

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

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ABSTRACT

Surgical literature is inundated with references to Langer's Lines, Cleavage Lines, Wrinkle Lines and Skin Tension Lines. The author undertakes a detailed literature review to understand the "state-of-the-art" regarding skin lines in cutaneous surgery and puts forward a hypothesis that incisional and excisional lines are different. While the lines mentioned above are fine for making incisions, when wound tension is created after excision of skin lesions or cancers, as opposed to creating incisions for egress, the dynamics change -- and therefore (what the author terms) Biodynamic Excisional Skin Tension Lines matter and need to be determined accurately. On bony areas like the

scalp (due to no underlying attachment of muscles and the galeal aponeurosis layer) or the lower limb (due to the vascular plane) need special considerations in cutaneous surgery. Therefore, when it comes to current practice in dermatological and cutaneous surgery, the science of skin biodynamics suggests that best excisional lines do not always conform to current surgical practice.

Key words: Langer's Lines; Cleavage lines; RSTL; Skin tension; Excision; Wrinkles; Skin; Skin cancer; Surgery

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HISTORY AND REVIEW OF CURRENT CONCEPTS OF SKIN LINES

The observation that clefts created in skin were shaped different to the shape of the injury-causing instrument was noted by Baron Guillaume Dupuytren, a French anatomist and military surgeon in 1831^[1]. Dupuytren had been called to attend an attempted suicide where the patient-history suggested that the wounding instrument was a round-tipped stiletto. Dupuytren was in doubt as to the assertions of his patient, that the wounds had been inflicted using a round-bladed stiletto, because the deformities of the skin clefts suggested an instrument with a linear cutting edge. The first published anatomical account describing "cleavage lines" was that of Karl Langer, of Vienna, in 1861^[2]. Langer was to become professor of anatomy at Joseph's Academy in Vienna^[3]. Because Langer's original paper was written in German^[4], it took over a century before his work was noted by the English-speaking plastic surgical community^[5]. However, in trying to make Langer's work available, Gibson still omitted a

considerable portion as he found the ‘descriptive anatomy most boring’^[5]. Langer used the term “Spaltbarkeit” which was translated into English as “cleavability” by Gibson, and this led to the term “cleavage lines.”

CLEAVAGE LINES

In 1892, Emil Kocher, a Swiss surgeon suggested adopting Langer’s lines as surgical lines and therefore some people called these as Kocher’s lines, based on Kocher’s writings^[6]. However, there were certain inconsistencies in these lines produced by Langer’s technique -- Malgaigne, for example, whose studies of skin texture and lines pre-dated Langer, and followed Dupuytren’s original experiments -- noted that these lines were sometimes different in people and also were not always conforming to the same anatomical pattern. However, Malgaigne did not make any specific recommendations as to their usefulness during surgery^[7].

Pathological conditions on skin have shown distributions along cleavage lines -- a report described lichen planus pigmentosus-inversus (LPMI), a rare variant of lichen planus, following the pattern of cleavage lines^[8]. The reasons for skin conditions or rashes occurring along cleavage lines is not known. One possible theory is the haematogenic dissemination of (pathologically) activated leukocytes along these lines^[9].

The theory behind cleavage lines is that when a spike is thrust into the skin, “the skin yields immediately and a tension load radiates from the struck point”^[10]. Networks of collagen assume an alignment parallel to these lines. Gibson and Kenedi concluded that when there was movement of collagen following the creation of cleavage lines, the lines of *least* extensibility are the original Langer’s cleavage lines^[11]. Eschricht’ studied the relationship between hair follicles and cleavage lines and concluded that the former mimic rivers or streams -- and that there is a correspondence between hair follicles and cleavage lines^[12].

One of the problems with cleavage lines being used as surgical lines is that there are variations between patients. For example, when Hutchinson studied cleavage lines of infants and adults, he found that in infants, these lines were annular in the extremities, whereas in adult limbs they were generally longitudinal^[13]. The question then arises -- at what age does the pattern change? We already begin to doubt their suitability as surgical lines in all ages. Studies on contracture of skin grafts and cleavage lines suggested that graft contraction was less in the direction of cleavage lines, and these findings were both consistent and significant^[14].

Langer observed that circular wounds always gaped in the same direction as his lines of cleavage^[15]. But the question arose -- was there a size that mattered, given the studies on skin grafts mentioned contractures earlier? Kennedy and Cliff created square wounds with areas of 6.25 cm² and 2.25 cm² and circular wounds with areas of 6.25 cm² in rabbits, rats and guinea pigs -- and found that the wounds always gaped upon cleavage^[16]; however, cleavage lines on pig wounds created by Gross stayed the same size^[17]. To add to the confusion, Catty then created wounds of 1 cm on the forearms of men -- and found that they expanded to 1.3 cm on average after round-shaped clefts were created^[18]. Unlike the findings on pigskin, Billingham and Medawar found that rabbit wounds always gaped, increasing in area by up to 50%^[19]. Nunez, while studying the importance of elasticity on wound edge retraction, concluded that elastin fibres were the cause of tension along skin cleavage lines^[20]. The disparity between some wounds gaping and some shrinking was explained by Ridge and Wright using the “lattice theory”^[21] --

this suggests that skin has individual components that are subject to tension forces, due to elasticity resulting in wound retraction. Wounds smaller than the rhomboidal unit (where rhomboidal pattern of collagen birefringence is evident) therefore shrink -- due to the intact tensional forces in the individual dermal components -- and larger clefts that disrupt more of the lattice structure, will gape^[22]. Bush and others in this study considered the “lattice” like Langer’s “kernel” (isolated islands of skin that were created in his experiments) wherein Langer^[23] also noted that wounds greater than a “kernel” were likely to gape not shrink -- and experiments by Bush’s team suggested that this size may be 3 - 8 mm^[24]. Ksander again reflected Nunez’s views earlier that asymmetrical retraction seen in circular punch wounds are due to an inherent asymmetry of elastic forces^[25].

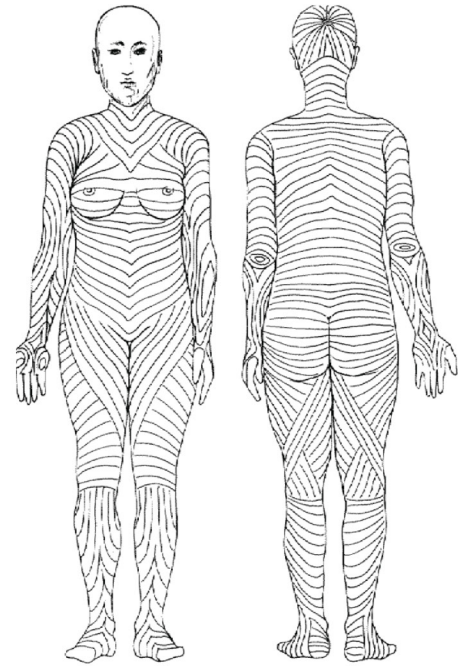
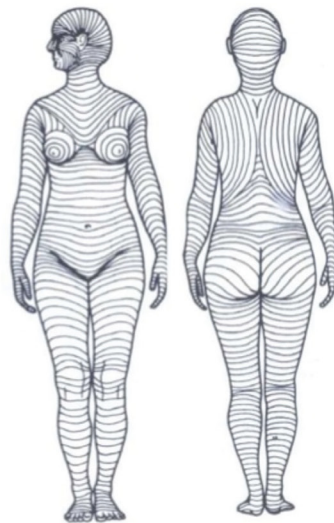
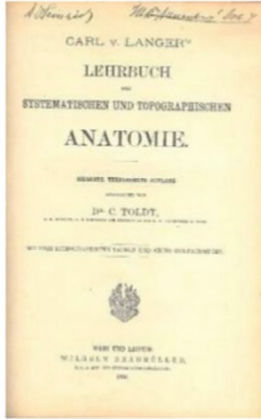
The other problem in considering cleavage lines as determined by Langer as de facto surgical lines is that they are changeable even in the same person. When Bush and others studied Langer’s lines and their variability with facial expression, they found in 171 out of 175 cases, these cleavage lines were dynamic -- with a rotational variability of up to 90°. They concluded that this rotation in the axis of mechanical tension could distort resultant scars, if these lines were used for surgical incisions^[26]. Further as Borges noted, Langer’s lines were first studied in cadavers stiffened with rigor mortis so can hardly be considered lines of relaxation^[27]. When a dissection of cleavage lines, using Langer’s original method was undertaken in Japanese cadavers, on the face, the lines seemed to have great individual variation. These authors noted “the parallel arrangement of the blood vessels and perivascular fibrous connective tissues (especially the collagen fibres) was the common histological finding obtained in all three regions”^[28].

However, many authors still advocate the use of Langer’s cleavage lines as surgical incision lines on the face. Motegi noted that an incision placed at right angles to the direction of skin cleavage lines had a higher risk of haematoma and tension, and thereby a higher risk of hypertrophic scarring^[29]. The authors explained this by pointing out that when incisions were made at right angles to cleavage lines, these ended up at right angles to the collagen fibres -- whereby the dermis stretches due to the straightening of the elastic fibres by 100-140 %^[30]. However, as we know skin behaves elastically only at low-load levels. For example, on the feet, due to weight-bearing tissues, skin reveals increased viscoelastic behaviour, i.e. strain becomes a function of load and time^[31]. These load-bearing properties of elastin fibres decrease with age^[32]. However, in the regions of the body like the toe, these factors are age-independent -- and are due to the destruction of the elastin network rather than elastin itself^[33,34]. Skin may be anisotropic, but it does exhibit orthotropy i.e. a degree of symmetry with respect to two normal planes^[35], which is due to the preferential orientation of collagen fibres^[36].

There is no doubt that Langer, the first person to study cleavage lines in detail, was a pioneer. While skin needs to be considered three-dimensionally, Langer’s experiments were essentially two-dimensional -- but began the inquisition into the surgical anatomy of skin. Indeed, since Langer’s study, 36 different lines have been described, and utilized by surgeons over the years^[37]! As Wilhelmi points out^[37], Malgaigne found cleavage lines vary in different parts of the body^[38]. Cleavage lines have also been shown to be prone to contractures when used over a joint^[39]. And, as other authors have noted, many surgeons describe “Langer’s lines” when they are in fact marking incisions in wrinkle lines^[40]. Indeed, many textbooks and authors depict Langer’s lines differently (Figures 1 and 2), and to add to the confusion many denote them as wrinkle lines. Let us now examine wrinkle lines in detail.

Langer Lines

Carl Langer Vienna Anatomist 1819-1887; impaled the skin of cadavers with a circular ice pick and noticed skin defect created was ellipsoid. He then connected the longitudinal axis of the defects. These lines correspond to the alignment of collagen within the dermis.

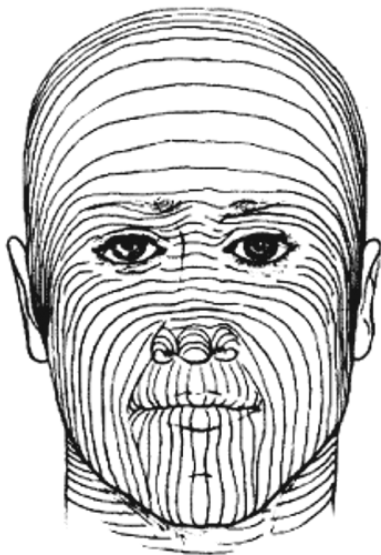


From Antoniadis S. Surgical Wound Healing Lecture. Upper Chesapeake Medical Center. 5, Sep 2014

<http://www.slideshare.net/spineant/lecture-wound-healing> accessed 22 Sept 2016

From Simon RR, Brenner, BE Emergency Procedures and Techniques. Williams and Wilkins, Baltimore, 1982

Figure 1 Differing depictions of "Langer's Lines" over the body.



Langer's Lines head from Marx J., Hockberger R, Walls R Eds. Rosen's Emergency Medicine: Concepts and Clinical Practice 2002

Langer's Lines head from The Open Access Atlas of Otolaryngology, Head & Neck Operative Surgery by Johan Fagan (Editor) johannes.fagan@uct.ac.za accessed 22 Sept 2016

Figure 2 Differing depictions of "Langer's Lines" on the head and neck.

WRINKLE LINES

One way of understanding wrinkles is to consider them as lines of dependency -- due to gravity and loss of suppleness due to age. Slackness in biological membranes such as skin manifests as wrinkle lines. Wrinkle lines satisfy the one-dimensional diffusion equation -- that typifies the behaviour under self-weight of flexible membranes supported in a vertical plane^[441]. Yet surgical reasoning sometimes confuses the dynamics of wrinkle, tension and cleavage lines. For example, some authors suggest pinching skin to determine wrinkle lines when they are not obvious, a method often described for relaxed skin tension lines that we shall discuss later in this article^[442]. Tellioglu described a technique of using a plastic adhesive sheet as a means of determining wrinkle lines^[443].

As Waldorf and colleagues noted, during a discussion on planning incisions, "Many current textbooks today show and discuss wrinkle lines and RSTLs but call them Langer's lines"^[444]. If experiments we discussed earlier in the article demonstrated the *dynamic* nature of Langer's lines, wrinkle lines, in contrast, are shown to be *static* lines. As Namiki and colleagues noted, "The orientations of facial static tensions were identical to the wrinkle lines in many facial areas. It is suggested that the wrinkle lines show the optimal directions of selective incisions in most facial areas *except* for the medial canthus and upper and lower lips"^[445].

Biomechanically, Danielson expects skin, as the soft outer tissue of the body to behave like an "elastic solid, consisting of a thin shell resting upon a continuum foundation"^[446]. In a previous paper, his team concluded that the two main factors that affect wrinkle biomechanically to be the bending stiffness of skin, and the thickness of the foundation. Bending stiffness of skin is preeminent in anatomical regions of the body where outermost tissues are extremely stiff such as the digits, and thickness of the foundation takes precedence in mobile areas such as the breasts^[447]. It therefore follows that more wrinkles will be formed where the foundation is relatively thin, such as over forehead and digits where the subcutaneous tissues are very thin.

As we age, skin loses both elasticity and recoil due to the degradation of elastin fibres. UV damage or photoaging is a major causal factor of wrinkling in sun-exposed skin^[448]. Wrinkles, for a cutaneous surgeon, in my view are essentially what geologists would consider fault lines -- and as Griffiths noted, wrinkles that we observe on skin are essentially "marked lines that represents the bottom of the wrinkle"^[449]. When skin becomes damaged due to sun-exposure one of the things that occurs is that the stratum corneum becomes drier than normal due to a lack of hyaluronic acid -- and this in turn creates a thicker, stiffer and fragile organ^[50]. Water in sun-damaged skin ends up in a "tetrahedron form" -- essentially free, and leading to a decrease in dermal compartment volume, and a reduction in the subcutaneous fat compartment of skin^[51], which is another occurrence that leads to wrinkling.

One of the problems in this author's view, of using wrinkle lines as surgical lines for excisional surgery (as opposed to merely placing incisions) is that there has been no demonstrable anatomical or histological basis that would suggest that these lines handle skin tension or load better. Many authors have studied this and concluded that there is no difference between wrinkles and the adjacent skin when observed histologically^[52]. Pierard felt that perhaps the anatomical basis for a wrinkle under the microscope lay beneath skin in the hypodermis where trabeculae of the retinacula cutis are broader in wrinkled areas^[53]. Other teams commenting on the relationship between the dermis and wrinkles -- teams led by Contet-Adonneau^[54]

and Tsuji^[55] noted decrease in actinic damage at the bottom of the wrinkle compared to its sides or adjacent skin. Some reports have noted that wrinkles may indeed be different at their depths compared to the walls of a wrinkle -- Scott and Green noted that chondroitin sulfate GAGs (glycosaminoglycans) are reduced under wrinkles, with asymmetrical variations between its flanks, probably due to differences in solar ray exposure^[56]. Herein lies one of the problems in using wrinkles for elliptical excisions after skin cancer -- on the wrinkle sidewalls, collagen fibres run parallel to the fold, whereas at the bottom, they are mostly perpendicular to the wrinkle^[57]. To complicate matters, when operating on sun-damaged skin, which is the predominant patient group when it comes to skin cancer, studies in mice have shown that collagen is mostly in a vertical, tail to head, with an orientation that corresponds to the meridian line of the body. However, in actinic damaged or UV-damaged skin, fibroblasts tend to align horizontally and synthesize horizontal collagen fibres, contradicting previous theories^[58]. Other theories suggest that decrease in dermal area, as compared to epidermal area, is one of the prerequisites for the formation of a wrinkle^[59]. Force-loads also matter -- because a loss of intra-dermal tensional strength has been noted to be a major component in the biomechanics of wrinkle formation^[60].

The current surgical understanding regarding wrinkles are, in my view, almost using geological principles that are observed during the process of buckling^[61]. Buckling involves two components -- namely Young's modulus and thickness, and therefore one can use computational methods to calculate the likelihood of this phenomenon^[62]. Kuwazaru extended this concept of buckling onto a 5-layered skin model and proposed an explanation as to why wrinkling only becomes apparent in old age^[63]. The mechanical approach to wrinkling has besotted not just surgical researchers, but also biomechanical engineers. Magnenat-Thalmann studied skin wrinkling with a three-layer model and showed a gradual enlargement of the buckling-length with aging^[64]. The proponents of the buckling theory of wrinkling with age explain it by suggesting that a wrinkle is initiated by the repetition of buckling caused by a muscle contraction at the same site^[65]. The three-layer model was shown to simulate wrinkling better than models involving fewer layers^[66]. One way of improving these multi-layer analyses is to simulate other effects of aging i.e. loss of moisture and thickness within these layers -- as there is an increase in collagen cross-links with age, which makes the dermis stiffer^[67]. Many computational methods are purely geometrical^[68] and have not replicated wrinkling and furrowing accurately enough to help surgical science^[69].

The modeling of wrinkling purely as a "fault line" or a "buckle" does not explain certain findings that indicate other biological factors at play. In animals like pigs, with age and fat deposition skin tension lines begin to run transversely, whereas in thinner animals, skin tension lines run more obliquely^[70]. Wrinkles can also simply disappear, as noted in a case of a baby with Michelin Tyre Syndrome^[71]. Furthering the research into wrinkling as a biological (rather than mechanical) phenomenon, researchers found that increased wrinkling may be a sign of impending heart disease, metabolic disorders, osteoporosis or degenerative disorders^[72]. Tybjærg-Hansen and others studied over 10,000 Danes and found that wrinkles -- especially ear lobe creases indicated the body's biological age, and was an indicator for heart disease^[73]. Studies on Shar Pei dogs show that wrinkling can be caused by mucinosis -- high hyaluronic acid levels in both cutaneous tissues and blood stream, and such high levels are due to an excess in the activity (overexpression) of the HAS2 enzyme^[74] that can, rather

paradoxically, cause wrinkling.

Mechanical approaches also do not explain accurately Borges's finding that when one pinches oneself, wrinkles become larger when they form parallel to Langer lines^[75]. Kraissl espoused a viewpoint that when cleavage lines such as Langer's lines and wrinkle lines were compared, it was the latter than were best used for surgical incisions^[76]. In support of Kraissl's theory, many other authors also concluded "wrinkle lines and RSTLs largely coincide and should be used instead of Langer's lines for planning incisions"^[77]. When studies were done on the effects of undermining skin, it was shown to not affect the configuration of skin when it came to skin lines^[78]. Others felt that wrinkle lines were best for surgery because while wrinkle lines ran parallel to muscles, muscle contractions did not affect tension within a wrinkle^[79]. And then Borges, who was widely published on the topic of skin lines, had reservations about wrinkle lines as guides for surgical incisions when he said "relaxed skin tension lines (RSTL) are the direction of constant tension in the skin while in repose, and do not always coincide with the wrinkle lines"^[80].

Relaxed Skin Tension Lines (RSTL)

After Cox^[81] and Bulacio^[82] replicated Langer's study, albeit with slightly different results, Rubin attempted to understand the relaxed tension lines of the face. Rubin presented a paper on skin tension lines, describing his method of making an imprint of facial skin lines using a chemical-coated paper^[83].

Borges first described the concept of relaxed skin tension lines (RSTL)^[84]. When the skin is relaxed, furrows are formed – these are made more noticeable by pinching skin and noting the direction of furrows and ridges^[85]. Of course, these are not to be confused with the sleep lines, skin lines formed due to posture or pillow pressure after relaxation^[86]. A decade after he first described RSTL, Borges refined the technique of determining these lines by stating that it is important to note that when pinching skin one needs to consider *both* furrows and ridges -- because when contour lines are produced by muscle of joint action, one only notes furrows^[87].

It is also important to note that while RSTL lines were non-contentious on the face – when asked about RSTL on the rest of the body, Borges generally referred to Kraissl^[88], who essentially described wrinkle lines or Courtiss's^[89] technique of using the Ω -shaped skin incision – both suggesting that the RSTL concept on the rest of the body is essentially following wrinkle lines. Given we know that wrinkle lines have no increased ability to handle load, this theory or RSTL therefore becomes biomechanically unproven -- especially when one considers areas like the scalp and lower limb -- both situations the author will be discussing in more detail. In many books, Langer's lines and RSTL are marked identically especially on the limbs creating confusion. In attempts to solve this conundrum, researchers studied the microanatomy^[90] to determine skin tension lines -- and concluded that skin tension lines are formed by the interrelation between elastic and collagen fibres, as well as fixed attachments between collagen fibres -- whereas Langer believed there was no elastin in the skin during his investigations, especially in his third article^[91]. Many surgeons believe that knowledge of RSTL on the face must be a pre-requisite for, and form part of fundamental plastic surgical training^[92].

At a basic level, resting skin tension lines matter, because there exists a positive correlation between tension and increased scar tissue formation^[93,94]. And, release of tension in a fibroblast populated collagen lattice results in cellular apoptosis^[95]. Part of the problem is, most studies have been done after creating clefts or incisions and

not after excisional surgery such as after skin cancer. The author's hypothesis that excisional lines must be bio-dynamically relevant, and differ based on bodily site and dimension is supported by the fact that the primary factor on relieving tension at skin edges-sutures-need to retain their tensile strength for 6 weeks to 6 months to be effective in preventing scar widening or hypertrophy^[96]. Neither Langer's, Borges's or any other method sought to study the effect after *excisional* surgery and this is the reason why this author's surgical research has been focused on *best excisional skin tension* (BEST) lines. In certain conditions -- such as Ehlers-Danlos syndrome type I^[97] and cutis laxa^[98], resting skin tension lines are almost absent. Therefore, whether lines of cutaneous tension have an anatomical basis is still a subject to scientific debate^[99], and have never been studied properly for excisional surgery.

Kenedi and others hoped to prepare "tension maps" of the human skin surface, that would indicate the magnitude and orientation of local tensions -- but this was not accomplished because the variations were too great with their testing apparatus^[100]. One way to consider skin is to consider it as a 3-D network of lines, with multidirectional tensions of elastic fibres and the collagen beams -- and this has in some ways contributed to the confusion between tension lines, wrinkle lines and cleavage lines^[101]. As discussed earlier, skin resistance to traction predominates in the Langer's lines direction and varies with body site. In many situations, the skin tension is greater in the direction of Langer's lines^[101], and their dynamic nature may accentuate their unsuitability as excisional lines. However, in some situations like the lower limb, the situation is different when compared to facial skin -- on the lower limbs Langer's lines are aligned along elastin fibres -- in a study 76% were in the direction of Langer lines, and 5.1% perpendicular^[101]. Skin is anisotropic i.e. has different values of tension when measured in different directions, and due to the Young's modulus, the distribution angle is maximal along Langer's lines^[102].

Stark developed a special compass-like instrument (each measurement only took 1.5 seconds) -- and noted that direction of the maximum tension can be found by stretching the skin using his device with equal force -- and this direction of minimum elongation is aligned along Langer's lines^[103]. Borges's method, widely used in surgery is possibly the least accurate, especially in areas like the scalp or pretibial areas overlying bone. This is because other than the face, Borges's lines follow Langer's lines, and in directions against Langer's lines, they are impeded by the skin tension that ends up making them irregular^[104]. Barbenel used a suction method to understand skin tension -- his theory suggests that when the contour of a chamber is drawn in during suction and when this chamber is removed -- an oval outline is observed instead of a circle, and its main axis corresponds to Langer's lines^[105]. Others like Zahouani experimented with using 3-D imaging -- three-dimensional imaging of skin using a "signature" printed on the surface of the stratum corneum^[106,107]. It is clear from all these different methods achieving different results that skin morphology contains a network of lines whose organization reflects the multi-directional nature of elastic and collagen fibres in the superficial dermis^[107] and therefore all these lines are suitable for making incisions, but when it comes to excisional surgery especially for larger wounds, these may not be accurate.

Hashimoto^[108] classified skin morphological lines by mapping this ultrastructure: with a precise four-level classification: (1) The primary lines are clearly marked and are between 20 and 100 μm deep; (2) The secondary lines are more discrete and correspond to a depth of 5 - 40 μm and are perpendicular to the primary lines; (3) The tertiary

lines correspond to the corneocyte border (about 0.5 μm); (4) The quaternary lines correspond to the morphology of each corneocyte (about 0.05 μm).

Hashimoto also concluded that lines of type (I) are ones that are visible on pinching; lines of types (III) and (IV) are not visible without microscopy^[108]. Analysis of skin tension lines of Caucasian women aged between 20 and 80 years, shows a decrease of the density of lines of depth < 60 microns and an augmentation of deep lines beyond 60 μm -- the former is due to elastin and the latter are what we note as cleavage or tension lines^[109].

One of the main reasons why incisional and excisional lines must be considered differently is because of the properties of skin extension under load -- to begin with there is a rapid increase in length for very small increments of force; towards the end, relatively small extensions result from relatively large increases in force^[110]. Morgan noted that the final part of this curve is almost identical to the force obtained when testing pure collagen^[111]. Studies have also shown that when skin is stretched and thickness of skin is measured, there comes a time when the volume decreases^[112]. This is especially why in thin actinic-damaged skin on the lower limb, excisional lines end up different to resting skin lines or wrinkle lines -- resulting in skin grafts when pinching skin indicated that primary closure would be possible otherwise.

When it comes to excisional lines, the two important parameters are closing tension and extensibility i.e. how far margins can be advanced^[113], and these three forces -- midline modulus, closing tension and terminal modulus^[113] can be calculated using the modulus of elasticity^[114]. Some authors propose that parallel arrangement of collagen and elastin fibers is to allow collagen fibers to buckle to allow for extension of elastin fibers at low strains^[115]. At high strains, the collagen fibers bear the load by straightening^[115]. We also know that when it comes to excisional surgery, mechanical response of the skin can be highly asymmetric -- and becomes a function of the locus and direction of the applied force vector^[116]. Because the SMAS (superficial musculoaponeurotic system) layer on the face places certain parts of the face under constant tension this asymmetry is amplified^[117] and that is why RSTL lines end up most suitable on the face -- however this isn't the case on the rest of the body. The other issue on the face is that there is improvement due to moisture of the skin -- for example studies done showed that the tension dissipation region is increased by 28% after 1 month of moisturizer use^[118]. To summarize the relationship between collagen and elastin, given the role of the latter in cleavage lines has been discussed -- collagen fibers exist as a biaxial orientated wavy fiber network in skin^[119]. Elastin makes up 2 to 4% of the dermis and is entwined with collagen in varying thickness and density^[120]. Internal forces are transmitted from the muscles through the dermis to the epidermis and generate skin deformation that we note as skin tension lines.

SPECIAL SITUATIONS: SCALP AND LOWER LIMB

What determines scar-formation is what happens at the dermis layer of skin -- in fact, 75% of the dry weight of the dermis is due to collagen^[121] -- and in the scalp this is important due to the galea (aponeurosis) layer attached to the dermis. Given the occipitofrontalis muscle on the scalp, skin lines we have discussed behave differently on the scalp when compared to other areas -- for example, Kraissl's^[122] lines run transversely (coronal), whereas Langer's lines run vertically (sagittal) and while Borges's lines are in the same direction as Kraissl's lines, they are not identical^[123]. If

we decide to measure wound tension across the scalp, essentially, there are two methods -- Harvey's technique^[124] is one of determining intraluminal pressure to disrupt a wound, while Howe's method^[125] is measuring forces required to pull apart a wound. However, in both these techniques, there has been a difficulty in the experimental method used being convenient and consistent. Previous authors have also commented on the lack of information about the forces needed to close a wound after excisional surgery^[126].

The scalp is also unique because the presence of hair follicles and their relationship to skin lines. Many authors have commented on the relationship between Langer's Lines and hair follicles -- experimental studies have shown that there is a good correlation between Langer's Lines and direction of hair streams^[127].

When it comes to surgical planes, we remember from our medical school days that the layers of the scalp are easily remembered by the mnemonic SCALP: S (skin), C (connective tissue), A (aponeurosis), L (loose areolar tissue), and P (pericranium)^[128]. Skin can be easily freed up during cutaneous surgery once one is working in the loose areolar tissue plane. Stress relaxation and creep are two viscoelastic properties that aid scalp wound closure -- stress relaxation is defined as the decrease in the amount of force necessary to maintain a fixed amount of skin stretch over time; creep is the gain in skin surface area that results when a constant load is applied^[129]. Both these also make the scalp especially suited to the use of saline expanders, sometimes for several weeks or months^[130] or even rapid intraoperative expansion^[131]. Camirand and Doucet compared parallel and perpendicular hairline incisions, and concluded that incisions perpendicular to the direction of the hair follicle allow hair to grow through the hairline incision and give a more natural cosmetic appearance^[132]. More than anywhere else, rotational skin flaps are employed on the scalp to close larger defects and single, double and triple flaps have been described in detail^[133]. Reducing wound tension is especially important on the scalp because when perfusion pressure drops below a critical closing pressure of the arterioles in the subdermal plexus, nutritional blood flow ceases and flap ischemia occurs^[134].

We know that if stress-relaxation is repeatedly applied over time deformation of the skin will result in permanent elongation^[135]. The scalp tissue's stress response to displacement is tri-phasic^[136] -- initially linear (load range: 0 to 500 g), the scalp's compliance gradually reduces (load range: 500 to 1500 g) and eventually shows an exponential stress-strain characteristic of rapidly increasing stiffness (load range: 1500 to 5000 g).

However there have been very little biomechanical tension studies on scalp skin lines to understand the concepts of cleavage, tension and wrinkle lines we have been discussing, and the author has already developed a bi-directional, real-time tensiometer^[137] with the specific purpose of determining and determining Biodynamic Excisional Skin Tension (BEST) Lines for cutaneous surgery -- and this device was first tested on the scalp^[137].

The skin tension problem is further complicated by the problem of poor vascularity, especially in older, actinic damaged patients^[138]. To overcome this problem, many authors have planned island flaps on the lower limb that incorporate fasciocutaneous tissue^[139] -- but these often need identification of perforators using a Doppler probe^[140], or are confined to specific pre-determined anatomical locations as in the case of the keystone design island perforator flap^[141]. In all non-islanded flaps, where the subdermal plexus is retained, there is a suppressive effect on vascular dynamics^[142]. After all, one of the reasons for island flaps in the first place is to try and improve cutaneous vascularity. Notably after experimental studies on island

flaps, Milton concluded that, “an island is safer than a peninsula” -- because when a flap is “islanded” it tends to almost solely depend on the vena comitantes rather than its arterial circulation^[143]. However, the problem with these island flaps is that they may offer solutions regarding vascularity, but when it comes to wound tension or handling load, they are inadequate -- especially when larger skin lesions have been removed. Random cutaneous flaps have fared poorly on the lower limb and probably because most flaps have been raised superficial to the deep fascia^[144]. Haertsch conducted a dye-injection study on 22 post-mortem legs that demonstrated the role of the fascial plexus and his studies showed that skin flaps in the leg can only perform reliably if the deep fascia of the leg is included -- concurring that for practical purposes, the “surgical plane” of the leg is deep to the deep fascia^[145].

In making a statement that “the keystone flap: not an advance, just a stretch”^[146], Douglas’s team suggested that the complete relaxation of skin in one axis (from in vivo length) does produce modest tension benefits in the orthogonal axis. However, the amount of increased orthogonal stretch was in the order of 1 mm, “a very minimal and dubious benefit”^[147].

CONCLUSION

Elliptical incisions or cutouts while excising skin cancers are the norm -- and lowering skin tension that may result after excision is paramount for complication-free surgery. Therefore, proper planning is very important while planning incisions and closure^[148]. We have discussed the differences (and similarities) that exist between Langer’s lines, wrinkle lines and relaxed skin tension lines (RSTL). An improperly oriented excision may mean the difference between primary closure or a skin graft following excision of a skin cancer^[149]. While undermining the wound reduces tension^[150], incorrectly placed scars result in unsightly cosmetic outcomes. The most important conclusion we can draw from this review is that wrinkle lines, RSTL and Langer’s lines are (and have been considered) acceptable and have been employed by many surgeons. However, when wound tension is created after *excisional* surgery, the dynamics change and these situations have not received the same surgical scientific attention.

If all these skin lines have not caused enough surgical scepticism, then we can add maximal skin tension lines (MSTL) to this mix. MSTL lines are especially confusing when Leshin discusses these as “lines of surgical excision” and suggests methods of determining MSTL^[151] thus: “The simplest approach is to pinch the skin in all directions to determine where the tension on the skin is least. Maximal wrinkling occurs with pinching in the direction of the short axis of the planned excision. Alternatively, having the patient move the underlying muscles by grimacing or smiling may unmask these lines”^[151]. Is this not the same technique to determine RSTL? Are wrinkle lines now being advocated as excisional lines instead of RSTL? Leshin’s MSTL have been described as not always congruent to RSTL^[152], or conforming to wrinkle lines^[153] or to the action of underlying muscles^[153]. Pinkus described “folding lines”^[154] that he thought would serve for surgical excisions but they are also confusing and too many to recall easily. Kraissl’s lines can be considered antimuscular lines^[155] and therefore only useful for incisions (for surgical egress) or excisions (of small defects) where the load is low^[156]. Striae distensae, a reflection of cellular, fibrillar, hormonal, and mechanical alterations -- lines that are implicated in various pathological and physiological conditions -- have also been described by authors as a possible alternative while planning surgery^[157].

Another problem with all these lines when considered individually

is that they seem to differ in different textbooks, and people have not hitherto separated incisional and excisional lines while studying them.

Lines for surgical egress that work in conditions of low tension are not necessarily suitable for excisional surgery -- and that’s why this author has introduced the term *Biodynamic Excisional Skin Tension* (BEST) Lines, and has been studying, mapping and publishing details regarding the orientation of these lines.

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