Assessment With the Dermal Torque Meter of Skin Pliability After Treatment of Burns With Cultured Skin Substitutes

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The assessment of visco-elastic (V-E) properties in cutaneous scars is critical to reduction of impairment and restoration of function after grafting of excised burns. Cultured skin substitutes (CSS) that consist of autologous keratinocytes and fibroblasts attached to biopolymer substrates are alternatives for permanent closure of excised, full-thickness burns, but assessment of scarring has been subjective. V-E properties of CSS were measured with a Dia-Stron Dermal Torque Meter (DTM 310, Dia-Stron, Ltd, Broomall, Pa), which applies a constant torque (10 mNm) for a fixed interval (10 seconds) and measures rotational deformation and recovery. Parameters of skin deformation were measured in patients (n = 10) after grafting of CSS or meshed skin autograft. Native human skin (NHS) of healthy volunteers (n = 13) served as the control. Skin healed after treatment with CSS or autograft was evaluated for 1 year or longer after grafting. Elastic stretch (Ue), viscous stretch (Uv), total extensibility (Uf), elastic recovery (Ur), total recovery (Ua), and residual plasticity (R) were measured as degrees of rotation, were tested for significance ($P < .05$) by Student *t* test comparisons between treatment groups and controls, and were subjected to regression analysis. Assessment of burn scar with the Dermal Torque Meter detected time-dependent increases of all individual parameters of V-E properties for both CSS and autograft during the first year after grafting. At 1 year or later, no statistical differences were found between CSS and autograft for individual parameters, but Ue and Ur for autograft were significantly lower than for NHS. At 1 year or longer, autograft was significantly different from CSS or NHS, with a greater ratio of Uv to Ue, and both graft types had a lower ratio of Ur to Uf than NHS had. These results suggest that instrumental measurement of scar pliability may increase objectivity in assessment of patient recovery and establish an absolute scale for quantitative analysis of V-E properties in skin after grafting of conventional or alternative skin substitutes. (J Burn Care Rehabil 2000;21:55-63)

Cutaneous scars after grafting of excised burns reduce function and cosmesis. Consequently, assessment of scars is very important for selection of intervention and improvement of outcome.[1] Pliability of scar has been rated by ordinal scoring with the Vancouver Scar Scale,[2,3] and with a similar scale for cultured skin substitutes (CSS).[4] Although ordinal scales provide relative rating systems, assignment of values is inherently subjective and, consequently, variable among investigators. Hypothetically, establishment of an absolute scale of scar pliability and measurement of pliability with instruments may increase objectivity in assessment of burn scars.

Instruments for measurement of visco-elastic (V-E) properties in skin have been developed for applications in dermatology.[5] Among the instruments that are validated for dermatology are the Cutometer (Courage and Khazaka, Cologne, Germany),[6] the Dermaflex (Cortex Technology, Hadsund, Germany),[7] and the Dermal Torque Meter (DTM 310, Dia-Stron, Ltd, Broomall, Pa).[8,9-12] In addition, burn scar has been evaluated with the pneumatonometer[13] and by acoustical methods with the shear wave velocity analyzer.[14] Except for the acoustical method, these

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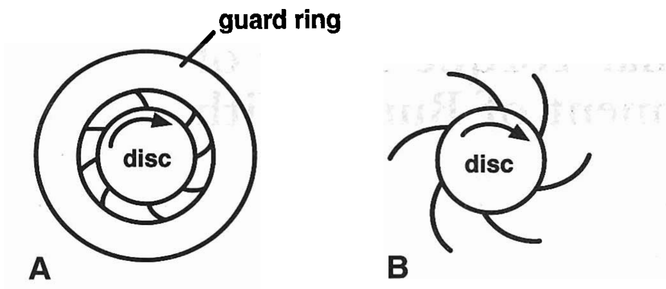

Figure 1. Diagram of the DTM. The DTM applies a constant load by rotation of a disk within a ring **(A),** both of which are attached to the skin with double-sided adhesive tape. The DTM measures the angular rotation of the disk during application of the constant load and records the rotation as angular deformation. After the load is released, the DTM records the rotational recovery of the skin. **B,** The rotational pattern of loading applied by the DTM without the outer guard ring. (Reprinted from Agache PG. Twistometry measurement of skin elasticity. In: Serup J, Jemec GBE, editors. Handbook of non-invasive methods and the skin. Boca Raton (FL): CRC Press; 1995. p. 319-28.)

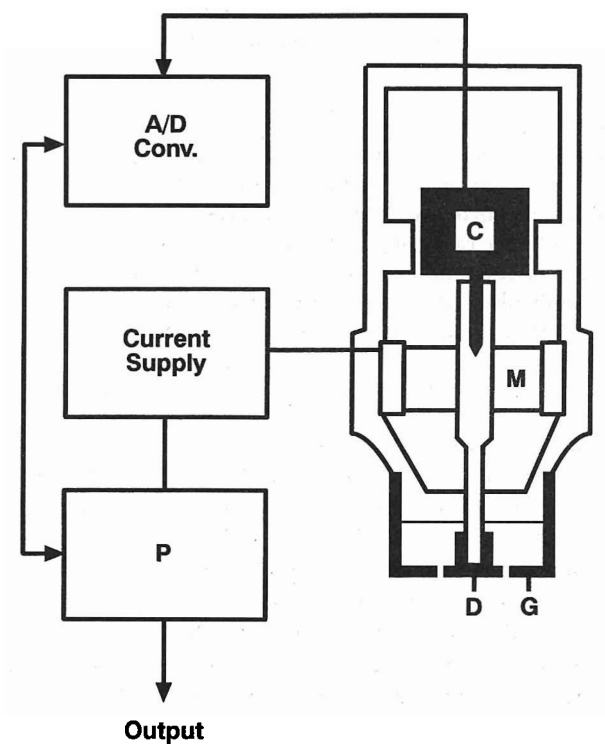

Figure 2. Diagram of the DTM system. *C,* rotational sensor; *M,* motor; *D,* disk; *G,* guard ring; *P,* microprocessor connected to a computer. (Reprinted from Agache PG. Twistometry measurement of skin elasticity. In: Serup J, Jemec GBE, editors. Handbook of non-invasive methods and the skin. Boca Raton (FL): CRC Press; 1995. p. 319-28.)

instruments operate by application of a mechanical load to the surface of the skin. The mechanical instruments measure skin deformation during loading and measure recovery after release of the load. Mechanical instruments divide the pliability of skin into elastic and viscous segments that correspond directly with rapid stretch and slow stretch in physical therapy after burn injury.[15,16] In comparison, the acoustical method detects differences in tissue density as a function of conductivity of an oscillating sonic wave. All of these instruments share common advantages; they are noninvasive and nondestructive to the study site. Importantly, these advantages permit repeated measurements of the same sites, which allows the determination of changes in scar over time. Hypothetically, determination of changes in scar formation may provide insights for diagnosis and prognosis of functional outcome.

In previous studies from this laboratory, the V-E properties in human skin after grafting of athymic mice with CSS have been measured with the Cutometer.[17] In this study, V-E properties in healed burn wounds were measured with the DTM after treatment with meshed, split-thickness autograft or CSS. The purpose of the study was to determine whether measurement of scar pliability with noninvasive instruments may provide a basis for objective assessment of wound closure with conventional and alternative skin grafts.

MATERIALS AND METHODS

Experimental design. CSS and split-thickness autograft were applied to matched sites after excision of full-thickness burns and compared for qualitative outcome.[3] Beginning at 3 weeks after grafting, the V-E properties of healed wounds were assessed with the DTM. Primary analysis was performed at about 1 year after grafting. Values from grafted wounds (CSS or autograft) were compared with values for native human skin (NHS) from the volar forearms of healthy, adult volunteers (n = 13).

Mechanical loading and unloading curves for assessment of V-E properties in skin. To measure V-E properties in skin, the DTM applies a constant load (10 mNm) for a constant interval (10 seconds). Schematic diagrams of the DTM system are shown in Figures 1 and 2. The rotating disk and fixed outer ring shown in Figure 1 are covered with double-sided tape that attaches the instrument transducer to the skin without slipping. Data from the transducer head are transferred to a computer file as two X-Y plots for collection of the loading and unloading curves. Components of the loading and unloading

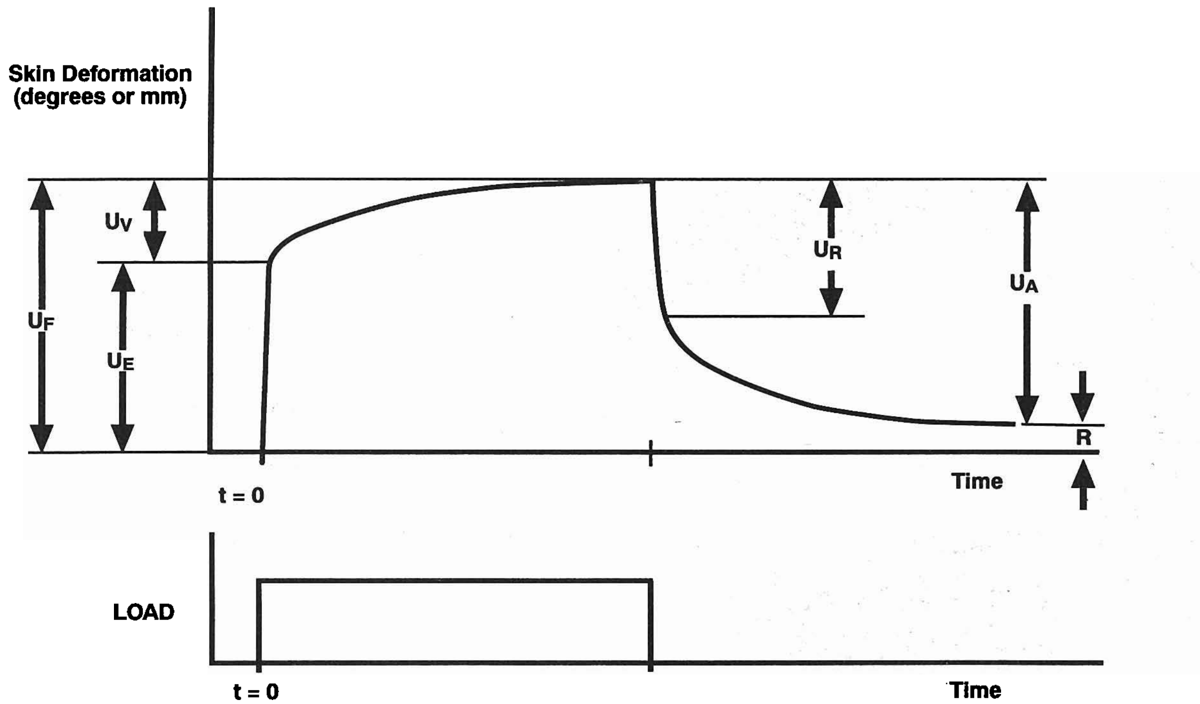

Figure 3. Typical plot of mechanical loading and unloading of skin with the DTM. The individual parameters of loading are Ue, Uv, and Uf. Recovery after release of loading consists of Ur, Ua, and R.

curves are shown in Figure 3. Total deformation from loading of the skin is defined as total extensibility (Uf) and is segmented into elastic stretch (Ue) and viscous stretch (Uv), as defined in Table 1. Unloading of skin has a component of elastic recovery (Ur), and a component of total recovery (Ua). Residual plasticity (R) is defined as deformation that is not recovered during the recording interval.

Patient Sampling and Statistical Analysis. Patients evaluated in this study were enrolled by informed consent into a protocol approved by the Institutional Review Board of the University of Cincinnati. Comparative sites for study of CSS and meshed, split-thickness autograft were established for assessment of qualitative outcome.[4] Eight male patients and 2 female patients who ranged in age from 1 to 12 years (mean ± SEM, 5.6 ± 1.2 years) and who had 58% to 91% total body surface area full-thickness burns (mean ± SEM, 77.8 ± 4.1) were included in the patient population. Measurements were performed with the DTM at periodic intervals after grafting (Figure 4). Data were grouped into three sets: (1) data gathered about 2 months and earlier (post-operative day [POD] 21-63), (2) data gathered about 1 year and earlier (POD 21-376), and (3) data gathered about 1 year and later (POD 356-832). For POD 21-63, 5 patients were sampled at 1 to 2 time points each (total, 7) with 2 to 4 samplings per time point for a total of 22 samplings each for CSS and autograft. For POD 21-376, 10 patients were sampled at 1 to 3 time points each (total, 20) with 1 to 4 samplings per time point for a total of 55 samplings for CSS and 54 samplings for autograft. For POD 356-832, 4 patients were sampled at 1 to 2 time points each (total, 7) with 1 to 3 samplings

Table 1. Definitions of the parameters of skin deformation during mechanical loading and unloading and ratios of parameters

Ue	Elastic deformation of skin due to application of a load (at 0.02 seconds of load)
Uv	Viscoelastic creep occurring after the elastic deformation (Uf-Ue)
Uf	Total extensibility of the skin (at 10 seconds of load)
Ur	Elastic recovery (at 0.02 seconds of unload)
Ua	Total recovery from deformation (Uf-R)
R	Amount of deformation not recovered (at 10 seconds of unload)
Ua/Uf	Total recovery to total deformation
Ur/Ue	Elastic recovery to elastic deformation
Uv/Ue	Viscous deformation to elastic deformation
Ur/Uf	Elastic recovery to total deformation

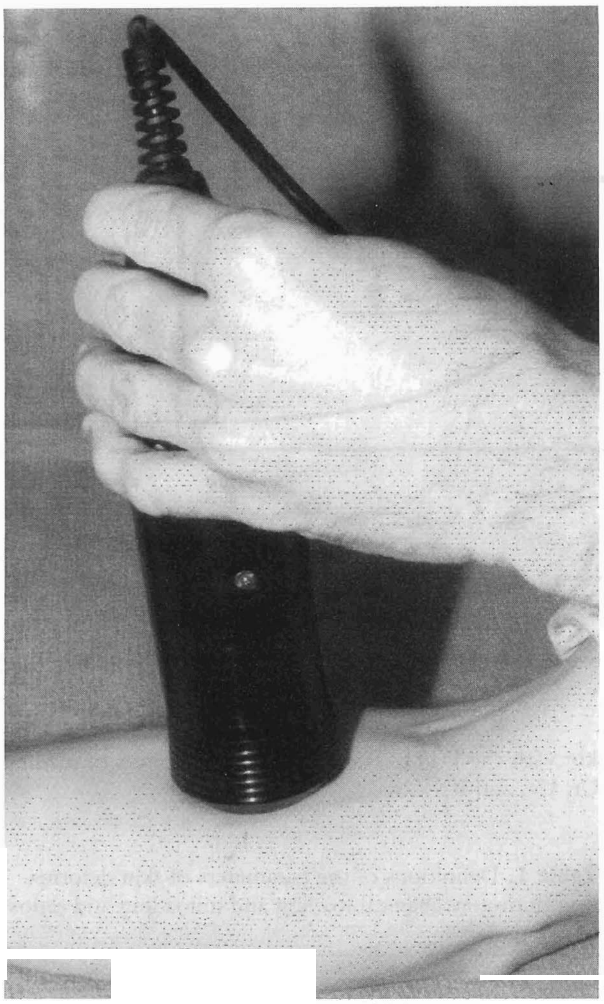

Figure 4. Data collection with the DTM. The instrument transducer of the DTM is a hand-held device with an activation switch. Data are fed from the probe through the instrument control box and into a computer. Software for the instrument displays the loading and unloading curves and transfers raw data into spreadsheets for further analysis.

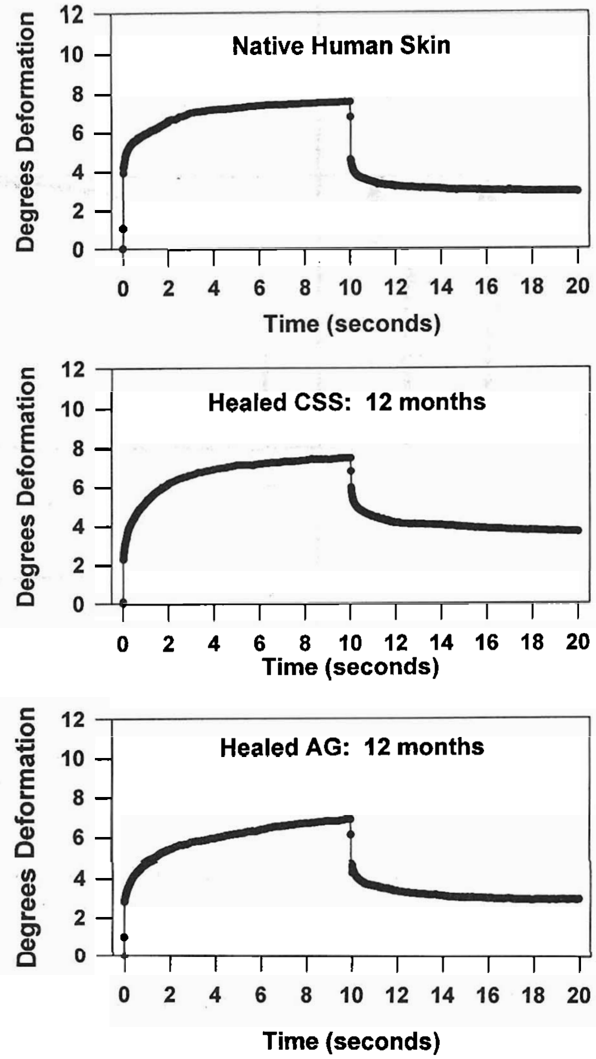

Figure 5. Representative plots of data recorded with the DTM for NHS (*top*), CSS at 1 year after grafting (*center*), and autograft (AG) at 1 year after grafting (*bottom*).

per time point for a total of 18 samplings each for CSS and autograft. Because the availability of patients often depended on clinic visits, sampling time points were irregular. Data were recorded during application of a 10 mNm load for 10 seconds followed by recovery for 10 seconds. To assess chracteristics of early (POD 21-63) and late (POD 356-832) scarring, individual parameters (Ue, Uv, Uf, Ur, Ua, R) and ratios (Ua/Uf, Ur/Ue, Uv/Ue, Ur/Uf) were evaluated. First-order regression analysis was performed and correlation coefficients were calculated for individual parameters of skin pliability between 21 and 376 days after grafting to evaluate trends in pliability as a function of time. Slopes of regression lines were tested for significant differences ($P < .05$) from zero. Data from POD 21-63 and POD 356-832 were analyzed as independent sets, and tested for significance ($P < .05$) by pair-wise comparisons between experimental and control groups.

RESULTS

Representative curves for loading and unloading of NHS and of healed skin grafts at 12 months are shown in Figure 5. Both the Uf and Ua of healed CSS and autograft were similar to NHS. CSS had somewhat less Ur and autograft had a somewhat greater magnitude of Uv than NHS had.

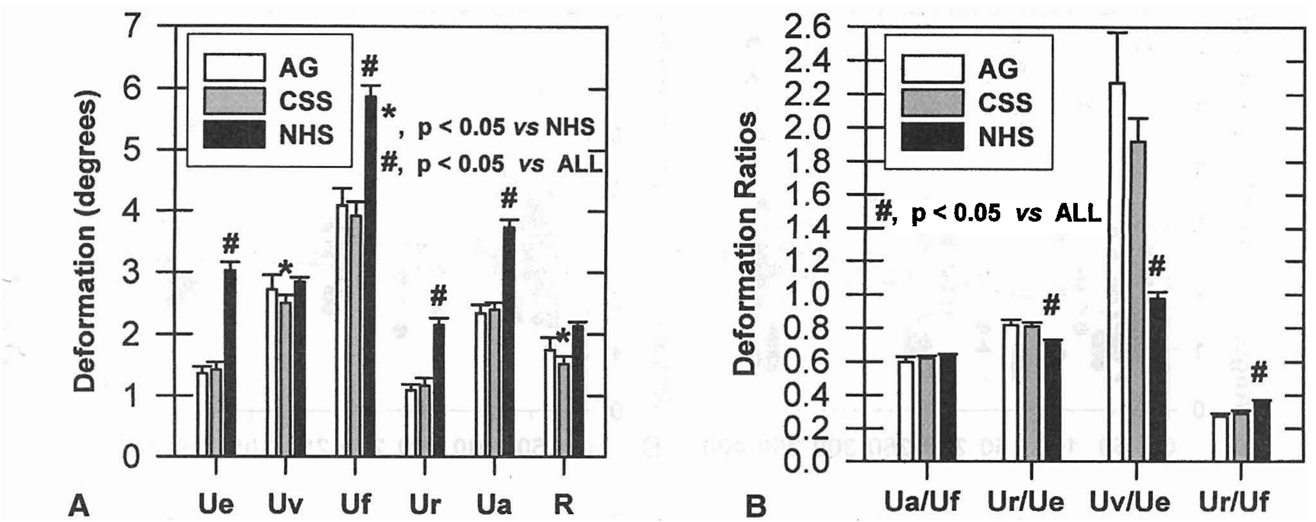

Figure 6. Plots of V-E properties of meshed, split-thickness autograft (AG), CSS, and NHS of the volar forearm at 21 to 63 days after grafting. **A,** Individual parameters of skin pliability were different between NHS and other groups for Ue, Uf, Ur, and Ua. CSS, but not autograft, was lower than NHS for Uv and R. **B,** Ratios of V-E parameters show significantly greater Ur/Ue and Uv/Ue for CSS and autograft compared with NHS. Both CSS and autograft were significantly less than NHS in the ratio of Ur to Uf.

Comparisons of individual parameters of V-E properties and ratios of parameters for CSS, autograft, and NHS from post-operative days 21 to 63 are shown in Figure 6. Individual parameters of skin pliability were different between NHS and both experimental groups for Ue, Uf, Ur, and Ua (Figure 6A). Ratios of Ua to Uf were not different among the groups (Figure 6B). Ur/Ue, Uv/Ue, and Ur/Uf ratios were significantly different between NHS and the experimental groups.

Figure 7 shows plots of individual parameters of skin pliability and regression lines for CSS and autograft and a reference line of the mean values from NHS. Correlation coefficients showed no positive correlation ($R < 0.35$) of individual parameters as a function of time after grafting in this small clinical population. Ue for both autograft and CSS had positive slopes during the first year after grafting that approached, but did not exceed, NHS (Figure 7A). Uv for both types of grafts is similar to NHS during the first year after grafting, with Uv for autograft slightly greater than for NHS and Uv for CSS slightly less than for NHS, on average (Figure 7B). Uf for both types of grafts was reduced at early time points and was very close to NHS by 1 year after grafting (Figure 7C). Ur was approximately half of NHS for both graft types at early time points and increased during the first year for CSS but remained unchanged for autograft (Figure 7D). Ua increased progressively during the first year, and CSS was closer to NHS than to autograft (Figure 7E). R increased modestly for both graft types during the first year, with autograft slightly greater than NHS and CSS slightly less than NHS (Figure 7F). Analysis of the slopes of the regression lines for data collected between POD 21-376 is shown in Table 2. For CSS, positive slopes for Ue, Uf, Ur, and Ua are significantly different from zero. For autograft, no parameters of pliability had a slope that was statistically different from zero.

Evaluation of data from 1 year and after is shown in Figure 8. Individual parameters of skin pliability were not significantly different among groups, except for Ue and Ur of autograft, which were significantly less than that of NHS (Figure 8A). Ua/Uf and Ur/Ue ratios were not different among groups (Figure 8B). Uv/Ue was significantly greater for autograft than for other groups. Ur/Uf was significantly greater for NHS than for both treatment groups.

DISCUSSION

The results of this study suggest that scar pliability can be measured quantitatively and noninvasively with biophysical instruments such as the DTM. Although similar results may be expected from the measurement of skin pliability with other comparable instruments, the absolute load applied and area of load are not standardized. V-E properties of CSS in athymic mice after healing have been quantified with the Cutometer in a previous study from this laboratory.[17] The Cutometer instrument was selected for that study because the measurement aperture of the

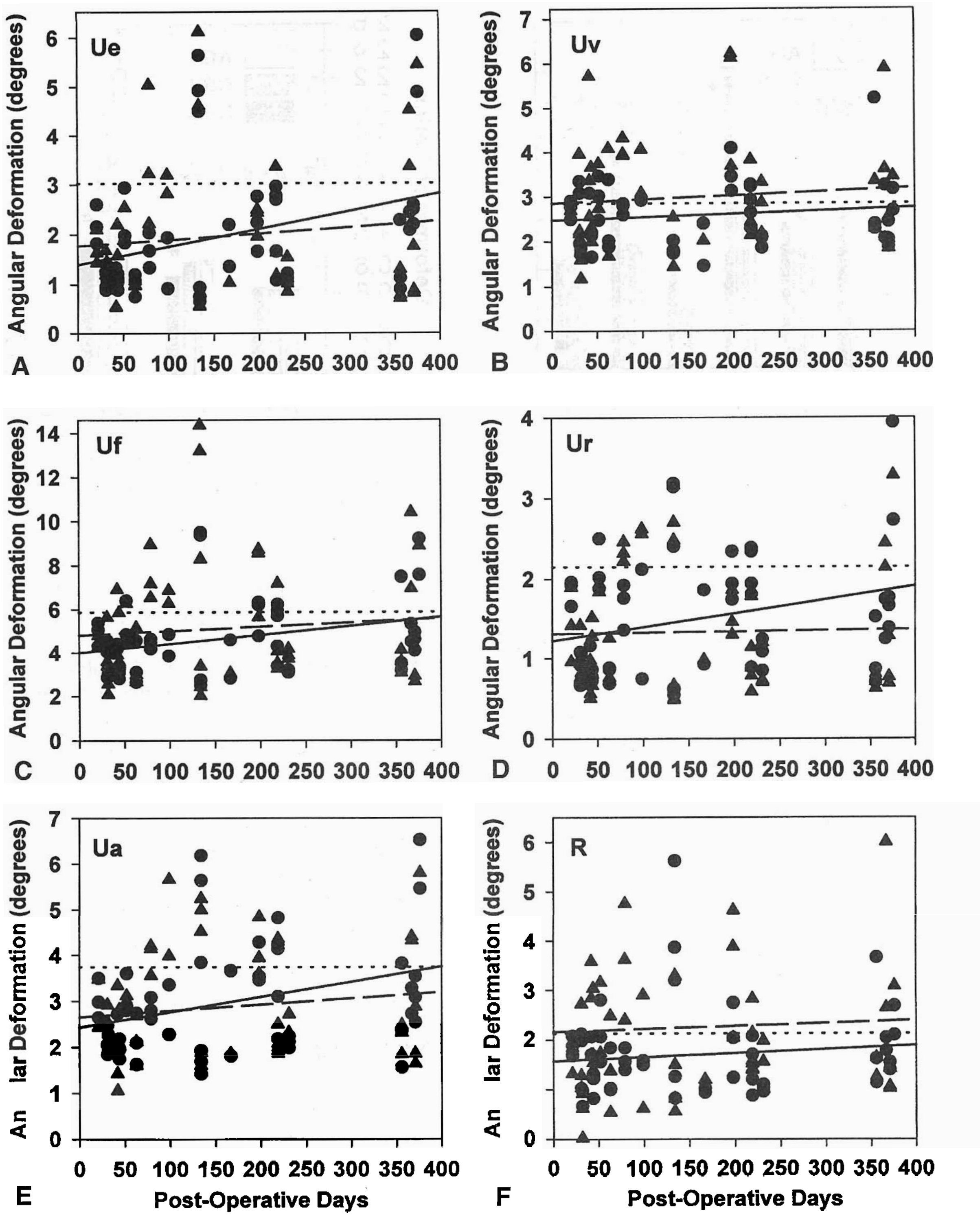

Figure 7. Plots of V-E properties of meshed, split-thickness autograft, CSS, and NHS of the volar forearm and individual data points for autograft *(solid triangle)* and CSS *(solid circle)*. Regression lines for autograft *(dashed line)* and CSS *(solid line)* during the first year after grafting. Mean values from NHS *(dotted line)* of volar forearm of healthy volunteers. **A,** Ue; **B,** Uv; **C,** Uf; **D,** Ur; **E,** Ua; **F,** R.

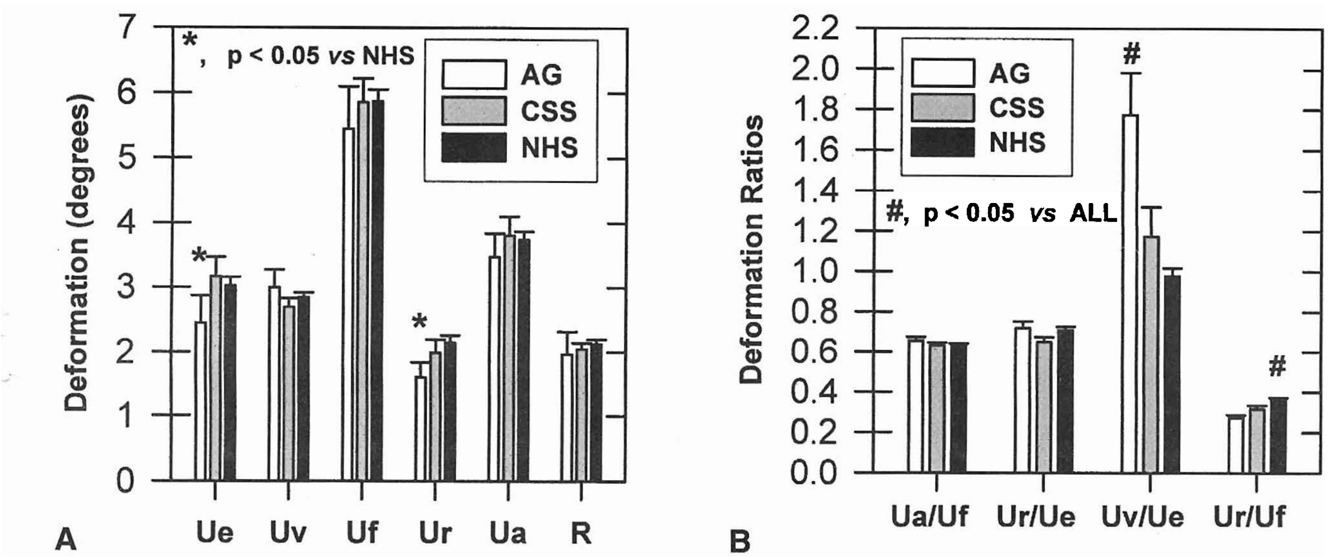

Figure 8. Plots of V-E properties of meshed, split-thickness autograft (AG), CSS, and NHS of the volar forearm at 1 year or longer. **A,** Individual parameters of skin pliability were not statistically different among groups, except for Ue and Ur, for which autograft was lower than NHS. **B,** Ratios of V-E parameters show that autograft was significantly different from both NHS and CSS in ratios of Uv/Ue. Ur/Uf was significantly greater for NHS compared with both CSS and AG.

Cutometer is 2 to 6 mm, which is an appropriate size for the murine model. However, because the aperture is small and the applied load is relatively low (500-mbar vacuum), the depth of measurement is predominantly in the epidermis. In comparison, the DTM applies a load of greater magnitude (10 mNm) over a greater area (2-cm disk in a 3-cm fixed ring), which results in greater depth of measurement. Therefore, the DTM was selected for clinical studies because it has greater magnitude of loading and greater depth of detection.

Data reported here demonstrate that excised burns treated with CSS develop scars at approximately the same rate, and to the same magnitude, as meshed split-thickness autograft. This finding suggests that skin substitutes that include a dermal component may increase stability in repaired skin. If so, it may be expected that frequency of reconstructive procedures after grafting with CSS of this kind would be no greater than for meshed autograft. Although those data are not yet available, they are expected to provide insights of whether measurement of V-E properties of skin with biophysical instruments may be predictive of medical and surgical prognosis.

Variability in data was greater than expected in this clinical study. The lack of correlation of individual parameters of V-E properties with time suggests the contribution of uncontrolled variables in the collection of data from patients. Possible experimental variables are anatomic site, mesh ratio of autograft, subcutaneous tissue density (hard or soft), subject movement during data collection, or congenital disposition for development of scar. These uncontrolled variables are exaggerated by the relatively small population size in this preliminary study. It is expected that better control of factors related to sampling procedures and increase of the population size will reduce variability in data collected and strengthen the validity of the DTM for assessment of burn scar.

Scars from CSS or from autograft resolve at approximately the same rate (6-12 months) and have viscous and elastic properties of pliability that are similar to uninjured skin. For autograft, these results are consistent with normal maturation of burn scar. For CSS, recovery of pliability that is essentially normal represents not only recovery of function but also recovery of cosmesis. Patients in this study also wore pressure garments during the first year after hospitalization, which may have contributed favorably to maturation of the scar.[15,16] It was notable that skin repaired with CSS, similar to autograft, also had only minimal ulceration from shear. Maturation of CSS into stable and functional tissue may result from inclusion of a dermal substitute and in vitro attachment of the epidermal substitute before grafting, in analogy to split-thickness skin. Finally, the maturation and softening of scar is also suggested by continued growth of skin from skin substitutes in this

Table 2. *P* values for slopes of regression lines in Figure 7 for parameters of skin deformation during healing of CSS and Autograft in the first year after surgery

Deformation parameter	CSS	Autograft
Ue	0.008*	0.473
Uv	0.554	0.684
Uf	0.042*	0.537
Ur	0.044*	0.878
Ua	0.009*	0.329
R	0.417	0.781

*$P < .05$ (slope of the regression line is significantly different from zero).

pediatric population.[18] Therefore, it is possible that measurement of scar pliability may predict meaningful, long-term benefits to patients.

The V-E properties of skin constitute one set of the biophysical properties for assessment of skin condition. A clinical examination of skin condition includes pliability, surface hydration, color, shape, and blood flow. The measurement of individual properties of burn scars with instruments may allow multiparameter analysis of skin condition to supplement a clinical examination. The use of instruments for measurement of cutaneous properties allows the establishment of absolute scales for assessment of skin condition. Absolute scales for measurement of skin properties may be expected to apply to any biophysical instruments. Therefore, if measurement ranges of an individual endpoint (ie, pliability) are overlapping for multiple instruments (ie, DTM and Cutometer), it is probable that use of the instruments may be interchangeable for that endpoint.

Validation of data collected depends on factors in the instrument and in the assessment site. Instrument factors require that sensitivity, accuracy, and calibration include the entire range of response of the subject tissue. Factors in the assessment site require proper control for the anatomic location and reference to an uninjured control. Also, virtually all grafted burns are heterogeneous in pliability. Bias may be introduced by selection of sampling sites within a grafted field. In addition, data collected represent a small fraction of the field, and not the entire treatment area. Without proper attention to these factors, sources of error may be introduced that may compromise or disqualify the validity of the data. Therefore, use of instruments for assessment should not be considered inherently valid because it is objective. Furthermore, extrapolation of biophysical data to anatomic and physiologic properties of the subject tissue requires careful consideration and qualification. Although the anatomy of scar, particularly the collagen organization, is understood to be different from that of normal skin, data from instruments must be correlated with controlled morphometric data before an anatomic basis for instrumental data can be concluded.

Results of this preliminary study suggest that the DTM is a valid instrument for assessment of burn scars and of normal skin. Because instruments for scar measurement are available and provide objective data on absolute scales, they provide a common denominator by which any caregiver can compare the outcome after grafting of burns with autografts or alternative skin substitutes. Therefore, the use of instruments is expected to facilitate assessment and comparison of outcome on an absolute scale. It is expected that objective measurement of outcome on an absolute scale will expedite the qualification of existing and alternative therapies for the greatest and earliest realization of patient benefits.

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