the orientation of the cleavage lines was related to the fibre arrangement of skin.\(^7\) This suggested a relationship between skin fibre arrangement and the dominant axis of tension in skin, a finding that has since been supported by other groups.\(^6,8\) Although it may be possible to demonstrate the orientation of the dominant axis of skin ‘tension’, it is correct to assume that all wounds will gape as a result? Movement of body parts often increases the length of certain skin segments which, at rest, may be tension free. This is the second article in a series which will document the mechanical properties of circular dermal punch biopsy wounds after the excision of benign head and neck naevi, and the subsequent effect of these mechanical properties on scar outcome. The aim of this study was to make detailed observations of the dimensional distortions of circular wounds on the face and neck, from which deductions could be made with regard to the effects of mechanical stress.

**Methods**

This research was conducted in the course of a randomised controlled clinical trial investigating the scar-improving efficacy of a drug, given as an intradermal injection, immediately after closure of the wounds resulting from the excision of benign head and neck naevi. The results of that trial will be published separately. Ethical Committee and Medicines in Health Regulatory Authority approval were obtained prior to commencing the trial and written informed consent was obtained from each volunteer prior to participation. The first article in this series included a description of the patients and lesions included, along with a detailed description of the surgical methods and wound care.\(^9\) To summarise, 175 benign head and neck lesions, predominantly naevi, were excised from 72 volunteers (28 male, 44 female) using dermal punch biopsies of between 3 and 8 mm diameter. The positions of excised lesions were recorded on a diagram of a face and a record was kept of the aesthetic unit in which each lesion was included, as reviewed by Fattahi.\(^10\) Dermal punch biopsies were placed on to unsupported skin around the lesion to be excised, i.e. the skin was not stretched in any direction prior to punch biopsy excision. All excisions included the full thickness of the skin. Elliptical distortion of wounds was observed after most excisions. Measurements were taken of the maximum and minimum diameter of the wounds, with the face in a relaxed posture, using sterile callipers to the nearest 0.1 mm. Wound closure and subsequent care were as previously described.\(^9\)

All measurements of wound dimensions were databased. All maximum and minimum wound diameters were expressed as ratios of the size of punch biopsy used for the excision (wound diameter/punch biopsy diameter). A ratio of 1.0 would, therefore, show that the wound diameter was the same as that of the punch biopsy used. A ratio > 1.0 would indicate that the wound diameter was larger than the punch biopsy diameter and a ratio < 1.0 would indicate a smaller wound diameter than that of the punch biopsy. The area of each wound was calculated, using the formula for the area of an ellipse \((\pi \times \text{maximum diameter} \times \text{minimum diameter}/4)\) or the formula for the area of a circle \((\pi r^2)\) as appropriate, and compared with the area of the punch biopsy used \((\pi r^2)\).

A copy of the diagram of the face used to record the positions of lesions was used to illustrate the positions of wounds which exhibited similar dimensional distortions. An analysis of variance with pairwise comparisons using \(t\)-tests was used to determine differences in the dimensional distortions of wounds between different aesthetic units; males and females; different age groups and with the different sizes of punch biopsy used for excision.
Results

The sizes of punch biopsy used for each excision were as follows: two 3 mm biopsies, 15 × 4 mm biopsies, 38 × 5 mm biopsies, 65 × 6 mm biopsies and 55 × 8 mm biopsies. The number of lesions excised from each aesthetic unit is summarised in Table 1.

Wound distortions

Only four of the 175 wounds remained circular after punch biopsy excision, two on the forehead, one on the alar rim and one on the upper cheek. The remaining wounds were distorted into ellipses, demonstrating a dominant axis of stress in the skin.

The ratio of the maximum wound diameter to the diameter of the punch biopsy used ranged from 0.70:1 to 1.85:1 (median 1.0:1). In 71 wounds (40.6%) the maximum diameter was smaller than the diameter of the punch biopsy used, this group included the four wounds that remained circular. In 17 wounds (9.7%) the maximum diameter was the same as the diameter of the punch biopsy used and in 87 wounds (49.7%) the maximum diameter was larger than that of the punch biopsy used. The distribution of these wounds is illustrated in Fig. 1. The analysis of variance showed a highly statistically significant difference in the ratio of the maximum wound diameter to the punch biopsy diameter in different aesthetic units (P = 0.0005). Table 2 shows pairs of aesthetic units which showed statistically significant differences in this ratio using t-tests. The ratio of the maximum wound diameter to the punch biopsy diameter was not affected by the size of the punch biopsy used for excision or the age or sex of the volunteer.

The ratio of the minimum wound diameter to the diameter of the punch biopsy used ranged from 0.07:1 to 1.08:1 (median 0.78:1). In 171 wounds (97.7%) the minimum diameter was smaller than the diameter of the punch biopsy used; again, this group included the four wounds that remained circular. In one wound (0.6%), on the neck, the minimum diameter was the same as that of the punch biopsy used and in three wounds (1.7%) the minimum diameter was larger than that of the punch biopsy used. Two of these wounds were on the upper lip and cheek of the same volunteer, the other was a neck wound. The analysis of variance showed a highly statistically significant difference in the ratio of the minimum wound diameter to the punch biopsy diameter in different aesthetic units.

![Figure 1](image)

**Table 1** Number of naevi in each aesthetic unit

<table>
<thead>
<tr>
<th>Aesthetic unit</th>
<th>Number of naevi</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forehead unit</td>
<td>21</td>
</tr>
<tr>
<td>Nasal unit</td>
<td>5</td>
</tr>
<tr>
<td>Eyelid units</td>
<td>4</td>
</tr>
<tr>
<td>Cheek unit</td>
<td>65</td>
</tr>
<tr>
<td>Upper lip unit</td>
<td>14</td>
</tr>
<tr>
<td>Lower lip unit</td>
<td>10</td>
</tr>
<tr>
<td>Mental unit</td>
<td>4</td>
</tr>
<tr>
<td>Auricular unit</td>
<td>2</td>
</tr>
<tr>
<td>Neck unit</td>
<td>50</td>
</tr>
</tbody>
</table>

**Table 2** Pairs of aesthetic units which showed statistically significant differences in the ratio of the maximum wound diameter to the diameter of the punch biopsy (t-tests)

<table>
<thead>
<tr>
<th>Aesthetic unit</th>
<th>Mean</th>
<th>Standard error</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Neck — forehead</td>
<td>0.14</td>
<td>0.04</td>
<td>0.0002</td>
</tr>
<tr>
<td>Neck — lower lip</td>
<td>0.18</td>
<td>0.05</td>
<td>0.0002</td>
</tr>
</tbody>
</table>

A positive mean indicates that the ratio for the second aesthetic unit of the pair was smaller than the ratio for the first unit.

Wound areas

The area of the wound expressed as a percentage of the area of the punch biopsy ranged from 6.0 to 198.9% (median 78.4%). After 158 excisions (90.3%) the area of the wound was smaller than the area of the punch biopsy used for
excision. Following the remaining 17 excisions (9.7%) the wound area was larger than the area of the punch biopsy used for excision. Two of these wounds were on the upper lip, nine on the cheek and six on the neck. The analysis of variance showed a highly statistically significant difference in the change in area from the size of the punch biopsy to that of the wound in different aesthetic units \((P < 0.0001)\). Table 4 shows pairs of aesthetic units which showed statistically significant differences in this change in area using \(t\)-tests. The change in area from the size of the punch biopsy to the size of the wound was significantly different when different sized punch biopsies were used for excision \((P = 0.0004)\) but was not affected by the age or sex of the volunteer.

Discussion

In 1861 Karl Langer proposed that the tension inherent in skin could be investigated by observing the wound edge retraction that occurred on skin incision.\(^5\) He made multiple circular wounds in human cadavers and observed the wound edge retraction that followed noting that, in areas where skin tension was uniform in all directions the wounds remained circular, and in areas where the tension was not uniform in all directions elliptical distortion was observed. Langer also measured the dimensions of the isolated island of skin, which he termed the ‘kernel’ and noted that the retraction of the kernel was always greater than that of the wound.\(^5\) For this reason he suggested that wound edge retraction could only be used to gain information on the direction of skin tension and not the magnitude. Langer noted that in certain areas the short axes of wounds stayed the same size as the original circle marked on the skin, or even became smaller, and concluded that in these areas ‘tension was nil or even negative’.\(^5\) This was observed in 98.3% of our wounds, suggesting that the majority of wounds experienced a stress perpendicular to their long axis resulting in compression, compressive stress being the stress applied to materials resulting in their compaction. Langer did not document any areas in which the longer diameters of wounds were smaller than the size of the initial circle marked on the skin in his cadaveric studies, which is in contrast to the results of this study in which 40.6% of wounds had a maximum diameter smaller than that of the punch biopsy used for excision. Langer did document that on the scalp, palm of the hand and sole of the foot circular wounds maintained their shape and diameter and concluded that in these areas skin tension was nil.\(^5\) Our results suggest that, although the wound edge distortions of circular wounds may not give information on the magnitude of mechanical stress, they do give information on the type of mechanical stress present. In certain areas skin does not appear to be under tension (tensile stress) but acts as though it is under compressive stress in all directions. The differences between our findings and Langer’s may be partly explained by differences in the properties of living and cadaveric human skin.

In certain areas our findings confirm that skin is under tensile stress, at least along the dominant axis of mechanical stress, as 49.7% of maximum wound diameters were longer than the diameter of the punch biopsy used for excision. In 1.7% of wounds skin was under tensile stress in all directions, as illustrated by the minimum wound diameter also being longer than the punch biopsy diameter.

Dimensional measurements of full thickness skin wounds have been made by other groups in several mammalian species during the investigation of wound contraction. Abercrombie et al. studied wound contraction in rabbits using \(2 \times 2\) cm wounds.\(^1\) They found that wound areas, initially measured at \(4.2 \pm 0.08\) cm\(^2\), immediately expanded to \(6.31 \pm 0.15\) cm\(^2\) and attributed this to the ‘expression of tension normally present in skin’. Billingham and Medawar found that rabbit wounds always gaped, increasing in area by up to 50%, with corresponding contraction of skin islands.\(^12\) In a later rabbit study Billingham and Russell documented that rectangular wounds with an initial area of 30 cm\(^2\) immediately expanded to 35–40 cm\(^2\).\(^13\) Four millimetre punch biopsy wounds in hairless guinea pigs were used by Davidson et al. who found that the wound edges always receded immediately.\(^14\) Kennedy and Cliff observed square wounds with areas of 6.25 cm\(^2\) and 2.25 cm\(^2\) and circular wounds with areas of 6.25 cm\(^2\) in rabbits, rats and guinea pigs and found that the wounds always gaped immediately after wounding, resulting in a wound area larger than the template used for marking.\(^15\) Kennedy and Cliff noticed differences between species with guinea pig skin being less mobile than rabbit and rat skin and gaping less. All of the species mentioned so far are loose skinned mammals in which wound edge retraction is unlikely to be

<table>
<thead>
<tr>
<th>Table 3</th>
<th>Pairs of aesthetic units which showed statistically significant differences in the ratio of the minimum wound biopsy diameter to the diameter of the punch biopsy ((t)-tests)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aesthetic unit</td>
<td>Mean</td>
</tr>
<tr>
<td>Forehead — lower lip</td>
<td>0.16</td>
</tr>
<tr>
<td>Forehead — eyelid</td>
<td>0.50</td>
</tr>
<tr>
<td>Nasal — eyelid</td>
<td>0.49</td>
</tr>
<tr>
<td>Cheek — lower lip</td>
<td>0.14</td>
</tr>
<tr>
<td>Cheek — eyelid</td>
<td>0.48</td>
</tr>
<tr>
<td>Upper lip — eyelid</td>
<td>0.44</td>
</tr>
<tr>
<td>Mental — eyelid</td>
<td>0.41</td>
</tr>
<tr>
<td>Neck — eyelid</td>
<td>0.41</td>
</tr>
<tr>
<td>Lower lip — eyelid</td>
<td>0.33</td>
</tr>
</tbody>
</table>

A positive mean indicates that the ratio for the second aesthetic unit of the pair was smaller than the ratio for the first unit.

<table>
<thead>
<tr>
<th>Table 4</th>
<th>Pairs of aesthetic units which showed statistically significant differences in the change in area from the size of the punch biopsy to that of the wound ((t)-tests)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aesthetic unit</td>
<td>Mean</td>
</tr>
<tr>
<td>Eyelid — upper lip</td>
<td>45.48</td>
</tr>
<tr>
<td>Eyelid — nasal</td>
<td>45.54</td>
</tr>
<tr>
<td>Eyelid — forehead</td>
<td>47.25</td>
</tr>
<tr>
<td>Eyelid — neck</td>
<td>49.64</td>
</tr>
<tr>
<td>Eyelid — cheek</td>
<td>52.41</td>
</tr>
<tr>
<td>Lower lip — cheek</td>
<td>22.55</td>
</tr>
</tbody>
</table>

A positive mean indicates that the change in area was greater for the first aesthetic unit in the pair.
comparable to that of humans and other mammals, such as
domestic pigs, in which the skin is firmly attached to under-
lying structures. Gross et al. noticed little change in the
shape or size of 2 × 2 cm wounds in domestic pigs immedi-
ately after excision. Catty, in a study of 1 cm² full thick-
ness wounds on the forearms of men, noted immediate
expansion of wound areas, to around 1.3 times the original
size, after skin excision.

All of the wounds discussed above increased in size after
the excision of skin with the exception of the pig wounds
used by Gross et al. which stayed the same size. This is in
contrast to the 90.3% of wounds in our study in which the
area reduced after skin excision. This may be partly ex-
plained by the size of the wounds and the microscopic
structure of skin. The largest wound in our study was a circle
with a diameter of 8 mm and hence an area of 50.265 mm².

Other than the 4 mm punch biopsy wounds (area =
12.566 mm²) made in hairless guinea pigs by Davidson
et al. the smallest wound described above was in a human
study using 1 cm² wounds.17 Our results showed that
changes in the minimum diameter of the wound and the
area of the wound were significantly different when differ-
ent sized punch biopsies were used for excision (P < 0.0001
and P = 0.0004, respectively), although this was not so for
the maximum diameter of the wound. Langer performed
microscopic investigation of skin sectioned horizontally
and found that skin fibres were arranged in rhomboidal
meshes, with their long axes in the same orientation as
his lines of cleavage, which coincided with the direction
of maximal wound edge retraction that he observed after
the excision of circles of skin. Ridge and Wright confirmed
that Langer’s lines follow the direction of the general orien-
tation of the skin fibres and proposed a lattice theory for
the structure of skin, supported by mathematical analysis
of extensimetry testing, with the long axis of the lattice
parallel to Langer’s lines.6 They postulated that, if the an-
gle between fibres in the direction of Langer’s lines was less
than 45°, the greater extensibility of skin perpendicular to
Langer’s lines, as opposed to parallel to Langer’s lines,
could be accounted for by the fact that more extension
would be required to bring skin fibres into orientation, par-
allel with each other. They also suggested that incisions
made along Langer’s lines would cut less skin fibres than in-
cisions made across Langer’s lines and would, therefore, be
subject to less tensile stress and, as a result, would gape less.

Langer suggested that the tension inherent in skin could
only be measured assuming there were no limitations on
elastic recoil. The importance of elasticity on wound edge
retraction was later suggested by Nunez, ‘our interpreta-
tion was that such (wound) elongation was produced by
the skin traction exerted by bundles of elastic fibres in
the direction of the tension lines’. This concept was ex-
anded upon by Ksander et al. who postulated that the
asymmetrical retraction seen in circular punch wounds
could be explained by ‘asymmetrical properties of the elas-
tic tissue in skin’. They used a custom designed appar-
tatus, incorporating a force-displacement transducer, to
show directional differences in wound retraction, closing
tension and the modulus of elasticity of the wound edge
calculated at the midline of the wound, parallel and per-
pendicular to local skin tension lines in pigs. Flint demon-
strated in a histological study that, in skin sections cut
parallel to tension lines, elastic fibres were arranged in
long straight bundles suggesting that they may be under
tension whereas, in sections cut perpendicular to tension
lines bundles of elastic fibres appeared short and coiled,
helping to explain why the edges of wounds cut perpendic-
ular to Langer’s lines retract more. Flint also found that
the dermal collagen fibres were arranged in ‘large open in-
tersecting diamonds’ in sections taken perpendicular to
cleavage lines, whereas, in sections taken along the cleav-
age lines these diamonds were ‘pulled out longitudinally’.

The lattice theory of Ridge and Wright may help to ex-
plain the reduction in wound size seen in our study. Wounds
with an area smaller than the size of the functional unit of
the lattice may shrink as a result of fibres being left intact,
with shrinkage occurring due to the removal of skin that
was resisting a compressive stress exerted by the fibres
(Fig. 2). Wounds larger than the functional unit of the lat-
tice may expand due to fibre transaction and loss of con-
tinuity in the unit that was providing a resultant compressive
stress (Fig. 2). The differences observed in dimensional dis-
 torsions and changes in wound area in the different

Figure 2 After Ridge and Wright. The direction of Langer’s
lines or the dominant axis of skin tension is shown by the heavy
arrow on the left. The upper rhomboid illustrates the proposed
lattice structure of skin fibres along with two hypothetical cir-
cular excisions, one larger than the functional unit of the lat-
tice and one smaller. The small arrows on individual skin
fibres represent the force resisting the skin tension present
within each fibre. In the upper rhomboid these forces are in
equilibrium. After excision the equilibrium is altered as shown
in the middle two rhomboids. In each of these the original ex-
cision is shown as a dotted circle and the distorted wound is
represented by a solid ellipse.
aesthetic units observed in this study may be explained by regional differences in the structure of skin and regional differences in the size of the functional units of the hypothetical lattice. Ridge and Wright found differences in the mechanical properties of skin in different anatomical areas which adds support to this idea. Of course, one simple reason for the reduction in size of wounds may be that a benign skin lesion has been excised which may have been exerting a space-occupying effect but, if that were the case, why did it not occur after all excisions?

1) In certain areas small wounds reduce in size due to elastic retraction in the lattice components of the skin giving the appearance of the skin being under compressive stress.

2) Larger wounds are more likely to increase in size due to the same elastic retraction in the lattice components of skin as a result of greater disruption of the lattice structure.

3) The stress inherent in skin varies with anatomical region/aesthetic unit and may be a function of regional variations in skin structure.

4) It is possible that these regional variations in stress will affect the appearance of the resulting scar. This issue will be addressed after further analysis of this cohort study.

Acknowledgements

Funding for this study was provided by Renovo plc. This work was carried out at the Welcome Trust Clinical Research Facility and Renovo, Manchester, UK.

References