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Carbon Dioxide Laser Ablation With Immediate Autografting in a Full-Thickness Porcine Burn Model

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Objective

To compare the long-term clinical and histologic outcome of immediate autografting of full-thickness burn wounds ablated with a high-power continuous-wave CO_2 laser to sharply débrided wounds in a porcine model.

Summary Background Data

Continuous-wave CO_2 lasers have performed poorly as tools for burn excision because the large amount of thermal damage to viable subeschar tissues precluded successful autografting. However, a new technique, in which a high-power laser is rapidly scanned over the eschar, results in eschar vaporization without significant damage to underlying viable tissues, allowing successful immediate autografting.

Methods

Full-thickness paravertebral burn wounds measuring 36 cm^2 were created on 11 farm swine. Wounds were ablated to adipose tissue 48 hours later using either a surgical blade or a 150-Watt continuous-wave CO_2 laser deflected by an x-y galvanometric scanner that translated the beam over the tissue surface, removing 200 μm of tissue per scan. Both sites were immediately autografted and serially evaluated clinically and histologically for 180 days.

Results

The laser-treated sites were nearly bloodless. The mean residual thermal damage was 0.18 ± 0.05 mm. The mean graft take was 96 ± 11% in manual sites and 93 ± 8% in laser sites. On postoperative day 7, the thickness of granulation tissue at the graft–wound bed interface was greater in laser-débrided sites. By postoperative day 180, the manual and laser sites were histologically identical. Vancouver scar assessment revealed no differences in scarring at postoperative day 180.

Conclusions

Long-term scarring, based on Vancouver scar assessments and histologic evaluation, was equivalent at 6 months in laser-ablated and sharply excised sites. Should this technology become practical, the potential clinical implications include a reduction in surgical blood loss without sacrifice of immediate engraftment rates or long-term outcome.

Although early excision and grafting of deep dermal and full-thickness burns has improved patient survival rates,[1] shortened hospital stay,[1] and reduced deaths from burn wound sepsis,[2] extensive blood loss during burn débridement is a source of ongoing complications.[3] The potential for viral transmission,[4,5] dilutional thrombocytopenia, hypothermia during surgery, pulmonary dysfunction,[6] immunosuppression,[7,8] and increased cost[9,10] as a result of blood transfusions warrant investigations to reduce such risks. Recently, investigators have explored the role of vasoconstrictive agents[11–14] injected into donor and escharotomy sites, the use of topical thrombostatic agents[15] during débridement, and the use of tourniquets[16,17] to limit blood loss and oozing from wound beds in extremity burns. Although these measures have shown some promise for reducing

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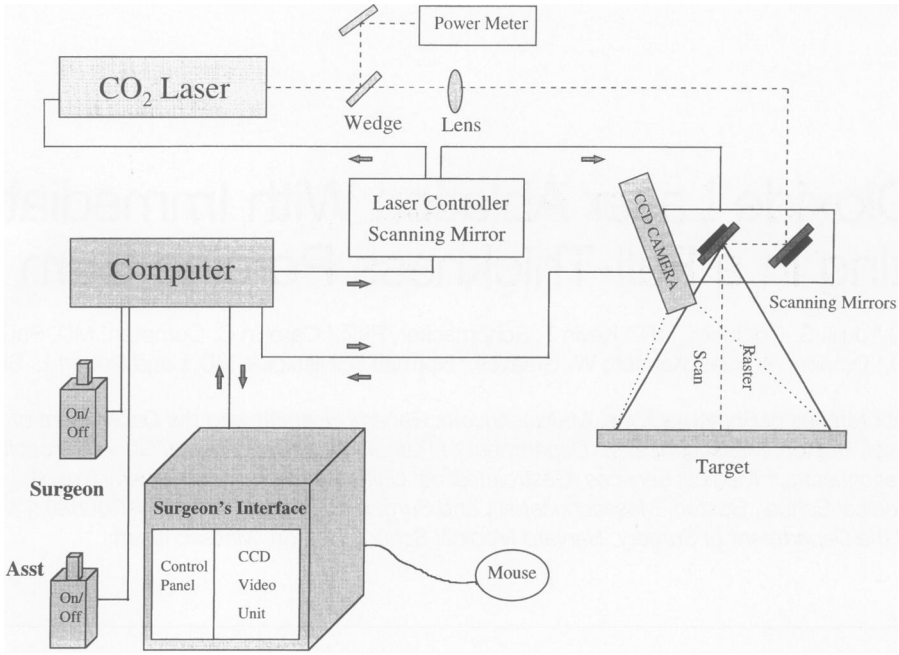

Figure 1. The laser burn débridement system, demonstrating the interrelationships of the laser, the computer, and the surgeon.

blood loss during surgery, the search continues for more efficient methods of limiting blood loss and decreasing the need for transfusions.

The use of continuous-wave CO_2 lasers as cutting tools to débride burn eschar was first studied in the early 1970s as a means of reducing blood loss.[18–21] Reduced bleeding secondary to extensive coagulation at the edge of laser-ablated wounds was demonstrated,[19–27] but this same tissue damage caused delayed wound healing and prevented successful skin grafting.[28–34] A new approach to this problem is based on the fact that a brief exposure to a high-energy CO_2 laser will result in tissue vaporization with minimal residual thermal damage if the laser exposure time (pulse duration) is less than the heat conduction time (thermal relaxation time) of the tissue.[35–40]

The goal of this study was to compare high-power continuous-wave CO_2 laser ablation with surgical excision for the removal of full-thickness burns in a porcine burn model. Immediate autografting was performed and graft take was evaluated after tangential laser and surgical excision. Wounds were evaluated clinically and histologically for 180 days to document any long-term differences in wound healing between laser- and surgically excised sites.

METHODS

Laser System

A radiofrequency-excited CO_2 laser (Coherent, Diamond 64, Palo Alto, CA) was used to débride porcine skin (Fig. 1). The radiofrequency was 6 kHz with a 50% duty cycle. The delivered power to the tissue was 145 to 175 Watts. The beam was focused by a single ZnSe lens with a focal length of 75 cm, giving a beam diameter of 1.4 × 1.6 mm at the target. The irradiance was calculated to be 8.2 to 9.9 kW/cm^2. The region of ablation was controlled using an x-y galvanometric scanner (General Scanning, G300 Series Galvanometer Optical Scanner, DE Series Digital Electronics, Waltham, MA) that raster scanned the beam over the tissue surface. The scanning velocity along the x axis was adjusted to give a radiant exposure of 35 J/cm^2 along its axis. The y axis was stepped after each line scan. The interline spacing along the y axis was set to 0.7 mm, half the beam diameter.

A red diode laser was used to adjust the height of the optical deck to focus the CO_2 beam onto the tissue surface. The diode laser beam was split into two beams and sent to mirrors on opposite sides of the optical deck. The mirrors were adjusted to superimpose the two red beams with the CO_2 beam at the focal plane with the x-y scan mirrors in their plumb position. A frequency-doubled, passively Q-switched Nd:YAG laser was adjusted to be colinear with the 10.6-μm invisible CO_2 beam. Dual-series fail-safe switches were used as a safety feature. This allowed the surgeon to disarm the laser should any potential problem arise. Operation of the laser required two persons to activate their respective switches in accordance with a designated sequence.

A computer interface is an integral component of the laser system. This enables the surgeon to image a burn area and select a region of débridement. Using a computer pointer, the surgeon can then outline an updated area of débridement after each set of laser passes. In using such an

efficient débridement system, a large plume of smoke is produced because of the high rates of tissue ablation. To control this plume, a high-efficiency smoke evacuator (Model 1201, Plumesafe, Buffalo Filter, Buffalo, NY) was used to remove smoke from the surgical field. Along with the smoke evacuator, a specially designed smoke evacuator enclosure was fabricated to confine the plume and to draw it away actively from the laser beam. As in all surgical procedures in which a plume or aerosol is generated, there exists, at least in theory, a risk of viral transmission from the plume. However, we are not aware of any published studies in which this has been documented. A high-efficiency smoke evacuation system may reduce this potential risk.

Burn Model

Eleven female Yorkshire farm swine (Parsons, Inc., Hadley, MA) weighing approximately 25 kg were cared for in a manner that conformed to the NIH Guide for Care and Use of Laboratory Animals. The experimental protocol was approved by the Massachusetts General Hospital Institutional Animal Care and Use Committee and the Subcommittee on Research Animal Care.

Before burn placement, each pig was sedated with ketamine (20 mg/kg intramuscularly) and placed left side down on the surgical table. Halothane (0.5% to 2% to effect), oxygen (4 liters/min), and nitrous oxide (1 to 2 liters/min) were delivered through a mask. After induction, the rate of halothane administration was decreased to 1% to 1.5% as tolerated. Heart rate and peripheral oxygen saturation were monitored throughout the procedure. The right paravertebral region and torso of the pig were clipped with an electric razor, then washed with chlorhexidine soap and povidone–iodine solution.

Burn Placement

The burn sites were placed on the right paravertebral region. A 6-cm × 6-cm brass block was heated in boiling (100°C) water and then held with mild pressure on the skin surface for 20 seconds to create a full-thickness burn. The brass block was reheated between each application. The wounds were dressed with silver sulfadiazine cream 1% (Thermazene, Sherwood Medical, St. Louis, MO) and a layer of petrolatum dressing (Xeroform, Sherwood Medical) and covered with sterile gauze. The dressings were fixed in place with an elastic adhesive bandage and stapled to the skin. A garment formed from stockinette (Alba-Waldensian, Rockwood, TN) was used to protect the wounds from destruction in the animal cage. An intramuscular injection of buprenorphine 0.3 mg (Reckitt and Colman, Hull, England) was given for analgesia on termination of burn placement, followed by acetaminophen 120 mg every 4 to 6 hours as needed.

Débridement Procedure

Forty-eight hours after burn placement, the pig was anesthetized again using ketamine, halothane, and nitrous oxide, as described above. In addition, the animal underwent endotracheal intubation with ventilatory support. It was necessary to intubate the animal before laser débridement to halt respirations while the laser scanned over the tissue surface. This was facilitated by the use of the neuromuscular blocking agent pancuronium (Elkins-Sinn, Inc., Cherry Hill, NJ; 0.1 mg/kg intravenous induction dose with a maintenance dose of 0.015 mg/kg every 25 to 40 minutes). An 18-gauge catheter was placed in an ear vein for intravenous infusion of 0.9% normal saline at 125 cc/hour. One gram of cefazolin (Marsam Pharmaceuticals, Inc., Cherry Hill, NJ) was administered intravenously 30 minutes before laser débridement. The heart rate and peripheral oxygen saturation were monitored by pulse oximetry.

After induction of anesthesia, the burns were exposed and the animal was prepared and draped in a sterile fashion. The site selected for laser débridement was chosen randomly for each animal. The smoke evacuator enclosure was sealed around the laser débridement site and laser scans were delivered in groups of 2 or 4 until 10 scans had been completed. After 10 scans, the adipose tissue was visualized and the liquefied fat was wiped away with sterile gauze. Wiping was repeated between subsequent scans to prevent ignition of oil collecting over the tissue surface during ablation. The number of scans performed at each burn site was determined by the appearance of the wound bed. Laser débridement was complete when the erythema, purpura, and thrombosed vessels in the burn eschar were removed and moist yellow fat was visualized.

Surgical Excision

One full-thickness burn on each pig was manually débrided to adipose tissue with a hand-held Goulian dermatome (Weck and Co., New York, NY) by an experienced surgeon. This served as the control site. The Goulian blade removed approximately 1 mm of tissue per tangential cut.

Skin Grafts

The skin on the right paravertebral region and torso was prepared for split-thickness autograft harvest. The grafts were harvested with a compressed nitrogen gas-driven dermatome (Model #102725, Zimmer, Dover, Ohio) set at 0.016″. The harvested skin was placed on a plastic dermacarrier (Model #2195-12, Zimmer) and expanded at 1:1.5 through a mesher (Zimmer). The grafts were cut to fit the 6-cm × 6-cm débrided burn wounds with minimal expansion of the mesh. Grafts were placed over the laser- and surgically débrided burns. Autografts were attached to the skin using 2-0 silk sutures applied every 1 cm around the periphery of the wound. The grafted wounds were then

covered with a tie-over stent of petrolatum gauze and sterile dry cotton roll, which was anchored tightly by silk sutures.

The donor sites were dressed with Scarlet Red Ointment Dressing (Sherwood Medical) and layers of sterile gauze, which were attached to the wound with 2-0 nylon suture. The pigs were dressed in 8″ stockinette with holes cut for the legs. An intramuscular injection of buprenorphine 0.3 mg was given for pain and was followed by acetaminophen 120 mg every 4 to 6 hours as needed. The animal was returned to its cage as the anesthesia began to wear off and was given food and water *ad libitum.*

Burn Depth Evaluation

Burn depth was evaluated by taking a 4-mm punch biopsy of the burn 48 hours after burn placement. Biopsies were evenly divided. One half was fixed in formalin, then processed with hematoxylin and eosin (H&E) stain. The remaining half was frozen and processed with lactate dehydrogenase (LDH) stain. The LDH stain is a vital dye that stains purple only in viable cells. The lack of staining with LDH denotes cells killed at 47°C[41] and provides a sensitive and precise measurement of burn depth by immediately revealing the extent of irreversible tissue injury. One half of each biopsy specimen was immediately frozen after excision, incubated in Michaelis Barbital-Na Acetate Buffer with paranitrophenyl-substituted ditetrazolium salt (Nitro-BT), betanicotinamide adenine dinucleotide, and sodium lactate (salt), and then placed in −80°C overnight. Subsequently, the tissue was rinsed in plain barbital buffer, fixed in 10% formalin, and processed for routine light microscopy. Before light microscopy, the specimens were dehydrated and stained with a diluted alcohol/eosin solution. This additional step made the unstained tissue (nonviable cells) easier to visualize because the eosin acted as a counterstain.

Burn depth was measured from the LDH-stained specimens using a calibrated reticle under light microscopy instead of H&E-stained specimens because of the greater sensitivity associated with LDH stain. Tissue measurements were evaluated in at least three random positions in each specimen. Specimens stained with H&E were used to evaluate histologic graft take and to assess the thickness of granulation tissue (neovascularization, immature and edematous collagen, and a dense cellular infiltrate) between the native subcutis and graft–wound bed interface.

Assessment of Laser-Induced Residual Thermal Damage

The laser-induced residual thermal damage in the graft bed was measured by taking a 4-mm punch biopsy of the wound immediately after laser ablation of the eschar. One half of each sample was processed and stained with H&E; the remaining half was immediately frozen for LDH stain, as described above. The residual thermal damage was measured using the LDH-stained slides with a calibrated reticle. Measurements were made from at least three random sites on the tissue specimen. H&E-stained specimens were used for comparison of findings noted on LDH stain.

Graft Take

Graft take was evaluated on postoperative day 7 by a blinded examiner. After each dressing was removed, wounds were coded with colored labels. Photographs were taken for comparison and review of wound sites. The examiner rated the percentage of engraftment, as defined by revascularization (blanchability) and graft adherence. A paired two-sample Student's t test was used to analyze graft take between laser and manual sites.

Wound Maturation

Vancouver Scar Assessments

Vancouver scar assessments[42] were used to evaluate long-term scarring in 5 of 11 animals for 6 months. The assessment is a graded composite score (0 to 13) that serves as an objective measure of the pigmentation, vascularity, pliability, and height of human burn scars. Each parameter has a numerical range to assess the severity of scarring. The lower an absolute overall score, the less significant the presence of scarring. The numerical assignments are as follows: pigmentation (0 = normal, 1 = hypopigmentation, 2 = hyperpigmentation), vascularity (0 = normal, 1 = pink, 2 = red, 3 = purple), pliability (0 = normal, 1 = supple, 2 = yielding, 3 = firm, 4 = banding, 5 = contracture), and height (0 = normal or flat, 1 = <2 mm, 2 = < 5 mm, 3 = >5 mm). Because of the similarities between human and porcine skin,[43–45] it was used in this study as a method to evaluate wound appearance quantitatively in swine. A surgeon blinded to the mode of excision determined Vancouver scores for wound sites every 30 days. The decision to follow only 5 of the 11 animals for 6 months was based on cost as well as study design. The purpose of the first six animals enrolled in the study was to examine engraftment and wound appearance to postoperative day 30. The remaining five animals were used primarily to study long-term scarring for 6 months.

Histology

Punch biopsy specimens (4 mm) were taken from the graft bed on postoperative day 7 and at weekly intervals up to postoperative day 30. Thereafter, biopsy samples were obtained at monthly intervals for the next 5 months in the remaining five animals in the study. The samples were fixed in formalin, embedded in paraffin, sectioned, and stained with H&E for light microscopy. Histologic assessment of graft take was determined by evidence of epidermal viability, neovascularization at the graft–wound bed interface,

Table 1. THERMAL DAMAGE EVALUATION OF HISTOLOGIC SPECIMENS

Pig #	Mean Burn Depth (μm)	Epidermal-Dermal Thickness (μm)	Laser Induced Thermal Damage (μm)
1	N/A	2280	N/A
2	2000	2750	200
3	1300	2750	150
4	1950	1950	200
5	2000	2370	100
6	2630	2500	250
7	2880	2700	N/A
8	2700	2440	140
9	2750	2750	190
10	2900	2870	180
11	2500	2620	180
Mean values ± S.D.	2360 ± 520	2540 ± 270	180 ± 40

Thermal damage data summarizing burn depth and residual thermal damage. All burns were debrided to adipose regardless of initial burn depth. Three random measurements were taken on each sample after biopsy and microscopic preparation to arrive at mean values.
N/A = data unavailable.

presence of a perivascular infiltrate (circulating cells within the graft dermis), and absence of wound denudation or tissue necrosis. Wound healing was compared between autografts on the laser sites *versus* manual sites. The width of the zone of granulation tissue at the graft–wound bed interface was measured with a calibrated reticle and tabulated for postoperative days 7 to 180.

RESULTS

Postoperative Day 0

Burn Depth

The mean burn depth was measured in 10 of 11 animals and was found to equal 2.3 ± 0.5 mm (Table 1). The mean epidermal–dermal thickness was 2.5 ± 0.3 mm. When burn depth was compared with the epidermal–dermal thickness, it was evident that 90% of all the burns placed were in the deep dermis or into adipose tissue. Regardless of the actual burn depth, all the laser-ablated burns were débrided to adipose tissue.

Residual Thermal Damage

The laser-induced zone of residual thermal damage, as measured by the LDH stain (see Table 1), comprised a thin layer of nonvital cells with a mean thickness of 0.18 ± 0.04 mm on the surface of the adipose tissue of the wound bed. It was difficult to detect the residual thermal damage of the tissue stained with H&E because of the modest amount of collagen distributed in adipose tissue. Thus, LDH results were used to assess this aspect of laser-induced injury.

Blood Loss

Laser-treated sites were nearly bloodless. During the study, one instance of breakthrough bleeding occurred, which subsequently resolved after a repeat laser scan. Manually treated sites required tamponade, topical epinephrine, and electrocautery to achieve hemostasis. Two standard surgical sponges were usually saturated with blood by the end of the manual procedure.

Time of Débridement

A similar amount of time was required for laser ablation and manual excision. At a mean power of 153 W, the laser completed one pass in 12.7 sec. Mean lasing time to débride bloodlessly a 6 × 6 cm^2 wound site to adipose tissue (13 to 18 passes) was 3.4 to 3.8 minutes. Additional time was necessary to set up the laser and to remove oil or debris from the wound bed between laser passes.

Six to 10 passes of the Goulian blade were needed to débride the wound manually to adipose tissue. The approximate time to complete manual débridement was 5 to 8 minutes, including time to achieve hemostasis.

Postoperative Day 7

On postoperative day 7, the split-thickness autografts were evaluated for graft take. Grafts placed on the laser-ablated wound bed appeared grossly identical to the manual sites. Although the interstices of the mesh were more prominent in laser-ablated sites, both grafts were pink, blanched with pressure, and were firmly adherent to the wound bed (Fig. 2). The mean percentage graft take for laser and manual sites were statistically equivalent (Table 2). Among manual sites, the mean percent graft take was 96% ± 11%, whereas in laser-ablated wounds, the mean graft take was 93% ± 8% ($p > 0.05$). Laser-ablated sites were more vascular and hyperpigmented than manual sites (Fig. 2). In contrast, manual sites displayed a shinier appearance and smoother texture.

Table 2. OVERALL DATA SUMMARY

Variable	n	Laser (±SD)	Goulian Blade (±SD)	p value
Thermal Damage (μm)	11	180 ± 40	0	N/A
Graft take (%) (POD 7)	11	93 ± 8	96 ± 11	0.07
Zone of Granulation (μm)				
POD 7	11	1010 ± 710	424 ± 260	0.01
POD 14	11	1300 ± 870	740 ± 530	0.11
POD 21	11	1580 ± 970	1080 ± 440	0.12
POD 30	11	1290 ± 660	1430 ± 1100	0.81
POD 60	6	1780 ± 190	1700 ± 1160	0.83
POD 90	6	1690 ± 520	1060 ± 340	0.054
POD 120	6	1300 ± 880	1430 ± 910	0.65
POD 150	6	1050 ± 840	1060 ± 770	0.97
POD 180	6	1060 ± 950	720 ± 500	0.23

POD = postoperative day; N/A: data unavailable.
Multi-variable data analysis for comparison of laser and manual debridement of full thickness burns.

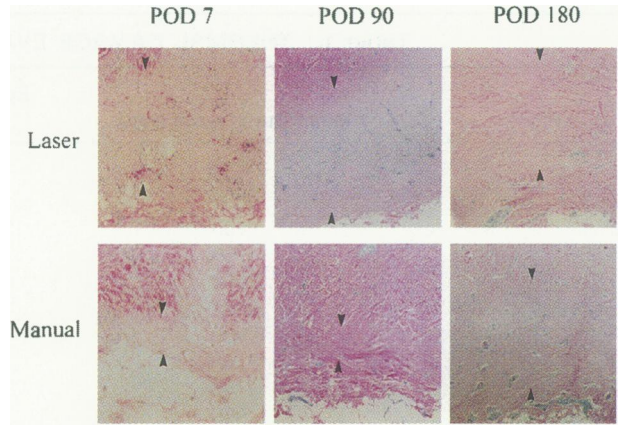

Figure 3. Histologic appearance of granulation tissue in healed split-thickness grafts after laser and surgical escharectomy 7, 90, and 180 days after grafting. The zone of granulation (black arrowheads) was significantly larger at postoperative day 7 and 90 in the laser-treated sites. Note the persistence of the zone of granulation (black arrowheads) at postoperative day 180 in both laser and manual sites.

Long-Term Wound Healing

Histology

By postoperative day 7, the epidermal interstices were reepithelialized in both the laser and manually débrided sites, and the epidermal thickness and architecture appeared normal. A mixed inflammatory infiltrate was present at the graft–wound bed interface. The infiltrate was immediately present at postoperative day 7 in the laser sites, but its magnitude regressed at later times. It took an additional week for the inflammatory cell response to peak in the manual sites (postoperative day 14). Rare foreign body granulomas were observed in greater numbers in the dermis of laser-débrided sites (in response to hair and denatured collagen).

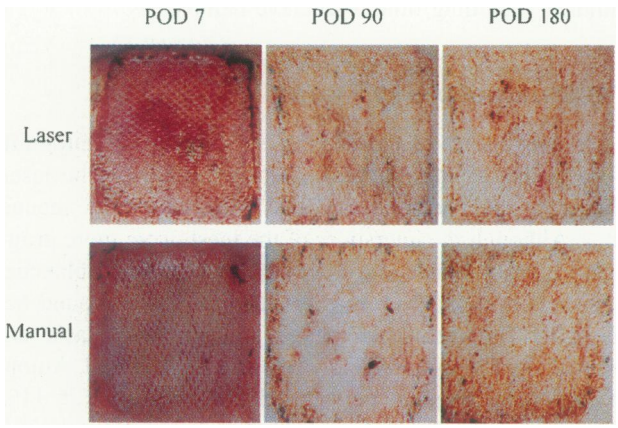

Figure 2. Gross clinical appearance of healed split-thickness grafts after laser and surgical escharectomy 7, 90, and 180 days after grafting. At postoperative day 7, laser-ablated wounds demonstrated hyperpigmentation and increased vascularity. By 90 and 180 days after grafting, laser and manual wounds shared a similar clinical appearance.

The most apparent difference between the laser and manual sites was the thickness of newly formed granulation tissue between the native subcutis and graft dermis. A comparison of the thickness of granulation tissue between laser- and manually débrided sites is shown in Figure 3. To quantify this effect, the thickness of granulation tissue was measured in all postoperative sites and tabulated in Table 2. It is evident from Table 2 that the laser-débrided sites had a significantly greater amount of granulation tissue at postoperative day 7 than manual sites ($p < 0.05$). However, based on the data, there were no significant differences noted in the thickness of granulation tissue from laser or manual sites from postoperative day 14 to 180 ($p > 0.05$). The thickness of granulation tissue peaked at postoperative day 60 in both laser and manual sites, and then decreased during the next 120 days.

Clinical Assessment

The Vancouver Scar Assessment was used to assess wounds in 5 of the 11 animals during a 6-month period after skin grafting (Fig. 4). The most distinct differences observed between the laser and manual sites were related to the degree of pigmentation, vascularity, and pliability of the wound beds. At postoperative day 30, laser-débrided wounds appeared to be more vascular and hyperpigmented but less pliable than the manually débrided sites. The height of the overall scar was comparable (<5 mm) in both groups. The differences were reflected by the Vancouver scores: the laser sites had a mean score of 5.8 ± 0.4 *versus* 2 ± 1.2 for the manual sites ($p = 0.001$). At postoperative day 120, the margin between laser (3.4 ± 2.5) and manual (2.8 ± 1.3) sites had narrowed considerably ($p = 0.62$). Both laser and manual sites demonstrated similar pliability, with minimal hyperpigmentation and vascularity. At postoperative day 180, there were minimal cosmetic and functional differ-

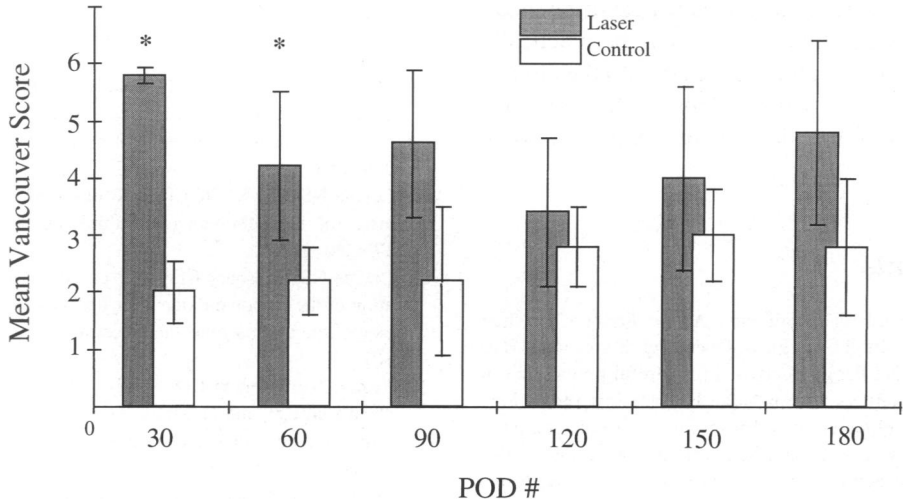

Figure 4. Vancouver Scar Assessment for laser *vs.* manual sites followed to 6 months after grafting. At postoperative day 180, laser and manual sites demonstrated no statistically significant differences ($p = 0.24$). * $p < 0.05$ laser *vs.* manual site.

ences between the laser and manual sites (see Fig. 2). The mean Vancouver score was 4.8 ± 3.4 for laser-débrided sites and 2.8 ± 1.6 for manually débrided sites ($p = 0.24$). Both sites were devoid of hair and had similar degrees of pigmentation, vascularity, pliability, and overall scar height. When compared with the surrounding normal skin, both laser- and manually débrided sites had less pliability because of scar formation, but otherwise had similar pigmentation and vascularity.

DISCUSSION

This study demonstrates that a high-power, rapidly scanned, continuous-wave CO_2 laser system can efficiently ablate full-thickness burns in a porcine model and allow immediate autografting with short- and long-term results comparable to sharp excision. The laser-ablated wounds were nearly bloodless. The ability of the laser to coagulate vessels is directly related to the degree of residual thermal damage produced after the laser interacts with the tissue. Using our system, it is expected that vessels <200 μm can be coagulated.[37] Vessels that exceed this size may require multiple scans or passes to achieve effective coagulation. Although the purpose of this study was to compare engraftment rates rather than blood loss between laser-ablated and sharply excised sites, it was evident that the use of the laser nearly eliminated bleeding during débridement.

The average power of 153 W used in our study was adequate for vaporizing burn eschar. Approximately 3.2 mm of tissue could be removed bloodlessly in 16 laser passes over a period of 178 to 228 seconds. However, as a result of using such high powers, the laser cannot be manually operated; instead, it must be scanned across the tissue surface by a scanning system. Scanning the beam across the tissue surface also increases the inherent precision of the laser,[35] further reducing dwell time and subsequent thermal damage.[39]

Although the thickness of granulation tissue was significantly greater in laser-débrided sites during the first 3 months after surgery, long-term examination and histology revealed no differences between the sites at 180 days. Specifically, the persistence of granulation tissue did not appear to have a significant impact on wound appearance from postoperative day 120 to 180 based on Vancouver scar assessment. Similar histologic findings have been described in incisional wounds created with either CO_2 laser or electrocautery when compared with scalpel incisions followed to postoperative day 42 in a miniature hairless porcine model.[46] Specifically, a greater amount of granulation tissue, necrosis of the reticular dermis, and degree of foreign body granulomas were observed in laser-treated sites *versus* scalpel sites in the first 21 days. However, 6 weeks after incision, the laser-treated wounds were histologically similar to manually incised wounds.

An important limitation of this study is that the pig does not provide a good model for hypertrophic scar formation in human burn patients. Therefore, it may be difficult to extrapolate the long-term outcomes seen in our porcine model to humans.

In summary, laser vaporization of full-thickness burn eschar was performed in 11 swine with a high-power, rapidly scanned, continuous-wave CO_2 laser with immediate engraftment that matched the sharply excised control. Residual thermal damage (180 μm) produced by the laser limited bleeding from the wound bed without affecting split-thickness skin engraftment. Long-term scarring, based on Vancouver scar assessment and histologic evaluation at

6 months, demonstrated no clinical or statistical differences. The implication of this technology, if it can be practically and effectively brought from the laboratory into the clinical setting, is a reduction in surgical blood loss without sacrifice of engraftment rates or cosmetic outcome. A pilot study in humans is underway.

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