
Identification of Cutaneous Functional Units Related to Burn Scar Contracture Development

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The development of burn scar contractures is due in part to the replacement of naturally pliable skin with an inadequate quantity and quality of extensible scar tissue. Predicted skin surface areas associated with limb range of motion (ROM) have a tendency to develop burn scar contractures that prevent full joint ROM leading to deformity, impairment, and disability. Previous study has documented forearm skin movement associated with wrist extension. The purpose of this study was to expand the identification of skin movement associated with ROM to all joint surface areas that have a tendency to develop burn scar contractures. Twenty male subjects without burns had anthropometric measurements recorded and skin marks placed on their torsos and dominant extremities. Each subject performed ranges of motion of nine common burn scar contracture sites with the markers photographed at the beginning and end of motion. The area of skin movement associated with joint ROM was recorded, normalized, and quantified as a percentage of total area. On average, subjects recruited 83% of available skin from a prescribed area to complete movement across all joints of interest (range, 18–100%). Recruitment of skin during wrist flexion demonstrated the greatest amount of variability between subjects, whereas recruitment of skin during knee extension demonstrated the most consistency. No association of skin movement was found related to percent body fat or body mass index. Skin recruitment was positively correlated with joint ROM. Fields of skin associated with normal ROM were identified and subsequently labeled as cutaneous functional units. The amount of skin involved in joint movement extended far beyond the immediate proximity of the joint skin creases themselves. This information may impact the design of rehabilitation programs for patients with severe burns. (*J Burn Care Res* 2009;30:625–631)

Burn scar contracture and hypertrophy plague survivors of severe burn injuries. The field of burn rehabilitation has yet to define optimal treatments for the prevention or correction of burn scar contracture and subsequent deformity, impairment, and dysfunction.^{1,2}

The development of burn scar contractures previously has been associated with burn depth and burn extent.^{3–5} In addition, the relative location of the burn wound to a joint and its associated skin crease is an important factor related to rehabilitation efforts. For unimpeded movement to occur, tissue compliance is needed for range of motion (ROM). Under normal conditions, as two body segments articulate about a joint, skin is recruited in progressive and sufficient amounts to allow movement to take place.⁶ Various scar contractures that develop after burn wound closure involve an area of skin linked with anatomic planes of motion of predicted joints. What is unknown is the quantity of skin recruited for joint ROM to occur. The purpose of this investigation was to extend previous research to document and identify fields of skin in-

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volved in joint ROM relative to usual sites of burn scar contracture development.

METHODS

After institutional review board approval and signed informed consent, 20 male volunteers without burns were recruited to participate in the study. Subjects were excluded if they had a history of skin disease or orthopedic conditions affecting joint ROM. Demographic and anthropometric measurements were recorded as given in Table 1. Percent body fat was determined by skin caliper technique using the three skinfold summation method of the chest, abdomen, and thigh areas.⁷ Body mass index (BMI) was calculated as (weight in kilograms)/(height in meters). Both determinations were performed by an individual credentialed through the American College of Sports Medicine.

Using a standardized template and colored marking pens, each subject had markings placed on the skin as previously described.⁶ The markings were drawn on the dominant upper and lower extremities and torso throughout the nine areas of skin previously identified in a pilot project (unpublished data) and associated with the development of burn scar contractures. Skin markings spaced at 2 inch (5 cm) increments were placed on the anterior and posterior torso. The iliac crest and tip of xiphoid processes were outlined as well. One-inch (2.5 cm) spaced markings were placed on the ventral arm, dorsal forearm, and hand as well as the posterior thigh and leg. The test areas and associated contractures are listed in Table 2.

Subjects were positioned supine and secured to a plinth to photograph movements of neck extension, shoulder abduction, and elbow extension. For neck extension, the head was positioned off the end of the plinth and lowered below the surface level of the plinth to complete the movement. Subjects were positioned and secured in a prone position on a plinth to

Table 2. Tested areas and associated burn scar contracture

Site	Associated Contracture
Anterior neck and torso	Neck flexion
Anterior axillary fold and torso	Shoulder adduction
Posterior axillary fold and torso	Shoulder extension
Anterior arm	Elbow flexion
Volar forearm	Wrist flexion
Dorsal hand	MP extension
Dorsal fingers	IP extension
Posterior thigh	Knee flexion
Posterior leg	Ankle plantarflexion

MP, metacarpophalangeal; IP, interphalangeal.

photograph movements of shoulder flexion, knee extension, and ankle dorsiflexion. Subjects were seated with their forearm supported on a table to photograph wrist flexion, isolated metacarpophalangeal (MCP) joint flexion, and hand fisting.

Subjects performed several trials of the desired joint movement to familiarize themselves with the movement and to precondition the skin.⁸ They were instructed not to breath during each movement that commenced at the time exhalation ended. The skin marks of each area were photographed at the beginning and at the end of movement using a previously described double-exposure photographic technique.⁹ All movements were performed in an active-assisted manner with assistance from the primary investigator except for ankle dorsiflexion which was performed actively. Assistance was provided to insure that full ROM occurred among the volunteers, to maintain segment stability, and to insure quiescence of the body part so distortions of the skin markings did not occur on the photographic film. Each definitive movement was performed three times in succession by each subject. The photograph demonstrating the greatest amount of skin movement of the triplicate series was used to determine maximum amount of skin recruitment for each movement by each subject.

Anthropometric measurements of body fat and BMI were used to test the influence of body morphology on skin recruitment using the motion of neck extension. Skin movement and joint ROM were correlated with active ankle dorsiflexion, because this motion was the most stable to eliminate accessory movement. The amount of skin movement for each tested area was normalized between subjects. Aggregate skin movement of each test site was compared. Linear regression of the anthropometric measurements was performed with a *P* value of .05, accepted as significant.

Table 1. Demographic and anthropometric information

Subjects	20 men
Age (yr)	33.9 ± 1.8 (19–47)
Dominant extremity	75% right handed 25% left handed
Height (m)	1.81 ± 0.02
Weight (kg)	86.28 ± 2.42
Percent body fat	19.8 ± 1.4 (6–34%)
Calculated body mass index	26.3 ± 0.6 (20.8–32.4)
Ankle dorsiflexion (active)	31.4 ± 1.6 degrees (15–39 degrees)

Mean ± SEM unless otherwise noted. The range values in given parentheses.

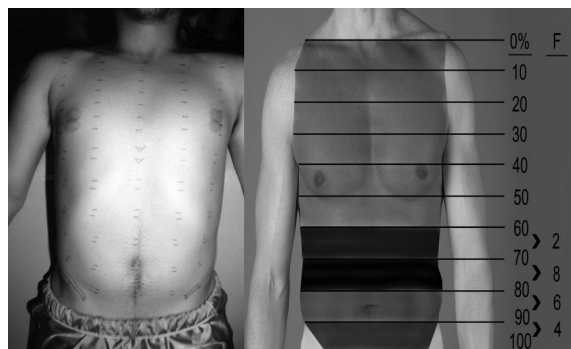


Figure 1. Neck extension.

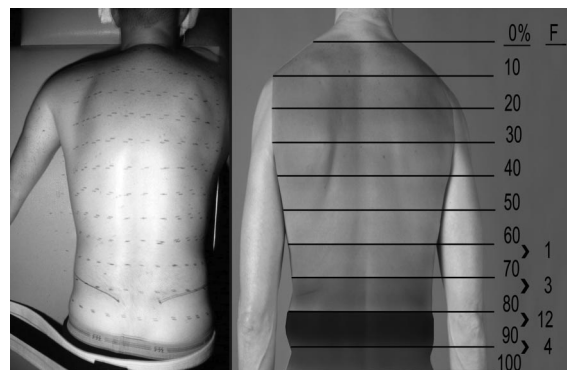


Figure 3. Shoulder flexion.

RESULTS

Demographic and anthropometric information is reported in Table 1. Mean (SEM) age was 33.9 (1.8) years with 19.7 (6.2%) body fat and BMI of 26.3 (0.6). Fields of skin associated with complete ROM of the nine joint areas were successfully identified and plotted as body maps as follows:

Neck extension (Figure 1): Four subjects recruited between 90 and 100% of the marked skin from the sternal notch down to the pubic bone; six subjects recruited 80 to 90% of available skin, eight subjects recruited 70 to 80% of available skin, and two subjects recruited 60 to 70% of available skin.

Shoulder abduction (Figure 2): two subjects recruited 90 to 100% of available skin down to the pubic bone; 12 subjects recruited 80 to 90% of available skin; five subjects recruited 70 to 80% of available skin; and one subject recruited 60 to 70% of available skin.

Shoulder flexion (Figure 3): four subjects recruited 90 to 100% of available skin down to the gluteal cleft; 12 subjects recruited 80 to 90% of available skin; three subjects recruited 70 to 80% of available skin; and one subject recruited 60 to 70% of available skin.

Elbow extension (Figure 4): 18 subjects recruited 90 to 100% of available skin as measured from the

elbow flexion crease to the acromion process; one subject recruited 70 to 80% of available skin; and one subject recruited 50 to 60% of available skin.

Wrist flexion (Figure 5): One subject recruited 90 to 100% of available skin measured from the dorsal wrist skin crease to the level of the elbow flexion crease; one subject recruited 80 to 90% of available skin; one subject recruited 70 to 80% of available skin; two subjects recruited 60 to 70% of available skin; two subjects recruited 50 to 60% of available skin; two subjects recruited 40 to 50% of available skin; five subjects recruited 30 to 40% of available skin; four subjects recruited 20 to 30% of available skin; and two subjects recruited 10 to 20% of available skin.

MCP joint (isolated) flexion (Figure 6): 14 subjects recruited 75 to 100% of available skin as measured from the MCP joint crease to the wrist extension crease; five subjects recruited 50 to 75% of available skin; and one subject recruited 25 to 50% of available skin.

Composite fist (Figure 7): seven subjects recruited 75 to 100% of available skin as measured from the MCP joint crease to the wrist extension crease; 11

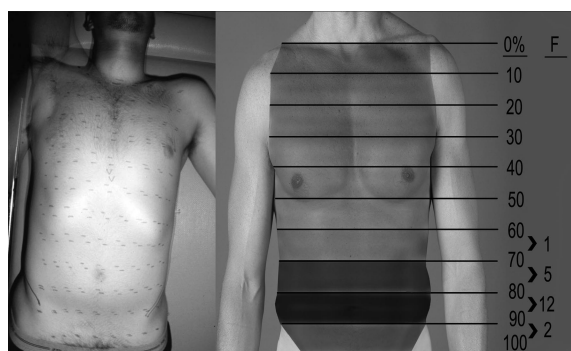


Figure 2. Shoulder abduction.

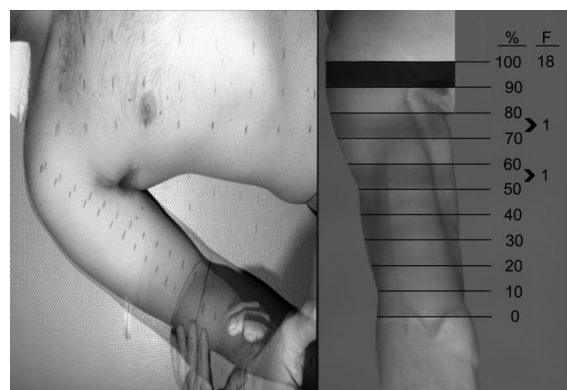


Figure 4. Elbow extension.

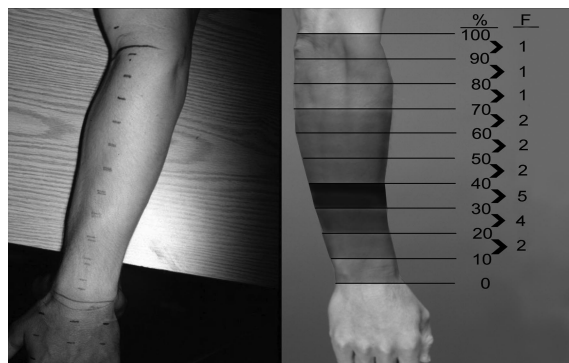


Figure 5. Wrist flexion.

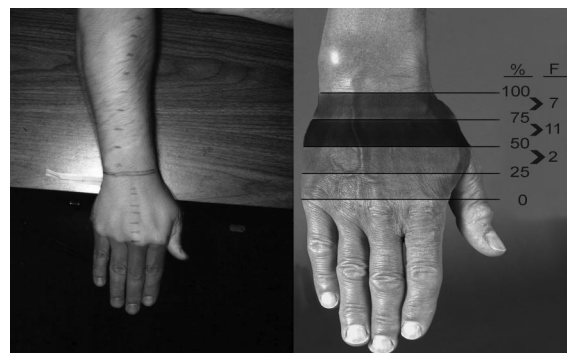


Figure 7. Composite fist.

subjects recruited 50 to 75% of available skin; and two subjects recruited 25 to 50% of available skin. Knee extension (Figure 8): all 20 subjects recruited 100% of available skin as measured from the popliteal crease to the gluteal-fold skin crease.

Ankle dorsiflexion (Figure 9): 13 subjects recruited 90 to 100% of available skin as measured from the apex of the calcaneus to the popliteal crease; one subject recruited 70 to 80% of available skin; one subject recruited 60 to 70% of available skin; three subjects recruited 50 to 60% of available skin; one subject recruited 40 to 50% of available skin; and one subject recruited 30 to 40% of available skin.

No correlations were found between the amount of skin recruitment and the subjects' percent body fat nor BMI as seen in Figures 10 ($r^2 = .002$; $P = .87$) and 11 ($r^2 = .06$; $P = .27$), respectively. A significant correlation ($r^2 = .32$; $P = .02$) was demonstrated between ankle dorsiflexion ROM and skin recruitment (Figure 12).

Skin was serially recruited in all skin areas and eight of the nine cutaneous functional units (CFUs) demonstrated some between subject variability in skin movement associated with full ROM. Knee extension demonstrated no variability in the percent of skin re-

cruitment (100% in all subjects). The greatest amount of skin recruitment variability was observed with wrist flexion (range, 18–100%). The mean amount of skin recruitment for all areas combined was $82.55 \pm 4.9\%$ with a range of 31.9% for wrist flexion to 100% for knee extension. The 95% confidence interval for all areas was 72.1 to 92.9%.

DISCUSSION

The integument that envelops the body is essentially one continuous sheet of tissue. Under normal circumstances, uncompromised skin accommodates joint movement because of its inherent mechanical ability to elongate and recoil. Contractures after a burn injury, which limit a patient's ROM, form when pliable skin is replaced with inelastic scar tissue. The development of burn scar contractures has been associated with percent TBSA burn with scar contractures having a predilection to develop within planes of motion.³⁻⁵ Additionally, the quantity of skin that needs to be involved in a burn injury before a burn scar contracture develops is unknown. Therefore, location of a burn wound relative to a joint skin crease is of particular importance. From a biomechanic viewpoint, research has



Figure 6. Isolated metacarpophalangeal joint flexion.

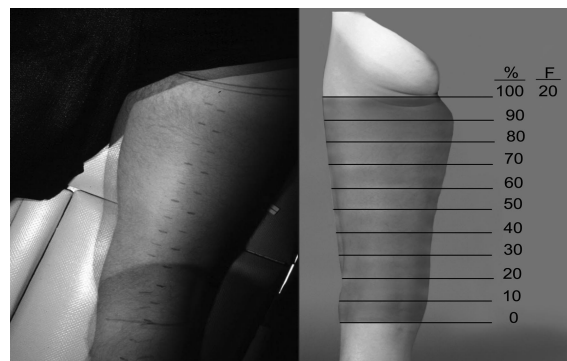


Figure 8. Knee extension.

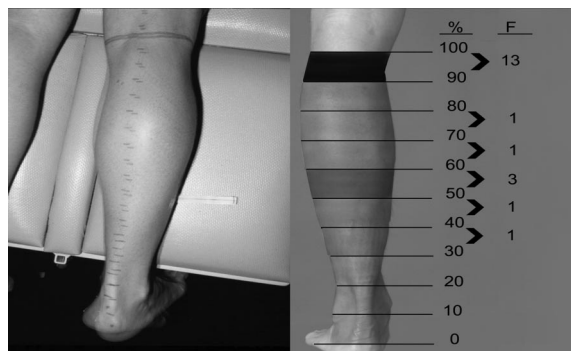


Figure 9. Ankle dorsiflexion.

demonstrated that native skin can lengthen up to 60% of its original length whereas scar tissue is approximately 15% extensible in its immature state of repair.¹⁰

Overall, the amount of skin movement within each previously identified skin field far exceeded that which was anticipated. Skin movement was found not only near the joint tested but occurred at great distances from the axis of movement, particularly with neck extension, shoulder flexion, and shoulder abduction. Although the greatest amount of skin recruitment occurred closest to the joint crease tested, skin was also recruited from distant locations. In accordance, previous research has documented serial recruitment of forearm skin during extension of the wrist joint and torso skin during pregnancy.^{6,11}

We identified fields of skin that functionally contribute to ROM and have selected to refer to these areas as CFUs. In general, skin was recruited serially and as ROM increases a larger percentage of the respective CFU was recruited. This presentation was quantified in the current investigation of ankle dorsi-

flexion. In this study, 32% of the variability in ROM was explained by the percentage of CFU recruited during active motion. However, there were few examples where skin recruitment failed to coincide with this trend. At the knee, all subjects recruited 100% of the CFU to attain full knee extension. In contrast, when performing wrist flexion, only three subjects (15%) recruited at least 70% of the identified CFU and half of the subjects required <50% of the available CFU to achieve full ROM. The reasons underlying these observations are unclear but may be related to the anisotropic nature of skin.^{12,13}

It was revealing to uncover that composite flexion of the fingers did not require a greater amount of skin recruitment from the dorsum of the hand than did isolated MCP finger joint flexion. A possible reason for this finding lies with the availability of a skin reservoir over the finger interphalangeal joints. As an individual moves from a position of full finger extension to a composite fist position, see Figure 13, the linear measurement of the finger lengthens. This pseudo increase in finger length has to do with the combined anatomy and arthokinematics of the MCP, proximal interphalangeal, and distal interphalangeal joints. By way of accommodation, the fingers have developed skin furrows over the interphalangeal joints to accommodate flexion of these individual joints. Future research should be performed on the skin of the hands and fingers using smaller increments between markings to capture more precise movement.

The empirical notion that heavy or overweight individuals with large BMI may be less susceptible to the risk of scar tissue contracture caused by skin redundancy was disputed by this study. Originally, it was hypothesized that since overweight individuals

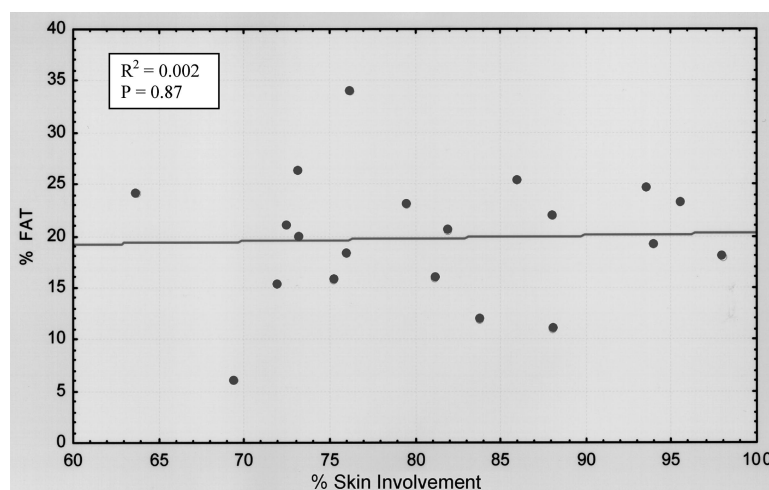


Figure 10. Correlations between the amount of skin recruitment and the subjects' percent body fat.

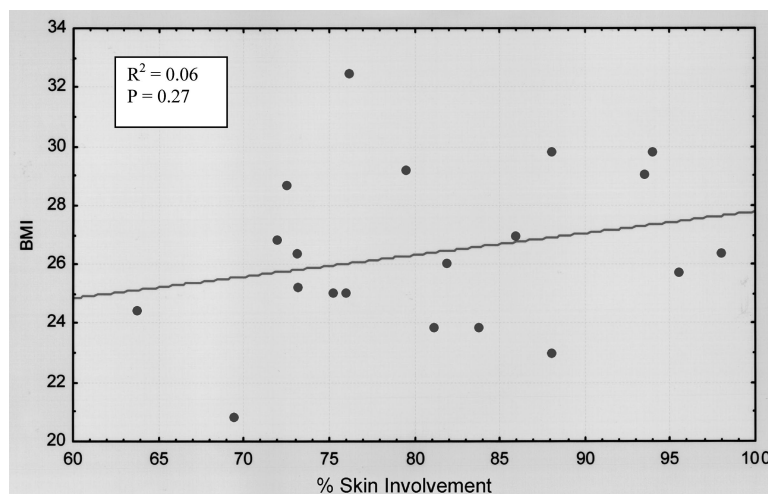


Figure 11. Correlations between the amount of skin recruitment and the subjects' body mass index.

possess more square meters of skin to cover their body's framework, this tissue would serve as a reservoir to recruit skin from to complete ROM. Although previous authors have shown a relationship between BMI and functional outcomes and after hospital disposition,¹⁴ our results suggest that skin recruitment is equal across all body types. However, it is acknowledged that the absolute and narrow range of measures for both percent body fat and BMI of the current group of subjects may not be generalizable to the full spectrum of healthy individuals or burn patients.

Identification of CFUs may have immeasurable value in predicting burn scar contracture susceptibility and designing treatment paradigms to minimize burn trauma sequelae. However, biodynamic factors of skin and scar tissue that contribute to contracture

formation require additional investigation as additional information is needed relative to the interaction between joint ROM, normal skin movement, and pathologic scar tissue before the prevention of burn scar contractures can be advanced.

Skin recruitment that contributes to the motion of specific joints prone to burn scar contracture formation involves a field of skin that extends beyond the near proximity of the joint itself. The CFUs identified by this research may influence the quantity of rehabilitation patients require and the development of optimized treatment programs to minimize functional losses caused by contracture development. Furthermore, the documentation of CFUs involved in joint ROM eventually may assist to predict patients who are at risk to develop scar contractures and,

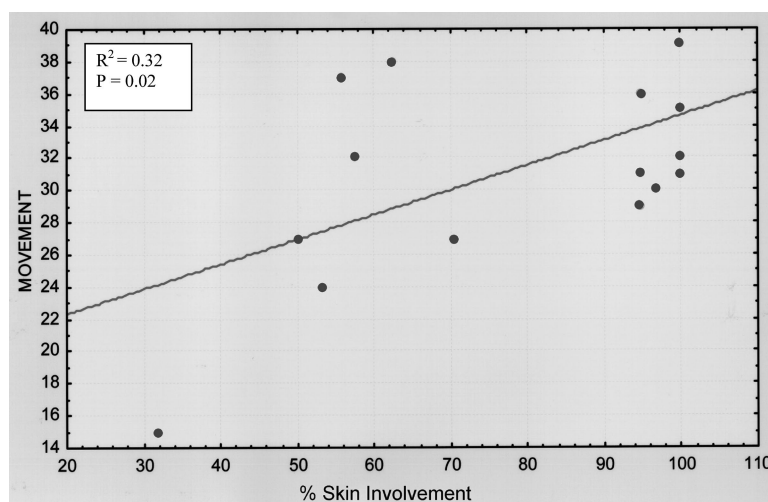


Figure 12. Correlation between ankle dorsiflexion range of motion and skin recruitment.

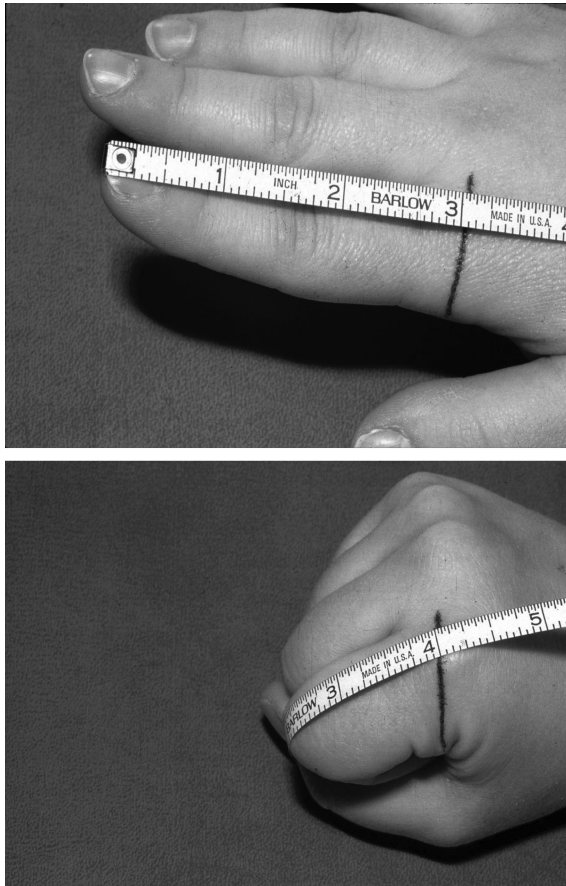


Figure 13. Full-finger extension to composite fist position.

where risk is low, help to decrease the amount of procedural pain patients experience as treatment strategies improve in their precision.

CONCLUSION

In this study, CFUs associated with joint ROM were identified. Joint skin surfaces prone to burn scar contracture involve a CFU that extends far beyond the immediate proximity of the joint itself. Quantity of skin recruitment is correlated with degree of joint movement. The anecdotal belief that heavy people possess more skin for elongation is disputed. Documentation of CFUs has implications that extend to 1)

prediction of patients at risk for scar contracture development based on burn location within a given CFU and 2) establishment of a rehabilitation treatment plan.

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