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CHAPTER 7

BURN SCAR ASSESSMENT - A SYSTEMATIC REVIEW OF OBJECTIVE SCAR ASSESSMENT TOOLS

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Abstract

Purpose

All deep second and third degree burns are at risk to develop hypertrophic scars which can severely undermine the quality of survival. To assess the severity of scarring, several technical devices or tools have been introduced to evaluate one or more aspects of the scar, enabling comparison of different treatment protocols and allowing an objective follow-up. The objective of this study was to review which tools can be used in objective burn scar assessment.

Basic procedures

The Systematic literature search involving PubMed, the Web of Science (incl. Science Citation Index).

Main findings

51 articles with burn scar assessment as main topic were found. Several characteristics of the scar can be assessed, such as color, metric features and elasticity, but none of the available tools covers the whole aspect of the scar. Especially subjective factors such as pain and itching cannot be assessed with those tools, in spite of their great impact on the patient's quality of life.

Conclusions

Scar tools enable objective and reproducible evaluation of scars, which is essential for scientific studies and medico-legal purposes, and in selected cases for the clinical follow-up of an individual patient. Further studies to evaluate these tools on scars are nevertheless required.

Introduction

In the past decennia, major improvements in burn management have resulted in a substantially increased survival of severely burned patients[1-3]. Unfortunately, this has not always been paralleled with a similar increase in quality of life for these patients[4,5]. One of the major long-term problems in burn care is the formation of hypertrophic scars, which lead to aesthetical but also functional problems (e.g. contractures) and also cause a considerable psychological burden. Therefore, even the early burn treatment is guided and influenced by the risk of hypertrophic scar formation. The assessment of the natural healing potential is for example based on depth assessment, which also predicts the risk of abnormal scarring. The critical depth for excessive scar formation is in the deep dermis meaning that superficial burns should heal without leaving a scar, while deep burns always are 'at risk'[6-9]. Consequently, the longer the healing, the higher the risk of hypertrophic scarring[10]. The general rule in burn surgery is therefore to operate burns which will not heal within 2-3 weeks after the initial trauma[7,11,12].

To assess the severity of scarring, several scar scales have been developed over the last 30 years, of which the Vancouver Scar Scale and the POSAS scale (Patient & Observer Scar Assessment Scale) are the most widely used[13-16]. Scar scales include several variables such as color, extent and may even contain subjective factors such as pain and itching which are subject to major inter-patient variations. In general, scar scales are considered to be a subjective scoring system, because it is susceptible to important variation between different assessors (inter-assessor variation). To obtain a more objective evaluation of the scar, several devices or tools used in other medical specialties or even in the industry (e.g. assessment of textile color, elasticity of plastics) were introduced for the assessment of scars. These tools should provide a more objective and reliable evaluation of the scar, by a better reproducibility and lower inter-assessor variation.

In this overview we only focus on the scar tools, addressing the applied physical principles, and mentioning the most commonly described tools used for burn scar assessment.

Methods

Criteria for considering articles for inclusion

Articles dealing with non-invasive burn scar assessment with technical devices as a major topic were included. Scar scales without any technical analysis are excluded as well as histopathologic evaluations of scar biopsies. Articles comparing the influence of wound or scar treatments were also excluded.

Search methods

We conducted a systematic literature search involving PubMed and the Web of Science (which also contains major congress abstracts)[17,18]. The Cochrane Library did not contain relevant articles. We searched PubMed from 1960 until February 2009 (date of search 18 February), using the Medical Subject Headings (MeSH) 'Burns' and 'Cicatrix' (**Figure 1**). This search retrieved 1974 articles, whereof only articles with those terms as major topic were included, and the MeSH 'burns' were not exploded, excluding articles about chemical, electrical, eye and sun burns and inhalation injury (n = 928). Limits were set to English, French and Dutch articles about human studies (n = 597). The MeSH terms 'Surgical flaps' and 'Neoplasms' excluded irrelevant articles dealing with flap surgery (n = 78) and cancer development in burn scars (n = 91). From the remaining 428 articles, 67 articles were selected based on title and abstract, of which 30 articles corresponded with the inclusion and exclusion criteria[19-48].

We also searched the Web of Science on the terms 'scar', 'cicatrix', 'burns' or 'burn', but this search was too wide, because, even after language selection, it led to almost 44,000 hits. Therefore, more strict combinations were performed ('burn', 'burns', 'thermal injury', 'cicatrix' and 'scar'), leading to six additional articles[15,49-53].

After searching reference lists and Science Citation Index of the relevant articles, 15 additional articles were included[54-68]. We finally selected 51 articles, including six reviews and editorials.

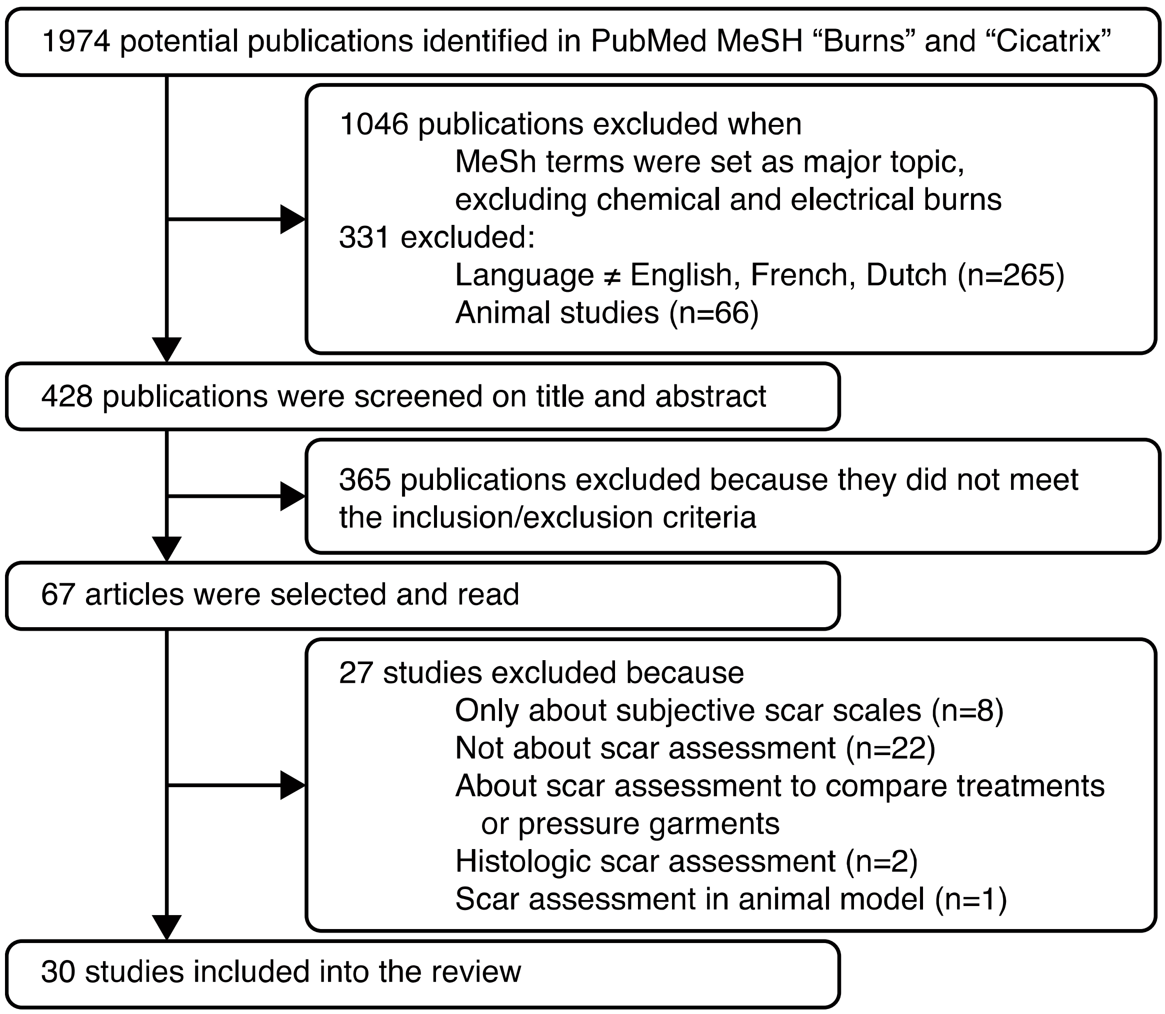

Figure 1. Flowchart of the systematic literature search (PubMed).

Quality assessment

Reproducibility of the assessments of these tools is evaluated (if described), and if possible the additional value of the device compared with visual assessment (e.g. with the scar scales) and/or other tools is discussed. The amount of articles (number of references) discussing a certain technique for scar assessment also reflects the relevance of implementing a similar device in clinical practice and its current popularity.

Results

Original articles, reviews and editorials dealing with burn scar assessment were retained. We chose to classify these tools into 4 groups based on the assessed variables: (A) color (vascularization, pigmentation), (B) metric variables (extent, height and volume), (C) biomechanical properties (e.g. elasticity, stiffness) and (D) physiologic changes (e.g. hydratation).

Colour evaluation

Color is probably the most complex characteristic of a scar and is mainly composed out of 3 components: the brown melanin pigment, the red oxyhemoglobin in the cutaneous vasculature (amount and oxygenation of blood vessels) and the yellow/ orange bile and carotene pigments[39]. The thickness of the skin layers, the reflection from the skin surface (texture) and the circumstances (e.g. temperature, light) also influence the color perception[38,39,69]. When using video or photographic images, these are strongly influenced by the settings of the camera (e.g. aperture, shutter-time) and the circumstances (e.g. light, temperature)[59].
Visual assessment is an effective but subjective way to evaluate color, with a considerable inter-observer variation[15]. Although the observer may distinguish thousands of colors, the human brain cannot reliably and accurately quantify the color or its intensity[15,31,33,42]. Moreover, memorizing colors is difficult, complicating the quality of scar color ratings for follow-up[33]. Therefore, several tools are developed to evaluate color in an objective and reproducible way, classified by the used principles: (1) reflection or absorption of light, (2) laser based methods and (3) computerized analysis of photographs.

Reflectance and absorption of light

It is not possible to obtain a perfect correlation between skin melanin or blood content and skin color[30]. Therefore, the optimal method to assess skin color is not histologic or chemical but spectrophotmetric[30,56,70,71]. Spectrometry is based on the reflectance and absorption of light and describes (i) the brightness and changes along the red-green and yellow-blue axis or (ii) the absorption of red and green light by melanin and hemoglobin respectively, resulting in the erythema and melanin index[30].

Different devices are used for color analysis of scars and skin diseases: (i) tristimulus colorimeters such as the Minolta Chromameter® (Konica), Labscan® (HunterLab) and the Micro Color (Dr. Lange GmbH), and the (ii) narrowband simple reflectance meters such as the DermaSpectrometer® (Cortex Technologies) and the Mexameter® (Courage&Khazaka)[20,27,52,71]. These tools assess the vascularity and pigmentation better than scar scales and enable immediate 'on-site' evaluation[20].

Laser based methods

The laser based methods assess the bloodflow and apply red or near-infrared wavelengths[33]. A considerably higher bloodflow is noted over immature burn scars, due to a higher vascularity. Structural changes may nevertheless interfere with perfusion measurements[33,73].

The Laser-Doppler Flowmeter (LDF) is used for the evaluation of cutaneous bloodflow to evaluate scar color[15,30,42,59,60,66,72]. It measures the flow over a small location, limiting its value for extended, heterogeneous surfaces[59]. This flowmeter is less sensitive than simple visual assessment of erythema and is therefore not recommended for color assessment[66]. The Laser-Doppler Imaging (LDI) is a laserbeam which is used to scan several points across a tissue surface, generating a 2D color coded image directly related to the bloodflow[19,31,33]. It is used for burn depth assessment[7,74-77] but can also be used for scar evaluation, with fast and reproducible results[19,31,33]. Another alternative is the Laser Speckle Imaging (LSPI) which uses digital image-processing techniques[31]. Moving red blood cells create dynamic interference patterns that change in time. The bloodflow maps are generated by coherent light reflected from stationary tissue producing a highly contrasted speckle pattern remaining static in time. LSPI allows for zooming in and increasing the resolution on a smaller field of view, in contrast to the LDI[31].

Computer analysis of colour

Even standardized photographing fails to compare scars objectively when analyzed by the human brain[30,66]. Therefore, several computer programs were developed to assess (digital) photographs[59,60]. At first, color photographs were converted into black and white (BW), because of its less complex electronic make-up[60]. The HSV-method analyzes three different aspects of color: the hue (dominant wave length e.g. red), the saturation (amount of white) and the value (amount of black), which are important in discriminating between colors, whereas in practice, differences in value mostly reflect varying levels of illumination[66,78-82]. The colors can also be represented as combinations of the amount of red, green and blue ('primary colors') (RGB model)[15,30,66], or by the proportions of cyan, magenta and yellow ('secondary colors') and black (CMYK model). These 3 color models are equivalent and conversion between them is simple[41]. A card carrying standard colors (e.g. Pantone®) is used to frame the scar so that every picture would include areas of known color properties[34,58]. Hereby, the influence of lightening conditions and camera settings can be subtracted, enabling an objective color evaluation[30,38,41,65,66].

Metric variables

Planimetry

Planimetry (or measuring surface area) is used to assess the extent of a scar and to detect contraction in time[15,30,41,65,66]. The main problem is that scar margins become more difficult to delineate during scar maturation. Tracing these margins on clear plastic film and photography are most commonly applied[66]. Photography is readily available, accurate and reliable (especially on flat or moderately curved surfaces), but standardized conditions are essential (distance, light, camera settings). Computer programs e.g. Image Tool® (C.C. Wilcox) can be used to determine the percentage of hypertrophic scars over the total scar area[30].

Height and volume assessment

Up to nine-fold increases in thickness have been described in scar tissue, but decreases can also be present[46]. Hypertrophy and atrophy are quantified by measuring scar thickness or volume. The height of a scar can be evaluated subjectively but inaccurately, since the portion of the scar below the surface is not included[44]. Some authors recommended histologic analysis of biopsied tissue (invasive technique), but skin biopsies may change in thickness when released from the tension and support provided in situ[30,66]. It can also be questioned if the biopsy site is representative[44]. Negative- positive moulds or replicas were used to make a 3D copy, accurately indicating height, extent and general appearance of a scar[46,66,67,83]. This technique can be combined with photographs and tonometric assessment, and is also useful for evaluating the roughness[46,60,66,84]. High frequency ultrasound (5-20MHz) tools such as the Dermascan® (Cortex Technology) provide reliable and accurate quantitative information on scar thickness[22,26,35,40,44,48]. It is very sensitive in the localization of scar tissues, distinguishing them from normal skin, and for assessment of thickness and delineation of the extent of the scar[40,44,65]. Therefore, portable devices e.g. TUPS (tissue ultrasound palpation system) were developed, facilitating clinical application. Although 3D ultrasound is available for clinical application, it is not widely used in scar evaluation because of its high costs[26]. MRI has been used for the evaluation of normal skin but has not yet been applied on scars[15].

Three dimensional techniques

Highly sophisticated, often expensive 3D methods became available for volume assessment, planimetry and analyzing roughness, including the use of full-body morphometric scanning, range scanners and 3D reconstructions (e.g. Vivid 900, Konica-Minolta and Vectra 3D imaging system, and Canfield Imaging Systems), but scientific studies assessing burn scars remain scarce[30,41,54,64,65]. Advantages are the fast and direct, non-contact measurement of the surface and volume of the scar, macro- and micro-topometry, high resolution, high precision, and ease of handling[60,85]. Range scanners project a light pattern onto a scene, which is photographed by a regular camera[38]. If the skin surface is uneven, which is the case in hypertrophic scarring, the projected light pattern appears distorted, which enables inferring the depths of points in a scene[38,52].

Biomechanical properties

Elasticity or stiffness

Several mechanisms can be used for evaluation of elasticity or stiffness. The elasticity of the skin is the property to return to its original shape when the stress is removed which caused deformation (e.g. external forces). Stiffness is the resistance of an elastic body to deformation by an applied force and can be quantified easier than elasticity. These methods described here originate from dermatology (e.g. Cutometer®, Dermaflex® and Dermal torque meter®), ophthalmology (tonometers) and from industrial applications (durometer). These 'elastometers' can be classified by the applied biomechanical forces[66], which can be in a vertical direction: (i) suction or (ii) pressure; or horizontal: (iii) torsion or (iv) extension.

1. Suction methods: a controlled negative pressure is exerted over a small area of the scar, resulting in a skin deformation which is analyzed by a computer[35,37,38,51,52,86]. The Cutometer® (Courage&Khazaka) proved to be highly reliable and reproducible for burn scars except for the most severe scars[23,24,51,68,86], but the size of the tool can be considered impractical[30]. The Dermaflex® (Cortex Technology) is an alternative device with a larger diameter of the suction chamber (10 mm vs. 6 mm), but no scar assessment trials have been published yet[49,66].
2. Pressure methods or 'tonometers'[38,66] originate from measuring intra-ocular pressure[43,48] and hardness of metals and plastic[57,87] and calculate the power required to produce a certain deformity[43]. Several devices are developed and evaluated for skin elasticity measurement[87], of which several prototypes were tested on scars: cicatrometers[48], pneumatonometers[30,62], tonometers[25,28,43] and durometers[30,57]. They produce good results, but cannot be applied on scars above bone structures[66].
3. Torsion methods[49,66] such as the Dermal Torque Meter® (Dia-Stron Ltd.) measure the torsion force needed to deform the skin. Only one scar study has been published, which reports resemblance with measurements with the Cutometer®[49,66].
4. Extension methods or 'extensometers'[66] stretch the skin between two tabs to assess differences in extensibility or stiffness. This method has been described for scar evaluation[38,50,66], but scientific results are scarce[68].

Acoustic methods

Sound waves (5-8 kHz) are used to detect heterogeneity in the scar tissue, e.g. Shear Velocity Device, Reviscometer® (Courage&Khazaka)[36,66]. A higher velocity (or speed) of wave transmission indicates a more dense structure (less deep penetration of the waves), correlating with a higher degree of stiffness, related with scar contraction[36]. These waves lie within the spectrum of normal hearing (which is 20Hz-20 kHz) and penetrate deeper in the skin than the ultrasound waves (5-20MHz), but both techniques have not been compared yet for scar evaluation[36].

Disability measuring

Because contractures primarily occur in joints, burn scars often compromise mobility. The mechanical impairment can be estimated by measuring the range of motion of a joint and is even included in some subjective scar assessment scales[88]. The range of motion can be measured with goniometers (Greek for 'measuring an angle')[66,89,90]. This term is used for simple plastic tools as well as computerized devices[91].

It is also recommended to measure the disability itself (coordination, strength, skin sensibility)[66], e.g. by assessing daily life activities e.g. hand function[66]. The faciometer® is an electronic device originally developed to assess the results after reconstructive surgery in cases of facial palsy. It consists of two calipers connected to a digital display, showing the actual distance between the calipers. Measurements of distances between specific stable and moving points are made at rest and after standardized maximal and submaximal (mimic) movements, enabling a 3D analysis[53]. This tool proved to be useful for objective description of results after surgery for facial burns[53].

Pathophysiologic disturbances of the scar

Transcutaneous oxygen tension

Scar maturity has been related to transcutaneous oxygen tension[15,52,55,61] which can nowadays be measured with electrodes on the skin (previously by subcutaneous needles)[61]. It is based on redox reactions occurring in the electrode modified by the inclusion of a heat source measuring the oxygen and the carbon dioxide that diffuses through the skin[92]. In hypertrophic scars the PO2 is lower than in healthy skin, but an increase is described which correlated with clinical improvement over 60 weeks of therapy[55,61]. This technique seems to be abandoned for scar assessment, but is still used to assess limb ischemia[92,93].

Transepidermal water loss and moisture content

The skin acts as a barrier against permeation of external substances, as well as the water evaporation from the internal living tissue[52]. The water content in the skin preserves the softness and smoothness of the skin surface[52], and this can be measured directly or by the transepidermal water loss (TEWL)[52,56,94-100]. TEWL is strongly related with the moisture content of skin and can be measured with open or closed (insensitivity to external air currents) chamber systems. The open systems (e.g. Dermalab TEWL module, Tewameter®, Courage&Khazaka) are the oldest and still most widely used[52]. The advantages of the closed chamber systems (VapoMeter, Delphin Technologies) need to be determined[95].

Another method measures the hydratation of the skin surface (stratum corneum), which is directly proportional to retention of electrical charge, and can be measured by e.g. Skicon-2001 conductance meters (I.B.S. Co., Ltd), CorneoMeter® (Courage&Khazaka), and the DermaLab® (Cortex technology, also measures TEWL and elasticity)[52,56,99,101,102]. These techniques are popular in the cosmetic industry, but also useful for evaluation of contact dermatitis and burn scars[52,56,94]. Scar sites are dryer than control sites and seem to become dryer as they mature[52,56,94,100]. The effect of environmental factors such as humidity (sweating) should be avoided, and showering and topical products are not allowed hours before measurement[56,103].

Discussion

Because hypertrophic scars are one of the major long-term problems after severe burns, scar prevention, treatment and assessment are of utmost importance. However, scar assessment is still a neglected area in the burn care, and a consensus about the ideal scar scale or tool is still lacking, probably due to the scarce amount of scientific studies. Several tools are currently promoted for (burn) scar evaluation, but these tools are mainly developed and commercialized for dermatologic use or for the cosmetic industry. Consequently, reference material for scar tissue is usually lacking, and no trials have been performed to compare the different tools for scar evaluation. Nevertheless, for most devices, the evaluation of skin or scar tissue should always be compared with a reference area of the patient, e.g. the other arm, because skin properties may vary considerably depending on the location on the body. The most important characteristics of the scar which can be analyzed by scar tools are the color, the thickness, the stiffness and the measurement of transepidermal water loss. These can all be assessed by different biomechanical techniques (sometimes combined in one device), with various degrees of complexity. The test results are preferable directly registered or integrated automatically in the computer system.

The question may rise what the therapeutic consequences are of evaluating scars, if you already use all preventive measures currently available. Nowadays, it is still difficult to predict which burn wound will certainly result in hypertrophic scarring and therefore preventive measures such as pressure therapy, splinting and silicones have become routine practice for all deep, extended burns in most burn units. Yet, it is useful to have an objective method to evaluate the degree of maturation of a scar, because it enables early adjustment of the therapy by introduction of extra preventive measures or earlier treatment e.g. by corticoid injections.

There is no doubt that objective scar assessment by scar tools definitely has an additional value in scientific studies, because different scars can be described and analyzed in more detail and compared mathematically. Therefore tools are statistically superior to scar scales and pictures; however the number of assessed variables is more limited than in scar scales. The role of scar tools in the daily clinical practice is less clear, because the tools are often large and expensive and increased workload, time and costs. For this reason, scar scales are considered more cost-effective and can also be used more easily in clinical practice (optimally combined with digital photographs). However, the scales are less objective than the tools due to the large inter- and intra-observer variation. In the (near) future, scar tools should become more accurate and reproducible than scales, and should detect derailment of the scar maturation earlier on, enabling earlier adjustment of therapy. Yet, at this stage, it is not possible to point out one ideal tool, and the optimal balance between accuracy, clinical and cost-economic applicability is still not reached within one single scar tool. Which tools will become more important will also be guided by the insight into the pathophysiology of scar formation. Recent studies report for example the major impact of the moisture content in scar maturation[104]. Further comparative clinical trials are required to compare the reproducibility and accuracy of the scar tools.

To conclude, advances in technology resulted in several new promising techniques, but more scientific studies are needed before these scar tools can be implemented in the scientific and routine burn assessment. Besides scar tools, which can only assess a limited number of characteristics, an additional clinical evaluation will remain necessary, preferably by applying digital photography and a scar scale including the patient's perception of their scar (including pain, itching…) and the impact of the scar on the quality of life.

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