Acellular Dermal Matrices in Hand Reconstruction

Chandra V. Ellis, M.D.
David A. Kulber, M.D.

Los Angeles, Calif.

Background: The goal of this article is to review the current literature on the use of acellular dermal matrix in forearm, wrist, and hand reconstruction.
Methods: A comprehensive literature search was performed using the Cochrane Database of Systematic Reviews, MEDLINE, PubMed, and Web of Knowledge. Articles were categorized as acellular dermal matrix used in soft-tissue repair and in ligament reconstruction. Search terms included "acellular dermal matrix," "biologic dressing," "skin replacement," "dermal allograft," "AlloDerm," "FlexHD," "Permacol," and "Strattice." These were all cross-referenced with "forearm," "wrist," and "hand." Data extraction focused on indications, surgical techniques, clinical outcomes, and complications. Exclusion criteria included regeneration templates, neonatal foreskin, and review articles.
Results: More than 100 articles published between 1994 and 2011 were identified. Upon final review, five prospective case-control studies, three retrospective case-control studies, four case reports, one cross-sectional cohort, one prospective consecutive series, and one study type unknown were evaluated. Matrix was most commonly used in burn reconstruction. It has also been used in ligament and joint reconstruction for first carpometacarpal arthritis. One article illustrated the use of porcine matrix in basal joint arthritis, a practice that was abruptly terminated because of a concern over increased infections.
Conclusions: The clinical indications for acellular dermal matrix have increased throughout the last 15 years. Hand surgeons have been cautious but diligent in developing alternative treatment options in hand reconstruction, with a focused effort to reduce donor-site morbidity. Although acellular dermal matrices continue to find innovative uses to solve upper extremity surgical problems, more comparative prospective trials are needed. (*Plast. Reconstr. Surg.* 130 (Suppl. 2): 256S, 2012.)

Human acellular dermal matrix was released into the market in 1994 for replacement of inadequate integumental tissue due to burn injury. Since then, upper extremity surgeons have found these allografts useful as skin replacement after radial forearm flap harvest, in basal joint reconstruction, and more recently in rotator cuff repair.[1–4] Historically, hand surgeons have used several biologic and nonbiologic products to correct joint deformities in rheumatoid arthritis and as prostheses in functional joint replacement. With the increased popularity of acellular dermal matrix constructs and published clinical indications, we present a review of their use in hand and upper extremity surgery.

A property of acellular dermis that offers advantages in hand surgery is its ability to retain

From the Keck School of Medicine of the University of Southern California, Cedars Sinai Medical Center.
Received for publication February 14, 2012; accepted April 9, 2012.

DOI: 10.1097/PRS.0b013e318265a5cf

Disclosure : *The authors have no financial interest in any of the products or devices mentioned in this article.*

Supplemental digital content is available for this article. A direct URL citation appears in the text; simply type the URL address into any Web browser to access this content. A clickable link to the material is provided in the HTML text of this article on the *Journal*'s Web site (www.PRSJournal.com).

elastin and collagen fibers after undergoing decellularization and sterilization.[5] Histological studies have shown that although human acellular dermal matrices can incite a low-grade host inflammatory response, full immunogenic rejection by the host rarely occurs.[1,6] Permacol, a porcine matrix widely used in hernia repair, undergoes chemical collagen cross-linking, which confers strength and resistance to host collagenases. Although this cross-linkage does protect it from immediate enzymatic degradation, it also permits a prolonged chronic inflammatory response at the site of implantation.[6–10] We present the most up-to-date published clinical experiences of acellular dermis in forearm, wrist, and hand reconstruction, along with illustrations of specific case examples treated in the senior author's practice.

METHODS

Literature Search

A literature search using the Cochrane Database of Systematic Reviews, MEDLINE, PubMed, and Web of Knowledge was used for this study. Our search terms included "acellular dermal matrix," "biologic dressing," "skin replacement," "dermal allograft," "AlloDerm," "Flex HD," "Permacol," and "Strattice." These were all cross-referenced with the keywords "forearm," "wrist," and "hand." Inclusion criteria were studies published between 1994 and 2011; these selected studies showed a clear use of acellular dermal matrix in the upper extremity in human subjects. Exclusion criteria were articles that used regeneration templates, for example, Integra (Integra LifeSciences Corp., Plainsboro, N.J.), neonatal foreskin, Apligraf (Organogenesis, Inc., Canton, Mass.), and bovine pericardium. Review articles were excluded. Meta-analysis was not used because the sample sizes were small, and there were not enough comparable data.

Data Extraction and Statistical Analysis

On final review, articles were included that clearly described using acellular dermal matrix in the forearm, wrist, and hand (Table 1). Data of interest included surgical technique, indication for use, follow-up, and complications. Given the limited number of patients, case reports, and the retrospective nature of the review, comparable statistical analysis was not pursued. Complications were reported from individual articles. Statistically significant or insignificant differences, if stated, were included in the evaluation of the articles.

Table 1. Clinical Uses of Acellular Dermal Matrix in the Forearm, Wrist, and Hand

Soft-tissue reconstruction
• Forearm fascial dehiscence
• Skin coverage after radial forearm flap harvest
• Neuropathic pain/neuroma at the wrist
• Burn*
• Hand infection with palm contracture*
• Congenital/pediatric*
• Dupuytren's contracture*
• Degloving injury*
Ligament reconstruction/joint reconstruction
• Basal joint arthritis*

*Clinical case examples were from senior author, David Kulber, M.D.

RESULTS

Literature Search

A search of MEDLINE, PubMed, and Web of Knowledge databases together yielded over 100 articles in which the search terms "acellular dermal matrix," "biologic dressing," "skin replacement," "dermal allograft," and trade name products were cross-referenced with "forearm," "wrist," and "hand." When the search was limited to human acellular dermal matrix, English translations, articles published between 1994 and 2011, and queried for specific use, this number was reduced to 15. No studies were found in the Cochrane database. Review articles and articles not clearly identifying (1) the forearm, wrist, and hand as sites of reconstruction, (2) regeneration templates, and (3) nonskin source products were all excluded from this review. In our extensive review we did not find any randomized controlled trials or large volume patient series. We did find multiple articles where acellular matrix was used to replace forearm skin and fascia, in burn reconstruction, and in joint reconstruction for carpometacarpal arthritis (Table 2).

Forearm Muscle Herniation

The most common cited use of acellular dermal matrix in the forearm has been to replace the deep fascia after muscle herniation and to cover the volar forearm after radial forearm flap harvest. Forearm muscle herniation was first described in 1965, where the use of autogenous tissue was the primary choice of treatment.[11–16] In 2010, Kozlow et al. described two patients who had a flexor compartment fascial defect.[15] The 3 × 7 -cm forearm defect in patient 1 was repaired with AlloDerm (LifeCell Corporation, Branchburg, N.J.) as an inlay graft. The second patient presented with a similar story and was repaired with Flex HD (MTF Ethicon, Edison, N.J.). At 1-year follow-up,

Table 2. Literature Review: Acellular Dermal Matrix in the Forearm, Wrist, and Hand

Study	Type of Study	Clinical Indication	No. of Patients	Allograft	Overall Outcome
Kozlow et al., 2010[15]	Case report	Forearm herniation	2	Human AlloDerm and FlexHD	1-yr follow-up both with symptom relief, without reherniation
Sinha et al., 1999[21]	Prospective, case-control	Donor-site coverage after RFF harvest	52	Human AlloDerm	Complete wound healing may take up to 12 wk, no major complications, acceptable cosmesis
Wax et al., 2002[22]	Retrospective, case-control	Donor-site coverage, RFF harvest, comparing STSG to allograft	5	Human AlloDerm	ADM group longer time to complete healing and marginally improved cosmesis compared with STSG controls
Ho et al., 2006[19]	Cross-sectional cohort	Donor-site coverage, RFF harvest comparing STSG, FTSG, and allograft	7	Human AlloDerm	Comparable aesthetic and functional outcomes in 3 separate groups
Rowe et al., 2006[23]	Retrospective, case-controlled	Donor-site coverage after RFF harvest	15	Human AlloDerm	Better aesthetic and functional outcome compared to control (STSG-alone)*
Medina et al., 2011[24]	Prospective, case-control	Donor-site coverage after RFF harvest	16	Human AlloDerm	Primary closure of harvest site with improved cosmetic outcome
Peterson and Adham, 2004[25]	Prospective case-control	Wrist pain and nerve hypersensitivity	10	Human AlloDerm	Allograft used to isolate nerve branches done in conjunction with other procedures for neuropathic pain, all patients with symptomatic relief
Witt et al., 1999[32,33]	Case report	Skin replacement in RDEB	1	Human AlloDerm	1-yr follow-up, functional hand without blisters
Wainwright, 1995[1]	Case report	Acute burn, skin replacement	2	Human AlloDerm	Full take of allograft with no immunogenic rejection
Lattari et al., 1997[30]	Case report	Acute burn skin replacement	3	Human AlloDerm	Complete take with excellent cosmesis
Askari et al., 2011[31]	Retrospective, case-control	Burn contracture release	9	Human AlloDerm	Increase joint ROM†
Belcher and Zic, 2001[36]	Prospective, case-control	First CMC joint repair	26	Porcine, Permacol	5 patients with erythema and pain, 3 with implant removal, elective early study termination
Adams et al., 2007[3]	Prospective, consecutive series	Arthroscopic, first CMC joint repair	17	Human GraftJacket	Minimal complications, symptomatic relief with no significant increase in postoperative pinch and grip
Kokkalis et al., 2009[2]	Retrospective, case-control	First CMC joint repair	82 (thumbs)	Human Graftjacket	Postoperative pain, grip and pinch improved, loss of metacarpal height by 31%‡
Zook et al., 2004[48]	Unknown, technique illustration	Pincer-nail deformity	20	Human AlloDerm	Corrects the deformity, cost may be higher, no donor dermis needed

CMC, carpometacarpal; STSG, split-thickness skin graft; RFF, radial forearm flap; FTSG, full-thickness skin graft; RDEB, recessive dystrophic epidermolysis bullosa.
*Comparable group (split-thickness skin graft alone) with only three patients at follow-up.
†At minimum, 10-month follow-up.
‡Statistically significant.

both patients described resolution of their symptoms, and there was no sign of recurrence.

The senior author has similarly treated professional bodybuilders who developed the same clinical problem in the volar forearm. He has had good results using acellular dermal matrix to repair the fascial defect, without reherniation at 2-year follow-up.

Radial Forearm Flap Harvest

In 1981, Yang et al. described anatomical studies and the operative technique of radial forearm flap harvest.[17] The biggest drawback to its use has been the aesthetic outcome of the volar forearm and the potential functional limitations of the hand and wrist.[18–20] In addition, flap harvest on the radial side of the distal forearm is more likely to produce a defect with exposed tendons and neurovascular structures. In 1999, Sinha et al.[21] described covering 52 radial forearm flap donor sites with AlloDerm as a sheet graft without an overlying split-thickness graft. The total time to complete healing, by granulation, was between 10 to12 weeks. Seromas required drainage in five patients, and any scar contractures were minimal. In 2002, Wax et al.[22] retrospectively reviewed 15 patients with radial forearm donor defects, where five patients received allograft at the donor site and 10 patients received split-thickness skin grafts. The acellular dermal matrix group required 12 to 16 weeks to completely heal, whereas the split-thickness skin graft group healed in 2 to 3 weeks. There were no significant differences in cosmesis between the two groups. In 2006, Rowe and colleagues[23] evaluated 12 patients who had received acellular dermal matrix to cover the radial forearm donor site. They found that although 50 percent described reduced range at the wrist, patient satisfaction scores were higher when compared with the group who received a split-thickness skin graft alone. More recently, Medina et al. published a novel use of acellular dermal matrix at the radial forearm harvest site to improve the aesthetics.[24] Sixteen patients requiring subtotal glossectomies underwent a two-stage approach to tumor extirpation and flap preparation. Skin flaps on the nondominant forearm were raised 2 weeks before tumor resection. Acellular dermal matrix was placed with the dermal side facing the wound bed and the skin was closed. Two weeks later, at the time of cancer resection, the forearm skin flaps were re-elevated, and the matrix was raised on its vascular pedicle. Primary closure of the forearm defect was achieved in all 16 patients. The authors commented on an improved aesthetic outcome of the volar forearm by allowing for a straight-line scar. Currently, there is no consensus on the best way to cover radial forearm flap defects, especially when tendons and neurovascular structures are exposed. Our group has found that having acellular dermal matrix as an option for coverage has been a useful adjunct in many of these cases.

Neuropathic Pain

Peterson and Adham[25] evaluated 10 patients with pain and hypersensitivity at the wrist who had undergone a prior wrist operation or who had experienced wrist trauma. All patients underwent excision or relocation of their neuroma stump and/or neurolysis along with acellular dermal matrix isolation of the nerve braches from overlying soft tissue. All patients reported a subjective decrease in their pain level.

Burn Reconstruction

In 1992, Engrav et al. described how the functional loss of the hand makes up a 57 percent loss of function in the individual as a whole.[26] Patients with upper extremity and severe hand burns can require multiple operations to treat significant functional deformities. Traditional options for covering dorsal hand burns include sheet or meshed split-thickness grafts. Deep palmar burns can be covered with full-thickness grafts unless there is an indication for a local or free-flap.[27,28] In 1995, Wainwright published his findings using acellular dermal matrix on two similar burn patients with full-thickness burn injuries.[1] He investigated the early clinical and histological outcomes of acellular dermal matrix grafted simultaneously with overlying meshed split-thickness skin graft. He also evaluated the immunogenic response of the host to the grafted matrix via a lymphoblastic proliferation assay. Wainwright found there to be no sensitization of the host lymphocytes to the engrafted acellular dermis. The "take rate" was 100 percent at day 5 for both of the patients, and at day 16 there was complete healing. The biopsy samples showed keratinocyte migration, neovascularization of the graft and of the matrix, with absence of an inflammatory component in the test site. He concluded that acellular dermal matrix would support fibroblast infiltration and neovascularization, as well as reepithelialization with migrating keratinocytes forming stable skin without subsequent blistering or fragility.

Sheridan and Choucair[29] and Lattari et al.[30] separately looked at engraftment of acellular dermal matrix in pediatric hand burns and adult hand burns, respectively. Sheridan and Choucair grafted six children in 10 separates sites using matrix with a thin overlying autograft alongside an autograft-only site as a control. They had a 90 percent successful engraftment with one loss of 40 percent of a graft due to infection. Vancouver scar scores showed no significant difference between the matrix test site and the control site. They concluded that using matrix could be a viable option of skin coverage in patients with limited donor sites due to massive burns.[29] Lattari et al. reported on two patients on whom acellular dermal matrix with overlying thin (0.008 inch) meshed autograft was used on the dorsum of the hand after full-thickness burns. Functional measurements, task performance, and cosmetic results were reported as being excellent by patient and family members.

The senior author (D. A. K.) began using acellular dermal matrix in 2006 for treating patients with long-standing hand contractures from burn injuries after having had prior multiple release operations. The entire case series was published in an April 2011 *Plastic and Reconstructive Surgery* article describing nine patients with burn contractures of the hand and wrist treated over a 4-year period.[31] The contracture was addressed in a two-stage process. At the first-stage, the contracture was completely released, and the meshed acellular dermal matrix was placed. The allograft was then bolstered with a vacuum-assisted closure device (Kinetic Concepts, Inc., San Antonio, Texas) for 10 to 14 days. At the second stage, the vacuum-assisted closure device was removed, and a thin 0.012-inch sheet autograft was harvested and placed over the matrix for final coverage of the wound. All nine patients showed an increase in passive range of motion of at least 25 to 30 degrees and even up to 90 degrees. Since that initial published series, the senior author has adjusted his practice by using a full-thickness graft over the matrix at the second stage and has seen a reduced recontracture rate (Fig. 1). He has also found that thin, 0.2-mm to 0.5-mm sheets give better results and incorporate within the tissues more readily in the treatment of burn contractures and basal joint arthritis reconstruction.

Contracture of the Palm Due to Hand Infection

Contractures of the palm, whether in burn reconstruction or due to infectious etiology, all end with the same pathology of nonpliable skin and subcutaneous fibrosis. We present a case of a 50-year old patient with delayed débridement after closed-space palm infection (Fig. 2). The outcome was severe fibrosis of the palmar fascia, ulnar digit contractures, and woody nonpliable skin. This patient underwent a series of operations requiring skin excision, tenolysis, release of fibrotic tissues with subsequent acellular dermal matrix engraftment, and full-thickness skin grafting.

Pediatric Hand

The role of acellular dermal matrix in reconstruction of the pediatric hand has so far been limited to one case report of pseudosyndactyly due to recessive dystrophic epidermolysis bullosa.[32,33] Recessive dystrophic epidermolysis bullosa is an inherited disorder in which minor trauma of the hand can lead to blister formation, epidermal sloughing, and subsequent scarring. Witt and colleagues[33] published a case report in 1999 of an 11-year-old with recessive dystrophic epidermolysis bullosa that led to a thumb adduction contracture. They released the contracture in the first web space, grafted with AlloDerm, and placed a thin split-thickness skin graft onto the bed. At 1-year follow-up, they compared allograft skin with native skin from the dorsal hand. Histologic evaluation of the allograft and of the dorsal skin showed a layer of inflammatory cells, which is indicative of the disease process. Interestingly, the allograft skin in the first web space was free of blistering at 1 year.

The senior author has had good success using matrix for forearm soft-tissue reconstruction in a neonate born with severe ecchymosis and skin blistering (Fig. 3). The patient developed brachial artery occlusion and required compartment release followed by soft-tissue débridement. Acellular dermal matrix was chosen over direct autografting because of the exposed underlying vital structures that would not support incorporation of a split- or a full-thickness graft. Once the matrix bed was mature, a split-thickness skin graft was placed. At 13-month follow-up, the patient was grabbing objects with the right hand independently, had increased flexion and extension at the wrist, and also had great pincer function.

Dupuytren's Contracture

A 54-year-old woman with Raynaud's and severe recurrent Dupuytren's contracture of the right palm extending to the small finger underwent a prior failed needle aponeurectomy and palmar fasciectomy (Fig. 4). She presented with functional loss and flexion contractures at the metacarpalphalangeal, proximal interphalangeal, and distal interphalangeal joints. The thick cord along with skin was excised, which left her with a defect measuring 7×2 cm. A 0.79-mm-thick AlloDerm sheet was applied, and at 2-year follow-up she had complete range of motion at the metacarpalphalangeal joint, although she required release and fusion of her proximal interphalangeal joint.

Degloving Phalanx Injury

A 27-year-old woman was treated for a degloving injury on the right ring finger, volar midphalangeal

Fig. 1. Mature burn contracture release of the palm and web spaces. (*Above*, *left*) Preoperative palmar and web-space contracture. (*Above*, *right*) Complete contracture release with exposure of tendons and neurovascular structures. (*Center*, *left*) Acellular meshed dermal allograft, 10-day bolster. (*Center*, *right*) Placement of full-thickness graft over incorporated acellular dermal matrix. (*Below*) Ten months postoperatively, maintenance of increased palmar and web spaces.

surface (Fig. 5). The defect was approximately 1 cm^2 with exposed tendon and neurovascular structures. The wound required minimal débridement and was covered immediately with acellular dermis. After 1 week with acellular dermal matrix incorporation, a full-thickness hypothenar skin graft was placed. At 15-month follow-up, the patient had full range of motion of the finger and a great aesthetic result. The graft had good color match, and there was a minimally palpable difference compared with the native skin.

Fig. 2. Palmar contracture due to hand infection. (*Above*, *left*) Preoperative palmar contracture with prior skin and fascial débridement. (*Above*, *right*) Complete release of palm, note tendon exposure. (*Center*, *left*) Acellular meshed dermal allograft to palm. (*Center*, *right*) Acellular dermal matrix engraftment after 10-day bolster. (*Below*, *left*) Placement of full-thickness skin graft over incorporated matrix. (*Below*, *right*) Postoperative result at 1 year.

Ligament and Joint Reconstruction

Upper extremity surgeons have long been challenged with finding the best tissue replacement for weakened, ruptured, or diseased tendons and ligaments. Eaton and Littler[34] first described beak ligament laxity in carpometacarpal joint arthritis and the need to reconstruct it using the flexi carpi radialis tendon. Since then, several authors have reported modifying Eaton's technique using flexor carpi radialis, palmaris longus, or abductor pollicis longus tendon. In 2007, Kokkalis et al. described an alternative to using native

Fig. 3. Ischemic forearm and hand in a neonate; initial coverage with acellular dermal matrix. (*Above*, *left*) Volar forearm with exposed tendons after débridement. (*Above*, *right*) Dorsal forearm after matrix incorporation. (*Center*, *left*) Volar forearm with overlying split-thickness skin graft at 13 months. (*Center*, *right*) Dorsal forearm after matrix incorporation. (*Below*) Final appearance at 2 years with full-thickness skin graft to dorsal hand and split-thickness skin graft to forearm.

tendon by reporting the use of acellular dermal matrix to suspend the first metacarpal, thereby eliminating donor-site morbidity.[2] Their technique required a complete trapeziectomy with ligament reconstruction and interposition arthroplasty using the human acellular matrix GraftJacket (Wright Medical Technology, Inc., Arlington, Tenn.). Kokkalis et al. described the procedure done on 82 thumbs of patients with stage II to IV carpometalcarpal arthritis, who were followed on average up to 30 months. No autologous tendon graft was harvested in any of their cases. Postoperatively they were able to demonstrate significantly reduced pain scores from 6.2 to 0.7 and improvements in grip and key pinch strength by 16 percent and 19 percent, respectively. Assess-

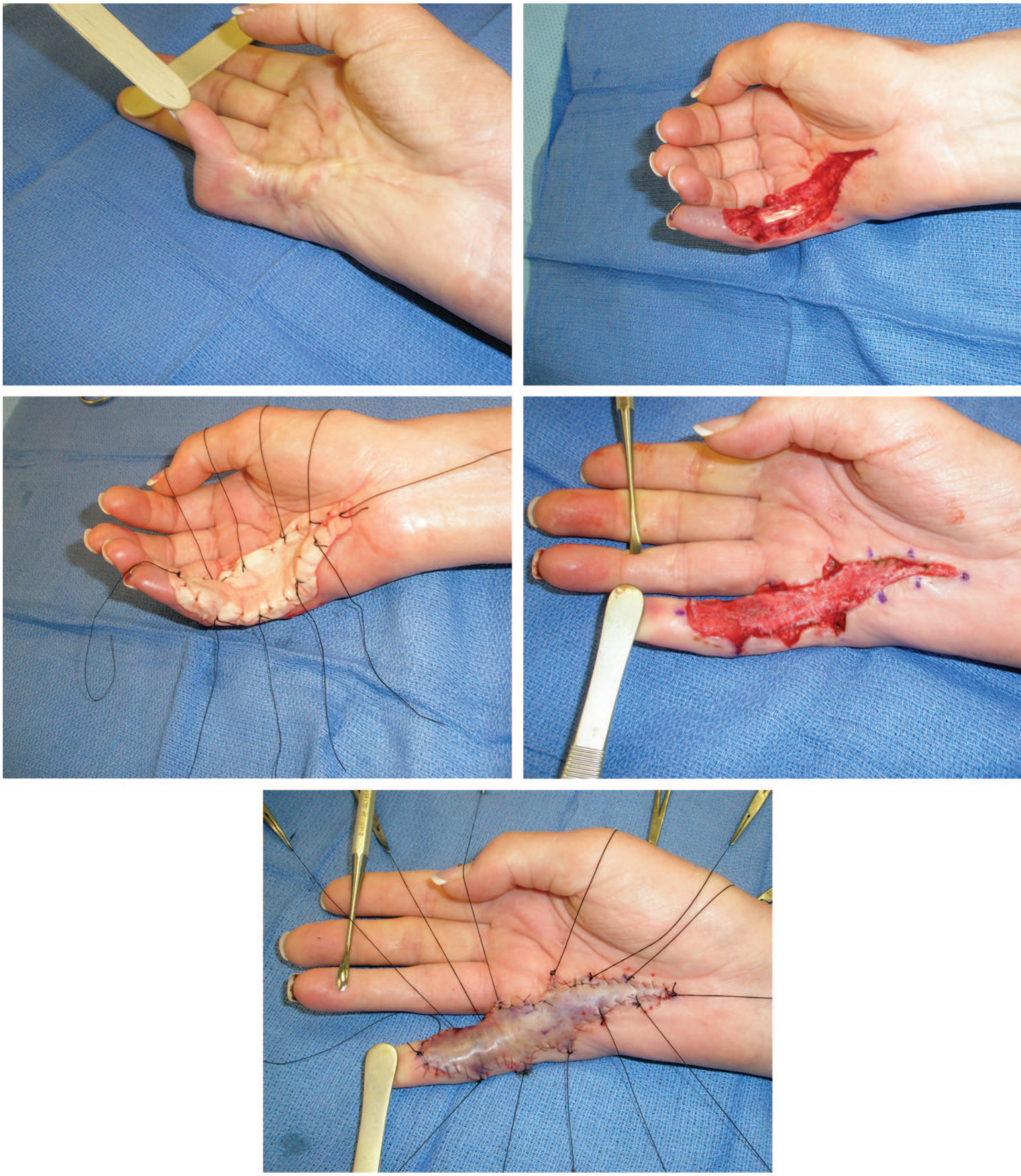

Fig. 4. Dupuytren's contracture release with acellular dermal matrix grafting. (*Above*, *left*) Recurrent contracture. (*Above*, *right*) Contracture release; note exposed tendon. (*Center*, *left*) Matrix placement with bolster for 10 days. (*Center*, *right*) After matrix incorporation. (*Below*) Full-thickness skin graft.

ment of the arthroplasty space on postoperative posterioanterior and oblique nonstress radiographs demonstrated an average of 33 percent metacarpal subsidence at follow-up, with no signs of degenerative changes or metacarpal-scaphoid impingement. There were two revisions.

In 2007, Adams et al. reported their results of arthroscopic partial trapeziectomy with interposition acellular dermal matrix.[35] They evaluated 17 patients with Eaton grade II to III, who were all recalcitrant to nonsurgical management. All of the patients described symptomatic relief; however, there was no statistically significant improvement in pinch or grip strength. They reported no surgical complications except in one patient with an ulnar neuropathy pre-

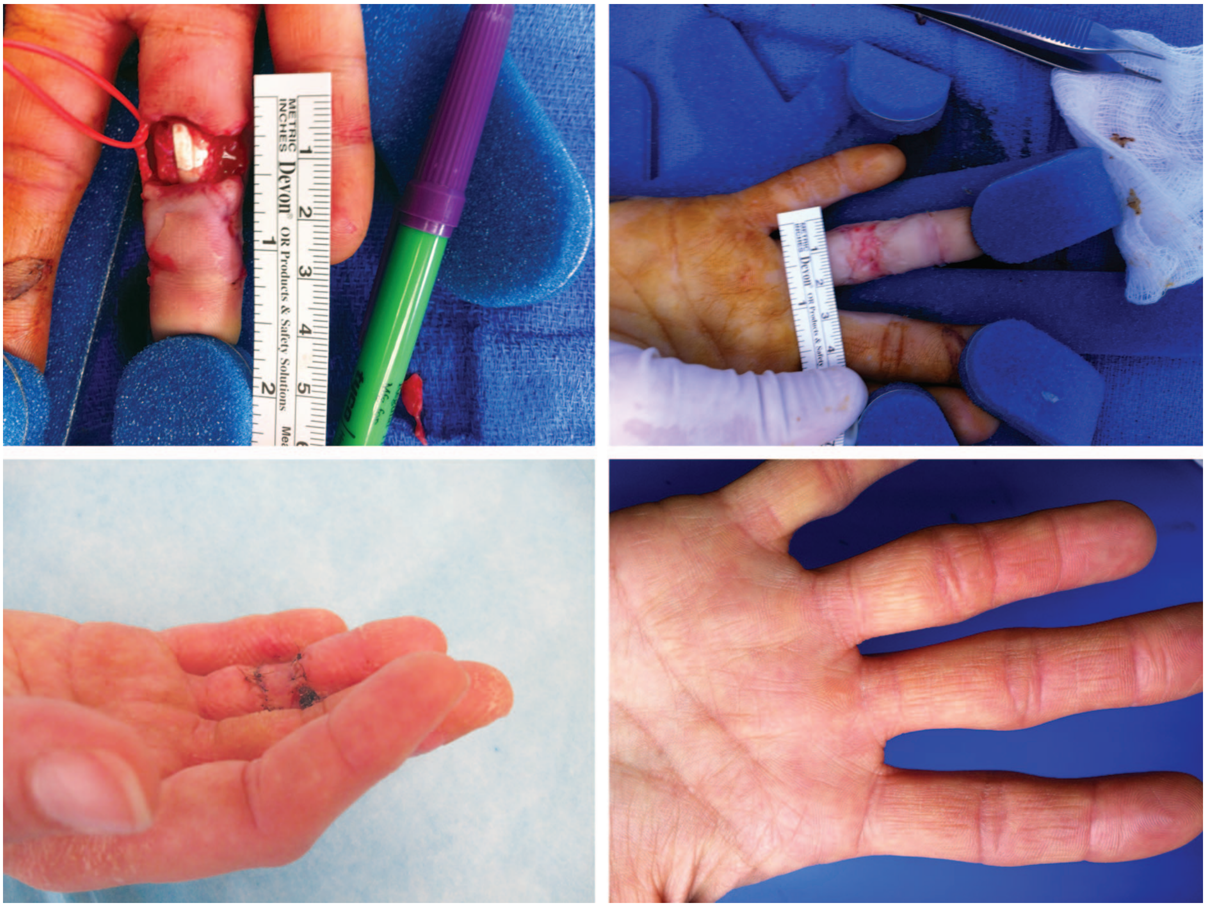

Fig. 5. Degloving ring finger with acellular dermal matrix grafting. (*Above*, *left*) Exposure of tendon and neurovascular bundle. (*Above, right*) Placement of matrix. (*Below*, *left*) Skin graft over matrix with complete healing. (*Below*, *right*) Final result at 15-month follow-up; note the nearly imperceptible difference in volar skin.

sumably caused by the placement of an axillary block for local anesthesia.

Our preferred technique for patients diagnosed with Eaton stage III and IV basal joint arthritis has been to perform a complete trapeziectomy with acellular dermal matrix interposition arthroplasty. Our early 6-month results have been promising, showing an improved grip and pinch strength (unpublished results). We have not experienced any matrix-related infections or foreign body reactions and have found it useful for symptomatic basal joint arthritis. (Fig. 6) (**See Video, Supplemental Digital Content 1,** which demonstrates carpometacarpal joint arthritis trapeziectomy with acellular dermal matrix interposition, ***http://links.lww.com/PRS/A566***.)

One series of 26 patients reported complications using porcine acellular dermal matrix for carpometacarpal arthritis. Belcher and colleagues[36] found a significant increase in postprocedure erythema and pain after using Permacol (Tissue Science Laboratories, Aldershot, United Kingdom) as an implant spacer. They prematurely terminated the study after biopsies showed matrix implants containing numerous multinucleated giant cells. In the description of the surgical technique, a central core resection of the trapezium was performed, and a folded sheet of matrix was placed to fill the space. Not having a well-vascularized surrounding bed to enhance matrix incorporation may have led to the increased infection rate seen in this series. In addition, the senior author has found that thinner matrix is more favorable to vascular ingrowth compared with thick matrices.

DISCUSSION

Acellular dermal matrix use in hand surgery has evolved over the past 15 years since its introduction as skin replacement in the treatment of burn injuries. Hand surgeons today have expanded its initial adjunctive role into a primary

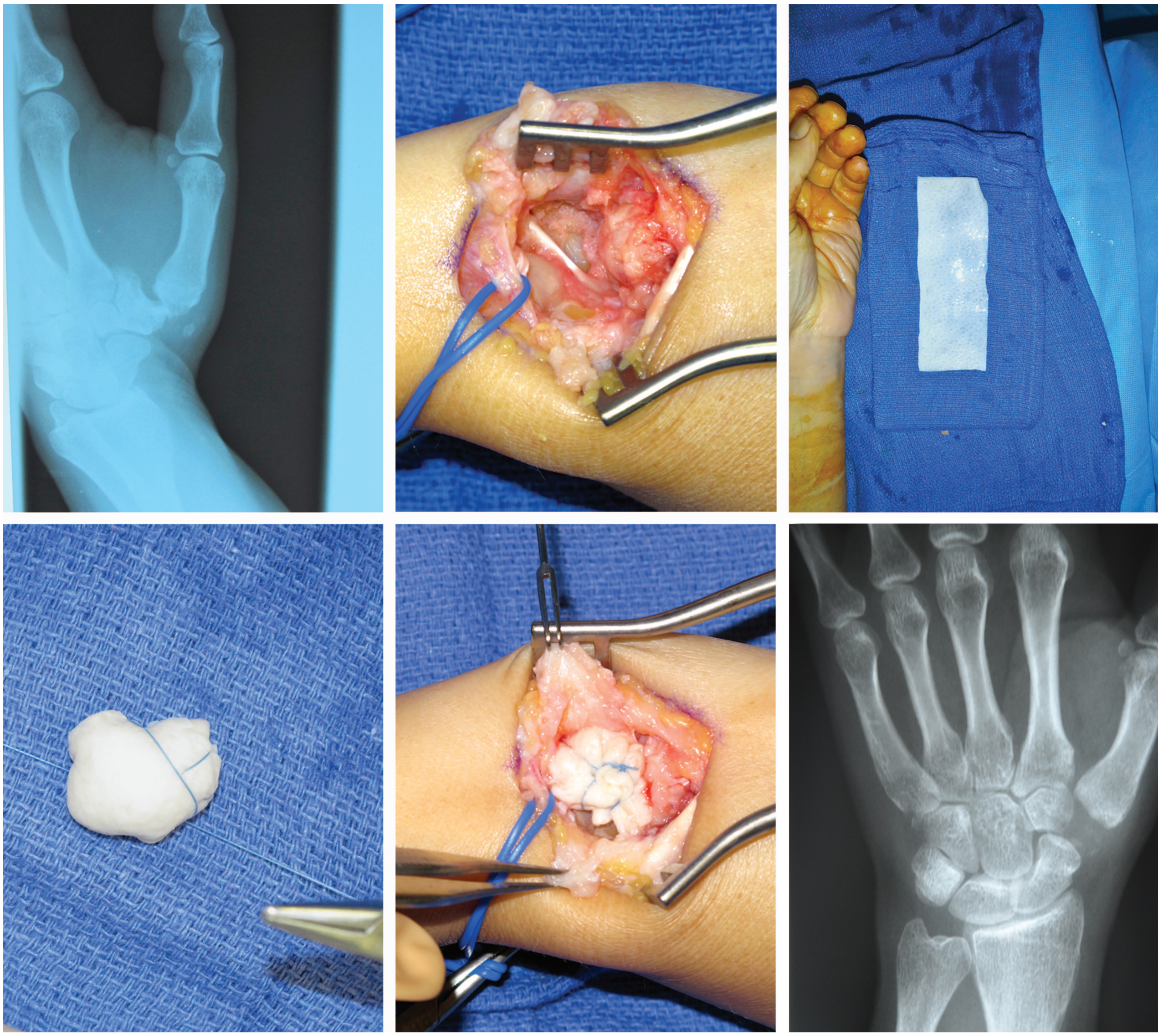

Fig. 6. First carpometacarpal joint arthritis: trapeziectomy with acellular dermal matrix interposition arthroplasty. (*Above*, *left*) Preoperative radiograph showing stage IV arthritis. (*Above*, *center*) Complete trapeziectomy. (*Above*, *right*) acellular dermal matrix allograft (3 × 7 cm). (*Below*, *left* and *below*, *center*) acellular dermal matrix interposition arthroplasty. (*Below*, *right*) Postoperative radiograph at 1 month.

treatment option for many diseases affecting the hand, wrist, and forearm. Sinha and colleagues were the first to report using acellular dermal matrix for skin replacement after radial forearm flap harvest.[21] Although the pool of articles addressing this clinical scenario is limited, many report aesthetic and functional results of acellular dermal matrix that are comparable to those of skin grafting. Wainwright found that the most appealing qualities of matrix over cultured keratinocytes and unprocessed cadaveric skin were its stability and its nonimmunogenic character.[1,37–40]

Our group has found acellular dermal matrix to be quite helpful in treating mature burn contractures of the palm. After full contracture release, neurovascular structures and tendons can be readily visible. Placing acellular dermis over nerves and vessels allows for a thicker interface between these structures and the grafted skin. Surprisingly, we did not find ample articles where porcine matrices have been used in the hand or forearm. One reason for this may be that decellularized xenografts can elicit a low-grade chronic inflammatory response. Biopsies of the implanted matrices have demonstrated the presence of foreign body giant cells.[36] More recent studies suggest that chemical cross-linking in some xenografts makes them less porous, thus preventing the cas-

Video 1. Supplemental Digital Content 1 demonstrates carpometacarpal joint arthritis trapeziectomy with acellular dermal matrix interposition, ***http://links.lww.com/PRS/A566***.

cade of events necessary for effective wound healing.[41–43] Ngo et al. found that porcine matrix had less collagen content than human matrix at the same time point after engraftment in an abdominal hernia animal model.[44] Despite this finding, the literature is abundant with their use in abdominal hernia reconstruction.[45,46] The appeal of acellular dermal matrices in hernia care is the elastic modulus of the mesh, which has been the rationale for the use in ligament reconstruction. Our group as well as Kokkalis and colleagues[2] have found that using human dermal matrix in basal joint arthritis has reduced the patient morbidity of flexor carpi radialis harvest with similar functional results. The reported complication rate has been low, and the patient satisfaction rate, in our experience, has been superior to using native tissues. No comparative studies evaluating dermal matrix versus native ligament reconstruction and tendon interposition for carpometacarpal arthritis were found in our search. One recent retrospective study by Sandvall and colleagues[47] comparing ligament reconstruction and tendon interposition to hematoma distraction found comparable objective and subjective results for all evaluated measures. In the senior author's experience, harvest of the flexor carpi radialis tendon after trapeziectomy can lead to prolonged pain and patient dissatisfaction with the donor site. Implantation of acellular dermal matrix has alleviated donor-site morbidity and addresses the concern for thumb metacarpal proximal migration.

The cost for this approach varies by manufacturer and hospital contracts; however, we have found the typical fee for a 20 cm^2 construct ranges between $600 and $1100 per sheet (verbal communication with acellular dermal matrix provider and in-office coder). The actual cost to the patient remains difficult to quantify when comparing carpometacarpal arthritis treatment with matrix to an alternative approach where native tissues are used. We have recently submitted a proposal to our hospital's institutional review board to evaluate objective and subjective postoperative outcomes and the long-term durability of this product.

CONCLUSIONS

The purpose of this study was to review the current uses of acellular dermal matrix in forearm, wrist, and hand reconstruction. The availability of multiple matrix products gives the hand surgeon another option in solving difficult reconstructive clinical problems where native tissues are unavailable or unacceptable to the patient. The senior author has found acellular dermal matrix to be a flexible and useful tool for burn contracture release and in diseases affecting the wrist. In addition, what he has found most remarkable is the ability to graft matrix over nerves, arteries, and tendons, where skin grafts would either "not take" or cause significant contracture. However, because of the need for matrix incorporation, its use would not be recommended when tissue vascularity is compromised or if there is concurrent infection. Both of these scenarios would inhibit matrix engraftment, and an operative technique using autologous tissue would be more appropriate.

Cost is certainly a concern when establishing alternative surgical treatment plans for common medical illnesses. Currently many insurers will reimburse the cost of the dermal matrix, based on Medicare standard rates, of up to 80 percent coverage (verbal communication with acellular dermal matrix provider and in-office coder). As upper extremity surgeons look to find ways to decrease donor-site morbidity and improve clinical outcomes, acellular dermal matrix remains a viable option. Nevertheless, as hand surgeons develop more innovative ways to solve upper extremity problems, and the indications for acellular dermis continue to evolve, more comparative prospective studies are needed to evaluate their long-term benefit.

David A. Kulber, M.D.
Department of Surgery
Cedars-Sinai Hospital
8635 West 3rd Street, #990-W
Los Angeles, Calif. 90048
David.kulber@cshs.org

REFERENCES

1. Wainwright DJ. Use of an acellular allograft dermal matrix (AlloDerm) in the management of full-thickness burns. *Burns* 1995;21:243–248.
2. Kokkalis ZT, Zanaros G, Weiser RW, Sotereanos DG. Trapezium resection with suspension and interposition arthroplasty using acellular dermal allograft for thumb carpometacarpal arthritis. *J Hand Surg Am.* 2009;34:1029–1036.
3. Adams JE, Merten SM, Steinmann SP. Arthroscopic interposition arthroplasty of the first carpometacarpal joint. *J Hand Surg Eur Vol.* 2007;32:268–274.
4. Adams JE, Zobitz ME, Reach JS Jr, An KN, Steinmann SP. Rotator cuff repair using an acellular dermal matrix graft: An in vivo study in a canine model. *Arthroscopy* 2006;22:700–709.
5. Musculoskeletal Transplant Foundation and Ethicon. FlexHD [brochure]. 2010.
6. Badylak SF, Gilbert TW. Immune response to biologic scaffold materials. *Semin Immunol.* 2008;20:109–116.
7. Badylak S, Freytes D, Gilbert T. Extracellular matrix as a biological scaffold material: Structure and function. *Acta Biomater.* 2009;5:1–13.
8. Alwitry A, Burns SJ, Abercrombie LC. Orbital implant exposure treatment with porcine dermal collagen patching. *Orbit* 2006;25:253–256.
9. Covidien Surgical. Covidien, Biologics, Permacol surgical implant. Available at: http://www.covidien.com/hernia/us/biologics/permacol. Accessed September 9, 2012.
10. Orenstein SB, Qiao Y, Klueh U, Kreutzer DL, Novitsky YW. Activation of human mononuclear cells by porcine biologic meshes in vitro. *Hernia* 2010;14:401–407.
11. Roberts JO, Regan PJ, Dickinson JC, Bailey BN. Forearm muscle herniae and their treatment. *J Hand Surg Br.* 1989;14:319–321.
12. Olch CL, Watson HK. Symptomatic forearm fascial hernia. *J Hand Surg Am.* 1996;21:693–695.
13. Golshani SD, Lee C, Sydorak R. Symptomatic forearm muscle hernia: Repair by autologous fascia lata inlay. *Ann Plast Surg.* 1999;43:204–206.
14. Iwasaki N, Masuko T, Minami A. Forearm fascial hernia after harvesting the palmaris longus tendon. *J Hand Surg Eur Vol.* 2009;34:408–409.
15. Kozlow JH, Beil RJ, Chung KC. Repair of symptomatic forearm hernias using acellular dermal matrix: Two case reports. *J Hand Surg Am.* 2010;35:2053–2056.
16. Gilardino MS, Loftus JB, Brutus JP. Successful repair of symptomatic extremity muscle herniation with synthetic mesh. *Plast Reconstr Surg.* 2009;123:44e–45e.
17. Yang GF, Chen PJ, Gao YZ, et al. Forearm free skin flap transplantation: A report of 56 cases. *Br J Plast Surg.* 1997;50:162–165.
18. Lutz BS, Wei FC, Chang SC, Yang KH, Chen IH. Donor-site morbidity after suprafascial elevation of the radial forearm flap: A prospective study in 95 consecutive cases. *Plast Reconstr Surg.* 1999;103:132–137.
19. Ho T, Couch M, Carson K, Schimberg A, Manley K, Byrne P. Radial forearm free flap donor site outcomes comparison by closure methods. *Otolaryngol Head Neck Surg.* 2006;134:309–315.
20. Kruse ALD, Bredell MG, Lübbers HT, Jacobsen C, Grätz KW, Obwegeser JA. Clinical reliability of radial forearm free-flap procedure in reconstructive head and neck surgery. *J Craniofac Surg.* 2011;22:822–825.
21. Sinha U, Shih C, Chang K, Rice D. Use of AlloDerm for coverage of radial forearm free flap donor site. *Laryngoscope* 2002;112:231–234.
22. Wax MK, Winslow CP, Andersen PE. Use of allogenic dermis for radial forearm free flap donor site coverage. *J Otolaryngol.* 2002;31:341–345.
23. Rowe NM, Morris L, Delacure MD. Acellular dermal composite allografts for reconstruction of the radial forearm donor site. *Ann Plast Surg.* 2006;57:305–311.
24. Medina CR, Patel SA, Ridge JA, Topham NS. Improvement of the radial forearm flap donor defect by prelamination with human acellular dermal matrix. *Plast Reconstr Surg.* 2011;127:1993–1996.
25. Peterson SL, Adham MN. Acellular dermal matrix as an adjunct in treatment of neuropathic pain at the wrist. *J Trauma* 2006;61:392–395.
26. Engrav LH, Dutcher KA, Nakamura DY. Rating burn impairment. *Clin Plast Surg.* 1992;19:569–598.
27. Hunt JL, Sato R, Baxter CR. Early tangential excision and immediate mesh autografting of deep dermal hand burns. *Ann Surg.* 1979;189:147–151.
28. Hunt JL, Sato RM. Early excision of full-thickness hand and digit burns: Factors affecting morbidity. *J Trauma* 1982;22:414–419.
29. Sheridan RL, Choucair RJ. Acellular allogenic dermis does not hinder initial engraftment in burn wound resurfacing and reconstruction. *J Burn Care Rehabil.* 1997;18:496–499.
30. Lattari V, Jones LM, Varcelotti JR, Latenser BA, Sherman HF, Barrette RR. The use of a permanent dermal allograft in full-thickness burns of the hand and foot: A report of three cases. *J Burn Care Rehabil.* 1997;18:147–155.
31. Askari M, Cohen MJ, Grossman PH, Kulber DA. The use of acellular dermal matrix in release of burn contracture scars in the hand. *Plast Reconstr Surg.* 2011;127:1593–1599.
32. Witt PD, Cohen DT, Mallory SB. Use of a permanent acellular dermal allograft in recessive dystrophic epidermolysis bullosa involving the hands. *Arch Dermatol.* 1999;135:503–506.
33. Witt PD, Cheng CJ, Mallory SB, Lind AC. Surgical treatment of pseudosyndactyly of the hand in epidermolysis bullosa: Histological analysis of an acellular allograft dermal matrix. *Ann Plast Surg.* 1999;43:379–385.
34. Eaton RG, Littler JW. Ligament reconstruction for the painful thumb carpometacarpal joint. *J Bone Joint Surg Am.* 1973;55:1655–1666.
35. Adams J. Arthroscopic interposition arthroplasty of the first carpometacarpal joint. *J Hand Surg Eur Vol.* 2007;32:268–274.
36. Belcher HJ, Zic R. Adverse effect of porcine collagen interposition after trapeziectomy: A comparative study. *J Hand Surg Br.* 2001;26:159–164.
37. Wainwright D, Madden M, Luterman A, et al Clinical evaluation of an acellular allograft dermal matrix in full-thickness burns. *J Burn Care Rehabil.* 1996;17:124–136.
38. Ingham E, Matthews JB, Kearney JN, Gowland G. The effects of variation of cryopreservation protocols on the immunogenicity of allogeneic skin grafts. *Cryobiology* 1993;30:443–458.
39. Compton CC, Gill JM, Bradford DA, Regauer S, Gallico GG, O'Connor NE. Skin regenerated from cultured epithelial autografts on full-thickness burn wounds from 6 days to 5 years after grafting: A light, electron microscopic and immunohistochemical study. *Lab Invest.* 1989;60:600–612.
40. Bannasch H, Stark G, Knam F, Horch R, Föhn M. Decellularized dermis in combination with cultivated keratinocytes in a short- and long-term animal experimental investigation. *J Eur Acad Dermatol Venereol.* 2008; 22:41–49.
41. Valentin JE, Badylak JS, McCabe GP, Badylak SF. Extracellular matrix bioscaffolds for orthopaedic applications: A comparative histologic study. *J Bone Joint Surg Am.* 2006;88:2673–2686.

42. Armour AD, Fish JS, Woodhouse KA, Semple JL. A comparison of human and porcine acellularized dermis: Interactions with human fibroblasts in vitro. *Plast Reconstr Surg.* 2006;117:845–856.
43. Bellows CF, Alder A, Helton WS. Abdominal wall reconstruction using biological tissue grafts: Present status and future opportunities. *Expert Rev Med Devices* 2006;3:657–675.
44. Ngo MD, Aberman HM, Hawes ML, Choi B, Gertzman AA. Evaluation of human acellular dermis versus porcine acellular dermis in an in vivo model for incisional hernia repair. *Cell Tissue Bank* 2011;12:135–145.
45. Butler CE. The role of bioprosthetics in abdominal wall reconstruction. *Clin Plast Surg.* 2006;33:199–211, v–vi.
46. Burns NK, Jaffari MV, Rios CN, Mathur AB, Butler CE. Non–cross-linked porcine acellular dermal matrices for abdominal wall reconstruction. *Plast Reconstr Surg.* 2010; 125:167–176.
47. Sandvall BK, Cameron TE, Netscher DT, Epstein MJ, Staines KG, Petersen NJ. Basal joint osteoarthritis of the thumb: Ligament reconstruction and tendon interposition versus hematoma distraction arthroplasty. *J Hand Surg Am.* 2010; 35:1968–1975.
48. Zook E, Chalekson C, Brown R, Nuemeister M. Correction of pincer-nail deformities with autograft or homograft dermis: Modified surgical technique. *J Hand Surg Am.* 2005;30: 400–403.