Silicones in the rehabilitation of burns: a review and overview

Eric Van den Kerckhove a,b,*, Karel Stappaerts b, Willy Boeckx c, Bert Van den Hof d, Stan Monstrey e, Alain Van der Kelen f, Jan De Cubber g

Abstract

This article gives an overview of the use of silicones in the treatment and prevention of hypertrophic (burn related) scars. Of all non-invasive treatment modalities the use of continuous pressure and occlusive contact media, e.g. silicones, seem to be generally accepted as the only ones that are able to manage hypertrophic scarring without significant side-effects. A summary of the current opinions of the assumed working mechanisms of pressure as well as silicones is given. The use of silicones, either alone or in combination with pressure, is discussed. The recent development of custom made silicone devices has led to combinations of both modalities. Some of these, including the inflatable silicone insert systems (ISIS®), are shown and discussed. © 2001 Elsevier Science Ltd and ISBI. All rights reserved.

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1. Introduction

Aesthetic and functional outcome have become increasingly important as overall mortality from burn injury has decreased. The development of hypertrophic scarring is one of the most common and frustrating problems after burn injury, due to its functional and aesthetic consequences.

These scars, which usually develop after 6–8 weeks after reepithelialisation, and usually after a burn injury that has involved the reticular layer of the dermis, are typified by the following characteristics: the scar presents with a red to deep purple colour of the scar which reflects an enhanced microvascular regeneration [1]. The capillaries have thick endothelial walls, which provoke a hypoxic granulation [2]. As a scar hypertrophies, it becomes more elevated, firm, warm to touch, hypersensitive and itchy but the lesion remains within the confines of the original scar [3]. The elevation, firmness and retraction of the scar is probably due to an overabundant collagen deposition as a cellular response of the fibroblast during the proliferation phase of wound healing [4,5]. The contraction of the scar has been linked to the presence of fibroblasts with contractile properties, called the myofibroblasts [2,6].

Generally, a period of at least 6–18 months is required for maturation of burns scars at which time the redness (erythema) of the scar subsides, the scar no longer appears inflamed and the scar contracture diminishes [7].

Many factors can influence the presence or severity of hypertrophic scarring after a burn injury. Genetic predisposition, race, anatomical location of the burn, age, depth of the burn are some of the factors that are known as ‘uncontrollable or extrinsic factors’ whereas infection, type of wound healing (surgical intervention or not) and tension are factors that can be considered as ‘extrinsic or controllable’ factors [4,8–10].
1.1. Approaches to therapy: pressure therapy

Application of local pressure to help regulate abnormal scar formation has been used for nearly 200 years [11].

In the late sixties, Dr Silverstein at Brooke Army Hospital in San Antonio observed that, in a patient with burns, vascular support garments for the treatment of a postphlebitic syndrome decreased scarring after a burn injury and Larson noted the same effect with pressure-exerting splints on scar tissue [12,13]. The use of compression in the prevention of burn scar hypertrophy was then further popularised by Linares and co-workers at Galveston Shriners’ Burns Institute at the beginning of the seventies.

Substantial work was carried out by Kischer and co-workers [14] in relation to the working mechanisms of pressure, in order to support its use. In 1975, these authors reported a reduction in fibroblast content, total chondroitin-4-sulfate and cohesiveness of collagen fibres in pressure treated hypertrophic scars. Under electron microscopy they noted a more rapid disappearance of the collagen nodules that are normally found in hypertrophic scars and reorientation of the collagen bundles parallel to the skin surface. Furthermore, large bundles of collagen fibres convert to smaller groups of fibres arranged in a less compact fashion [15]. The reduction in size and thickness of the hypertrophic scar may also be related to a demonstrated reduction of intralesional mast cell numbers and consequent reduction in histamine production [16]. Most of these changes are postulated to be due to local tissue hypoxia caused by occlusion of the microvasculature [14,17]. Baur et al. [7] presented a different hypothesis and proposed that the decrease in capillary blood flow secondary to the pressure increased collagenase mediated collagen breakdown. They also found a diminished number of myofibroblasts in pressure treated hypertrophic scars. In addition, compression produces a reduction in tissue oedema with less ground substance production [19,20].

Beranek et al. [21] on the other hand state that compression devices neutralize local venous hypertension by preventing a leakage of plasma proteins and by a subsequent amelioration of tissue oxygenation. Pressure is also said to accelerate maturation, decrease erythema, thickness and firmness of the scar [11].

More recently Krieger et al. [22] proposed that the mechanism of pressure therapy is related to an elevation in skin temperature in the range of 1–3°C caused by the blockage of skin surface heat loss.

1.2. Pressure therapy in practice

Continuous pressure on scars can be exerted by means of pressure garments, conformers, transparant face masks, casts or splints [18,19,23,24]. Ideally garments and appliances exerting pressure should be worn for 24 h a day from the moment that epithelialisation has occurred until scar maturation is evident [12,13]. The optimal level of pressure required remains controversial. Theoretically pressures that exceed 24 mmHg pressure to overcome capillary pressure are required. However, good clinical results have been reported with levels as low as 5–15 mmHg pressure. Reid and coworkers [15] stated that 15 mmHg is necessary to accelerate the maturation process and that the effects of pressures below 10 mmHg pressure are minimal. With pressures above 40 mm Hg maceration and paresthesia may occur.

Although many authors [25–30] have tried to measure pressure under pressure garments in a reliable and objective manner, none of them has succeeded in proving to be adequate and reliable enough to be used in a generalised way in clinical circumstances. The explanation of the working mechanism of pressure remains merely hypothetical and the question of the efficacy and benefits of the garments unanswered. Studies such as those by Chang et al. [31], which have addressed these issues, will continue to appear in literature.

2. Uses of silicone material: scar therapy

2.1. Silicones: terminology and chemical structure

Silicones are entirely synthetic polymers generally based on a dimethyl siloxane monomer. These contain a repeating unit of structure [SiO(CH₃)₂]. They therefore have a silica derived backbone and organic groups as SiOC chains attached directly to a silicon atom via silicon carbon bonds.

The most common example in surgical practice is polydimethylsiloxane (PDMS) with an index of approximately 130 (Fig. 1).

In woundcare and rehabilitation three types of silicones are used:
1. Silicone fluids: short, unbound, straight PDMS chains.
2. Silicone gels: lightly cross-linked PDMS chains (for instance H-bridges) usually formed in the presence of a catalyst.
3. Elastomers: long, strongly cross-linked PDMS chains also formed in the presence of a catalyst (usually silica).

![Fig. 1. Chemical configuration of a silicone polymer.](image-url)
Depending on the amount and the type of the catalyst, the final product can differ in physical and chemical properties [32].

2.2. Silicone applications in burn wounds and hypertrophic burn scars

2.2.1. Silicone fluids

In burn wound care the history of the use of silicones dates from the early sixties where silicone fluids were used as an immersion treatment for burn patients. This technique promoted the complete separation of the eschar, the early formation of a granulation tissue bed and early joint motion of a spontaneous healing or grafted burn wound. The technique was particularly effective in hands [33,34]. Unfortunately, the mode of action of silicone fluids in the treatment of burns was never explained and their use was stopped when impure industrial grades were injected to augment soft tissues [35].

2.3. Silicone elastomers and sheetings

Of all non-invasive therapeutic treatments, pressure therapy is one of the most successful and widely used techniques in the prevention and treatment of hypertrophic (burn related) scars [13,36]. It is therefore not surprising that the first silicone applications (elastomers) were individually made as a pressure device or pad to solve concavity problems under pressure garments [37]. Some clinical benefits, results and advantages of the method were examined by Van den Kerckhove and co-workers [38] in 1991. Also Carr-Collins [23] described some interface media and their clinical applications under pressure garments including silicone elastomers. Perkins et al. [39] had previously described the use of silicone gel sheets on burn related scars without the use of pressure and without any explanation for the mode of action of the apparently beneficial clinical results.

Regarding this technique, the authors published an article in 1987 that made a distinction between contact media used with and without pressure [40]. More recently, both techniques have been used alternately, and in combination. Considering in more detail these three different forms of application:

2.3.1. Silicone applications as a pressure or positioning device

The pressure pads are individually made using elastomer (medical grade with catalyst), putty or foam, and fitted directly on the patient. They are usually worn in combination with classical pressure garments, masks and splints [41]. Currently, thanks to a manufacturing and manipulation technique, these inserts can be custom made based on an imprint of the scarred limb or body part (Fig. 2a and b) [42]. These medical grade silicone elastomers (and foams or putties) lend themselves admirably to positioning limbs and fingers in splints (especially for little fingers in ‘sandwich’ hand-splints) (Fig. 3a and b).

The benefits of this technique are:

- Individually tailored manufacture and fitting.
- Ideal solution for concavity problems.

The disadvantages are:

- The frequent renewing due to progressive changes of the scar.
- The loss of mobility when used over a joint.
- Excessive sweating (and maceration) at healthy skin areas.

The working mechanism for these devices is unclear but the effects may be mediated both though the ‘pressure therapy principle’ (optimizing pressure) and hydration of the scar, due to a diminished water vapour loss through the silicone pad.
Fig. 3. (a) A palmar handsplint filled with silicone elastomer to position the fingers after a severe circular handburn. (b) The same splint as a ‘closed sandwich’ handsplint to keep the fingers in the required position.

2.3.2. Silicone applications without the use of pressure

With the exception of the ‘Elastofix technique’ (adhesive contact medium) that was described by Davey and co-workers [43] these applications consist mostly of silicone sheets. It is necessary to distinguish between silastic (elastomer) and gelsheets. Both types of sheets are applied directly to the scar without any intention to augment or establish pressure on the scar. Both have similar clinical results and indications for use (Fig. 4) [44,45]. There are a significant number of reports in the literature concerning these applications.

Initially, in the eighties, silicone gelsheets were effectively used in the treatment of burn related scars [35,39,46,47]. Farquhar [48] in 1992 reviewed the articles that were available up until the end of the 80s and highlighted the lack of standardised measurement procedures (assessing texture, colour and elevation of the scar and subjective complaints as pain and pruritis with valid and reliable instruments), treatment protocols and adjunctive treatments.

Thereafter, at the beginning of the 90s, publications concerning the use of silicone sheets as contact media in the prevention of hypertrophic scarring and contractions started to appear [49,50]. Simultaneously in the practice of dermatology, this type of occlusive dressing gained some interest [51,52].

Another remarkable evolution during the last decade in favour of the use of silicone gelsheets has been its use as a drug releasing medium. This applies either in treating hypertrophic scars with, for example, vitamin E or even burn wounds with topical antimicrobial agents [53,54].

Also during the last decade, silicone gels, silastic foams and silicone coated polyamide dressings were introduced for skin graft fixation [55–57].

Concerning the working mechanism of silicone sheeting therapy on scars, various mechanisms of action have been proposed. In 1985, Quinn et al. [35] found no effects with regard to pressure, change in scar tempera-
ture and differences in oxygen tension within the scars. They found that hydration of the skin was altered with the gel sheets, in that there was an evaporative water loss of one-half normal skin and they concluded that it was possible that the stratum corneum provided a reservoir for fluid.

This approach makes sense since scars have a greater transepidermal water loss than normal skin [3]. Also in a burn injury the evaporative water vapour loss may be increased 10 fold [58,59]. Furthermore, the reduction in water vapour loss has been postulated to decrease capillary activity, thereby reducing collagen deposition and scar hypertrophy [60]. Beranek [61] suggested that hydration of the horny layer of the skin results in increased skin permeability for water-soluble compounds permitting a diffusion of tissue interstitial soluble proteins (components of inflammation) in the direction of the skin surface. This would further contribute to hypertrophic scar maturation.

In 1987, Quinn [47] thought that there was a release of low molecular weight silicone that would enter the stratum corneum and so could affect the structure of the scar. This assumption is supported by the recent work of Shigeki et al. [62] who found silicone related compounds in rat skin, human axilla skin and hypertrophic scars in an in vitro situation. However, in vivo, other investigators found no penetration of silicone into the scar, neither did they find an inflammatory response in reaction to foreign body in biopsies that were taken from silicone gel treated scars [46,63].

Sawada suggested that hydration and occlusion are the principal modes of action of the silicone gel sheet method and that the presence of silicone is not essential to obtain beneficial clinical effects [64,65]. This opinion is supported by the work of Chang and co-workers [66] who found that hydration significantly inhibited the proliferation of human fibroblasts in vitro by a suggested keratinocyte–fibroblast interaction. Andriessen et al. [67] also found that epidermal processes play an important role in the occurrence of hypertrophic scarring. Ricketts et al. [68] found molecular evidence (cytokine mRNA changes) for extensive connective tissue remodelling occurring during occlusive dressing therapy. Further, Jemec et al. [69] have demonstrated that a short-term topical application of tap water on the skin can significantly influence its properties, especially those of the epidermis. Hydration should also benefit joint motion when used over a burn wound contracture [70]. Besides hydration beneficial effects could also be due to diminished mechanical stress on the tissue (tension or traction in the wound) [3].

A totally different opinion is given by Hirshowitz et al. [71] who proposed that silicone sheets produced a static electric field from friction on the silicone material surface, and that this field was responsible for the reduction of hypertrophic scars. As hypertrophic scars are associated with a significant increase in mast cells, it was suggested that electric stimulation was responsible for both the reduction in vascularity of the wound and subsequent mast cells, and that scarring was therefore reduced [72].

Skin temperature elevation occurs due to blocking skin heat loss and may also to play a role in the regulation of scar tissue metabolism [22].

Although Gibbons and co-workers [73] reported many negative results and complications in five pediatric patients most of the other authors do not exclude children from their trials. Minor complications such as rash, ulcer, erythema and pruritis do however occur more regularly in children, especially when the dressing is kept in place with pressure garments or adhesive tape [46,47,49]. These minor complications usually disappear when the therapy is stopped temporarily or the duration of wearing is diminished or when hygienic measures are taken. Nevertheless, these complications do deserve special attention since they are reported by some authors [46] in over 50% of the cases. It has also been shown that occlusion on healthy skin enhances vascularity, damages stratum corneum barrier function [74], raises pH, carbon dioxide emission and microbial flora of the skin [75] and enhances penetration of toxic or therapeutic products through the skin [76].

Although a recent study of Wittenberg et al. [77] did not find any clinical benefit from a silicone gel sheeting treatment in a controlled comparative trial on long lasting hypertrophic scars the cause of which was not defined, most of the other publications tend to support the fact that hydration and occlusion improve both clinical parameters (color, pliability and thickness) and subjective symptoms such as pain and itching. This is probably also the reason why other occlusive bandages (e.g. hydrocolloids, glycerin-based gels and occlusive tapes) have been introduced in the treatment and prevention of hypertrophic scars [78–81]. The lack of uniformity in assessment protocols (except for scar extensibility), means that different variables are examined in different (usually subjective) ways. There is therefore no agreement on which clinical parameter is reacting the best to the therapy.

The benefits of using silicone sheet application also include:
- Comfort in application, case of any dressing changes required in association with and wearing the sheets.
- No (or only little) hindrance to joint movements.

The disadvantages of using silicone sheet application include:
- Maceration (and even irritation) of the healthy skin due to occlusion when used without scrupulous hygiene.
- The commercially available silicone sheets do not allow fixed positioning of a joint.
They are mostly limited in their usefulness to smaller scars.

The sheets are very expensive.
The (presumed) working mechanisms include:
- Hydration and occlusion of the stratum corneum.
- Electrostatic influence.
- Pressure.

3. Combinations of modalities

As stated previously, combinations of modalities or therapies can be applied. The most common combination is that of a silicone silastic sheet, gelsheet or pad with a classical pressure garment. Using the previously mentioned manipulation technique, silicone orthosis and garments with a varying degree of stiffness or rigidity (depending on the therapeutic aims) can be made (Fig. 5 and Fig. 6a, b) [42]. The first applications, of which an example was published in 1992 [36] have since undergone many alterations and modifications. The latest development in this regard is that of inflatable silicone inserts to treat scars (ISIS®) in which the pressure on the scar can be adjusted by means of a pump. The system is indicated for the treatment of scars or keloids in concave areas (presternal, axillary, subclavicular) or in soft tissue parts of the face and neck. An example is shown in Fig. 7a–d.

The main advantage or benefit of this treatment modality is that two therapeutic techniques can be combined:
- **Pressure therapy** with a garment, pad (or inflatable insert) or splint (with the aim of flattening the scar and hastening scar healing) and when necessary combined with joint positioning devices (e.g. by using rigid silicone strips or adding thermoplastic splints).
- **Hydration and occlusion** of the scar (with the aim of softening the scar, diminishing the erythema and influencing scar maturation and thickness).

Fig. 5. A partial supple silicone pressure glove with interdigital strap to prevent webspac contracture of the first interdigital commissure.

Fig. 6. (a) A retracting hypertrophic burn scar at the palma side of the wrist. (b) A silicone wristsplint with an extention strap (situated palmarly) to extend the wrist on simultaneously compress the scar.

The disadvantages of combining modalities include:
- The maceration and possible irritation of the healthy skin due to occlusion.
- The need for a well-trained technician or therapist who is able to produce and fit these appliances.
- If not reimbursed through an insurance (national or private) these products can be expensive.

The working mechanism — when combined therapy is used it is evident that the presumed working mechanisms of the individual modalities (pressure, hydration and occlusion and static electricity) may combine and reinforce each other.

4. Conclusion

Silicones (creams, gelsheets, silastic sheets, orthosis garments, ...) have become a very useful tool in the treatment and prevention of hypertrophic scarring, especially after burns. Many authors agree that of all non-invasive treatments proposed and used in the past only those based on pressure therapy, hydration and occlusion have been shown to be clinically effective.
Fig. 7. (a) Hypertrophic scarring in neck and thorax after a scald burn in a three years old child. (b) Pressure garment, silicone elastomer pressure pad for the thorax and transparent chin mask with inflatable silicone insert (ISIS®). (c) Patient wearing all the pressure and silicone devices. (d) Result after 9 months of wearing of the garments, mask and insert.
The growing interest in the use of silicones to achieve beneficial effects of scars is mainly due to two reasons: Firstly, the fact that the product silicone itself is easy to manipulate and gives specialised manufacturers the opportunity to meet the specific needs of the therapy in every single treatment. Secondly, the perceived benefit that this ‘occlusive dressing technique’ has on a healing scar, whatever the working mechanism may be. Whether it is hydration of the stratum corneum of the epidermis or static electricity, or both, still remains a topic for further research.

When reviewing the literature, it is striking (except for the measurement of scar extensibility) that there is no agreement on the use of assessment protocols to evaluate the evolution of the scar. Most of the evaluations are done by means of self-developed subjective rating scales. Although they will produce numerical values for colour, thickness and pliability of the scar, none of the authors have examined the reliability of the instruments.

In our opinion the key to the success of this therapy is ensuring that hygienic precautions are taken. We recommend that the initial duration of the treatment be only 12 h per day, particularly when it is used in combination with pressure, on children or in warm weather or climates. Furthermore, that strict guidelines are followed for the cleaning and possible disinfection of both the product and the skin, to avoid irritation of healthy skin.

Although complications are reported to increase with the use of pressure garments, compressive bandages or tapes, it is our opinion that pressure can bring added value to the treatment of scar thickness. This is especially so in anatomical areas which do not respond well to silicone sheeting, probably due to the difficulty in maintaining gel contact with the skin, e.g. chin, breast, clavicle, neck and face. This opinion is also supported by the acknowledgement that combined therapies usually have better results than single treatments, especially in scars and keloids [82,83].

This overview has looked specifically at current ideas, opinions and knowledge surrounding the use of silicones in the rehabilitation of burns and burn scars. At the same time it has tried to provide a basis for further research and stimulate critical analysis of generally accepted opinions in this relatively new non-invasive therapy. Therefore, given the current trends in burn scar management it would be useful to perform a comparative prospective study of treatments and their effects on scarring. Comparison groups could be:

1. Occlusion treated patients.
2. Pressure therapy treated patients.
3. Combination of therapy treated patients.

Although silicones can provide an interesting additional tool in the prevention and treatment of hypertrophic scars and burn related scars, they do not by any means replace others. Successful outcomes can be achieved by using an intelligent and prudent combination of the existing tools, with silicones as a valuable component. In conclusion however, one should always aim for a realistic outcome. As stated by Van den Helder in 1994: “Even plastic surgery cannot erase without a trace” [84].

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References


