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ORIGINAL STUDY

Interposition arthroplasty using an acellular dermal matrix scaffold

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We have used arthroscopic debridement and interposition arthroplasty with an acellular dermal matrix allograft in treatment of first carpometacarpal joint arthritis successfully in a limited number of patients. The purpose of this investigation was to study the use of an acellular dermal matrix graft in a rabbit model of interposition arthroplasty.

Eleven rabbits underwent excision of the lunate bone and interposition of extensor tendon (control) or dermal matrix graft (experimental). Radiographic analysis and either histological or vascular studies were performed.

No adverse immunological response was noted. Increasing fibroblast like cells were noted over time in both groups with greater infiltration in control specimens. Vascular infusion showed infiltration in both arthroplasty groups.

Both groups maintained the resection space and promoted cellular ingrowth without adverse immune response. Vascular infiltration occurred in both arthroplasty groups. These results support use of this graft in interposition arthroplasty.

Keywords : interposition arthroplasty ; acellular dermal matrix graft ; rabbit model.

INTRODUCTION

Trapeziometacarpal joint arthritis is a common complaint, particularly among women (*4, 10*). It is estimated that one-third of all postmenopausal women are afflicted with this condition (*4*). Treatment frequently involves conservative measures, including splinting, rest, or injections (*3*). Surgical management may be indicated in cases of persistent pain or functional deficit, recalcitrant to nonoperative means (*3, 10*). Multiple techniques have been described, and each has unique risks and benefits. Trapeziectomy, originally described by Gervis in 1949, has long been used to treat trapeziometacarpal arthritis with reported high success rates (*4, 10*). However, when the trapezium is surgically absent, proximal migration of the thumb metacarpal may occur, with subsequent impingement of the thumb metacarpal upon the scaphoid or trapezoid (*4, 10*). Along with this painful hypermobility, problems with this procedure may include poor thumb mobility and the need for a protracted rehabilitation course (*10*). Others developed an additional step after trapeziectomy to guard against these effects, namely, interposition of soft tissue or an implant to occupy the post trapeziectomy space (*4, 10*). Since the early 1950's, interposition arthroplasty has been an option in the management of carpal arthritis (*9, 14*). Historically, an autologous

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tendon, such as the flexor carpi radialis tendon or the fascia lata has been utilised to occupy the space left following resection of the arthritic carpal bone (*4*). However, donor site morbidity, the need for a second operative site, and requirement for prolonged operative time has prompted investigations into alternative materials. Additionally, thumb shortening often ensues despite the interposition, or perhaps due to senescence of the graft (*4*). Use of prosthetic implants has been plagued by particulate debris from wear, osteolysis, and loosening (*4*). Schmidt *et al* (*14*) described successful utilisation of an allogenic tendon as an interposition graft in a monkey model. Radiographic studies demonstrated preservation of the thumb length and of the post-trapeziectomy defect height. Likewise, Belcher *et al* (*4*) examined use of a porcine collagen xenograft as an interposition material in 13 patients with osteoarthritis of the first carpometacarpal joint. An additional 13 patients underwent trapeziectomy alone, as a control group (*4*). The study was terminated due to adverse reactions to the porcine xenograft, including persistent pain and erythema (*4*). Two of the implanted patients had recurrent subluxation and adduction deformity, and three of the implants were removed due to persistent pain (*4*). Furthermore, the addition of the porcine collagen graft failed to prevent thumb shortening or abutment of the metacarpal upon the scaphoid (*4*).

GRAFTJACKET™ acellular dermal matrix (Wright Medical Technology, Arlington, TN, USA), is a commercially available material with a wide variety of potential applications. Donated cadaveric dermal tissue is processed to remove cellular components while the extracellular matrix is preserved (*5*). Because the material is rendered acellular during processing, it lacks many of the disadvantages attendant to the use of standard allograft tissue. Previous *in vivo* studies have demonstrated rapid infiltration of native cellular agents, including fibroblasts and vascular tissue, with minimal host inflammatory response (*5*). Prior applications have included use as skin grafts, in soft tissue reconstruction, dental implantation and as a periosteal replacement to aid healing in segmental bone defects (*5, 12*). This material appears to create a favourable biochemical and physical environment for infiltration and repopulation of cells (*5*). Because of these advantageous characteristics, use of this material for interposition arthroplasty following partial trapeziectomy was proposed, and has been associated with a high degree of patient satisfaction in limited clinical usage.

Published studies have investigated the histological, radiological, and vascular characteristics following allogenic or autologous tendon interposition. Additionally, studies at our institution and others have investigated histological and mechanical properties of acellular dermal matrix material following its use in tendon repair (*1, 4*). However, to date little information is available regarding the use of this material for interposition arthroplasty of the carpal bones. Our project seeks to investigate properties of an acellular dermal matrix graft for interposition arthroplasty of the carpal bones in a rabbit model.

The rabbit model

Multiple series have investigated utilisation of the rabbit carpal joint as a model for the human wrist joint in flexor tendon surgery, as a model for carpal tunnel syndrome, and as a model for interposition arthroplasty. The rabbit wrist is similar to the human wrist joint ; however, there are several important differences. There are nine carpal bones arranged in two rows, similar to the eight present in humans : the scaphoid, lunate, triquetrum, pisiform, trapezium, trapezoid, hamate, and capitate (fig 1) (*13*). Unlike the human counterpart, the rabbit wrist has an additional bone, the central carpal bone, in the distal row (*13*). The most notable difference, of course, is the weight-bearing function of the carpus in the rabbit, a role not normally encountered by the human wrist joint.

We utilised debridement of the lunate bone and interposition of human acellular dermal matrix graft into the subsequent defect as a model for interposition arthroplasty for basal joint arthritis of the thumb. Vascular, radiographic, and histological studies were performed. Additionally, subjective information regarding the animal's use of the affected extremity, including weight bearing status and gait was obtained.

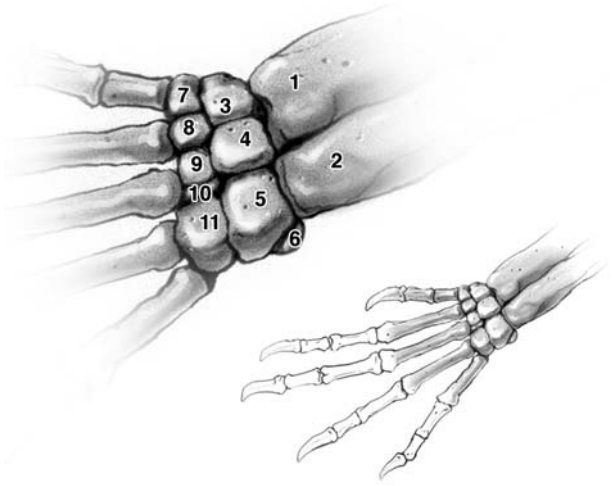

Fig. 1. — Artist's rendition of rabbit wrist joint. Key : 1 = radius ; 2 = ulna ; 3 = scaphoid ; 4 = lunate ; 5 = triquetrum ; 6 = pisiform ; 7 = trapezium ; 8 = trapezoid ; 9 = capitate ; 10 = central carpal bone ; 11 = hamate.

MATERIALS AND METHODS

Approval for this *in vivo* animal study was obtained from our Institutional Animal Care and Use Committee (IACUC) and all animal care guidelines of the National Institute of Health and the Department of Veterinary Medicine were followed. In order to investigate the use of human acellular dermal matrix graft as an interposition graft in a rabbit model of interposition arthroplasty, we utilised 11 New Zealand White rabbits (> 2.75 kg). Animals were obtained from a licensed vendor and housed and managed according to IACUC and Department of Veterinary Medicine standards.

Animals with pathological forepaw conditions were excluded. Each animal (n = 11) underwent excision and interposition arthroplasty of the lunate bone bilaterally.

Surgical Procedure

A standard dorsal extensile approach to the antebrachial carpal joint was used. The extensor tendons were exposed and retracted medially and laterally, and the extensor digitorum and extensor carpi radialis tendons were identified and removed. A dorsal capsulotomy was performed to gain access to the carpal bones. The lunate bone was exposed and then sharply excised. The cartilaginous surfaces of the adjacent bones were debrided to subchondral bone utilising a burr (Stryker, Kalamazoo, Michigan, USA).

For the control specimens, the previously harvested extensor digitorum and extensor carpi radialis tendons were prepared by rolling them into a "tendon ball" and securing with 5-0 Monocryl (Ethicon, Somerville, New Jersey, USA) suture. This was sized to fit the defect created by lunate excision.

For the experimental acellular dermal matrix specimens, a human acellular dermal matrix graft (GRAFTJACKET™ ; Wright Medical Technology, Inc, Arlington, Tennessee, USA) was prepared according to the manufacturer's specifications. Briefly, the implant was removed from its packaging and placed in a warm saline solution for rehydration. The graft was cut to size with a new #10-blade knife and was then folded upon itself and secured with 5-0 Monocryl suture. The interposition "ball" was sized to be equivalent in size to the tendon interposition graft and was then placed into the defect created by lunate excision.

The wrist capsule was then closed with 5-0 Vicryl (Ethicon, Somerville, New Jersey, USA) sutures, and the soft tissues closed in layers, with the skin reapproximated with 5-0 Monocryl in a running subcuticular manner. Rabbits were placed in a recovery cage and monitored according to Department of Veterinary Medicine standards postoperatively. An Elizabethan collar was placed on each animal to prevent self-mutilation of the wounds. Following the initial recovery period of 12 to 24 hours, animals were returned to normal kennels and were allowed activity and food as tolerated.

Postoperative care

Postoperatively, the animals were monitored for wound healing and pain. Antibiotics (cephalexin) and analgesics (buprenorphine) were administered during the perioperative period according to the discretion of the Department of Veterinary Medicine.

Animals were sacrificed at 4 and 8 weeks postoperatively. Radiographs were obtained. Specimens were randomised to vascular or histological processing.

Vascular studies were performed according to methods described by Arnoczky *et al* (2) and Schmidt *et al* (*14*). Briefly, the animal was sacrificed and immediately thereafter, each brachial artery was cannulated and injected with India ink dye. Infusion of dye was continued until the toe pads turned blue-black due to dye perfusion.

Following sacrifice (histological specimens) or administration of dye infusion (vascular specimens), forepaws were harvested from the ulnohumeral joint distally. Specimens were processed by removing all the

skin and subcutaneous fat and then placing and securing each specimen in full extension to a wooden support. Specimens were then preserved in 10% buffered formalin solution. Following fixation, the histological specimens were processed by embedding the wrist in paraffin and 5 mm longitudinal sections were cut and stained with haematoxylin and eosin. Sections were then examined under light microscopy.

After fixation in formalin, the specimens randomised to vascular analysis were then cut coronally approximately midway through the anteroposterior dimension of the wrist and examined grossly.

Statistical justification

Because this was a descriptive study, statistical analysis was not performed. However, multiple authors have found statistically significant differences between experimental groups involving cartilaginous or osseocartilaginous defects with sample sizes similar to ours.

Brittberg *et al* (*6*) studied cartilaginous defects in 14 rabbits (28 knees). The area filled by repair tissue was evaluated by computer-aided microscopy, and statistically significant results were observed. Likewise, in a series of experiments, Carranza-Bencano *et al* (*7, 8*) noted statistically significant results in studies involving rabbit chondral or osseocartilaginous defects (n = 36 : 18 experimental + 18 control).

Descriptive studies by others using similar sample sizes have been productive. Makino *et al* (*11*) investigated osteochondral transplants in rabbits. Sixteen rabbits underwent creation of a full-thickness osteochondral defect with subsequent fixation of the removed tissue back to the defect. Animals were sacrificed at four time periods and examined grossly and microscopically for healing status. Arnoczky *et al* (*2*) investigated tendon ball interposition in a canine model for basal joint arthroplasty. Animals underwent excision of the radial carpal bone followed by closure of the wound (control, n = 17) or interposition of an anchovy of the autologous extensor carpi radialis tendon (experimental, n = 22). Animals were sacrificed at four different time periods, and specimens were examined by light microscopy.

RESULTS

Clinical

Clinically, all animals were full-weight-bearing in the immediate postoperative period. One animal developed a superficial wound dehiscence and subsequent septic arthritis on the control (autologous tendon) interposition side, with a limp on that side. This animal was initially treated with oral cephalexin, but failed to respond and was sacrificed prior to study conclusion. The specimens from this animal were harvested and examined but were excluded from the study results. The remaining ten animals were full weight bearing and experienced no complications from the procedure.

Histological

Histological analysis was performed on 13 specimens (n = 7 control, n = 6 experimental) in the manner described in the materials and methods section. Sections were examined by light microscopy for subsidence of the graft material, foreign body reaction or other immunological cell infiltration, neovascularity, and infiltration of native cells.

In the 4 week survival group, a connective tissue attachment was noted between the acellular dermal matrix graft and the adjacent carpal bones which appeared to allow for infiltration of native cells into the graft (fig 2). Fibroblasts were noted lining the surface of the dermal matrix graft interposition arthroplasty adjacent to the native carpal bones. Scattered fibroblasts were observed infiltrating the graft with the highest cellular density near the native tissue surface (fig 3). In one specimen, vascular infusion was attempted but was not grossly successful ; therefore, the specimen was processed for histological analysis. Interestingly, one can note vascular infiltration as evidenced by dye in this specimen (fig 2).

At 8 weeks survival, sections demonstrated further infiltration of fibroblasts into the matrix of the graft with no evidence of immune reaction. Although a large portion of the dermal matrix graft remained acellular at the 8 week mark, a relatively increased cellular infiltrate was noted with remodeling of the tissue at the periphery (figs 4, 5). This tissue appeared to be fibrocartilaginous in nature.

In the specimens in which the autologous tendon was implanted as an interposition graft, similar connective tissue attachments between the carpal bones and the graft were noted. Wispy islands of fibrous tissue with degeneration were noted, with

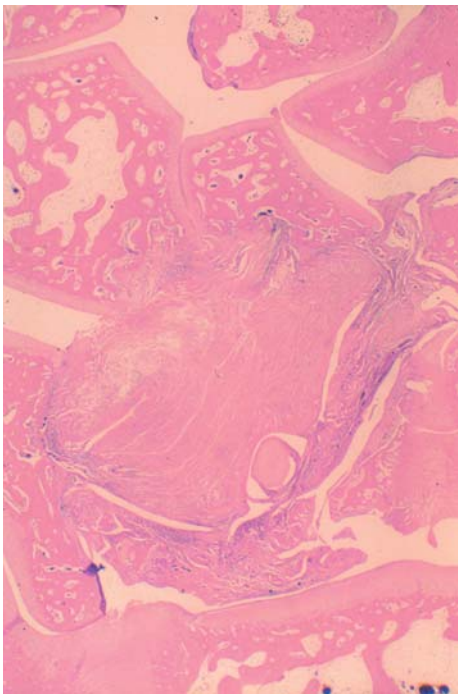

Fig. 2. — Connective tissue bridges between dermal matrix graft and carpal bones. Four week survival specimen, H & E, OM 10 ×.

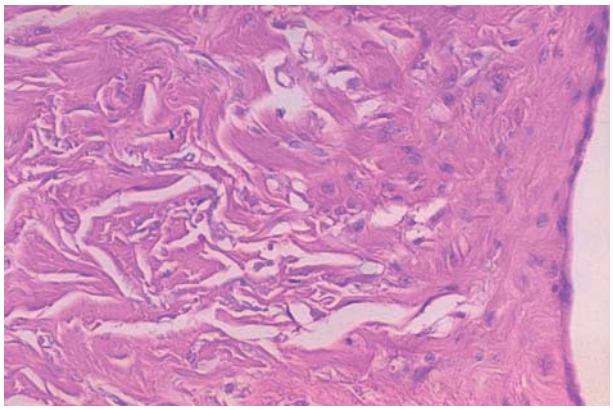

Fig. 3. — Scattered fibroblasts were observed infiltrating the dermal matrix graft with the highest cellular density near the native tissue surface. Four week survival specimen, H&E, OM 100 ×.

apparent growth of fibroblasts lining the graft surface. In some specimens, a large amount of cellular infiltration was present as early as 4 weeks. Scattered giant cells were noted in the tendon

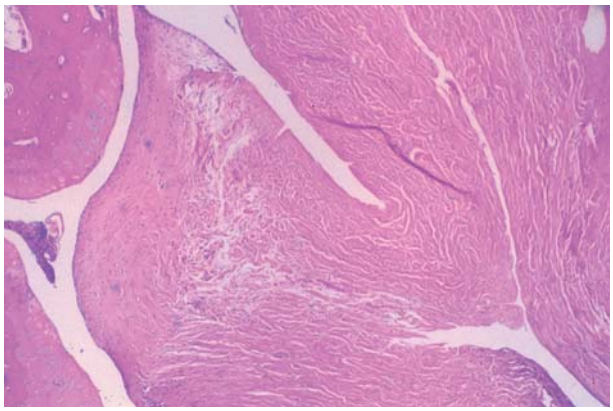

Fig. 4. — Dermal matrix graft (right) with infiltration of host cells. Eight weeks survival, H & E OM 40 ×.

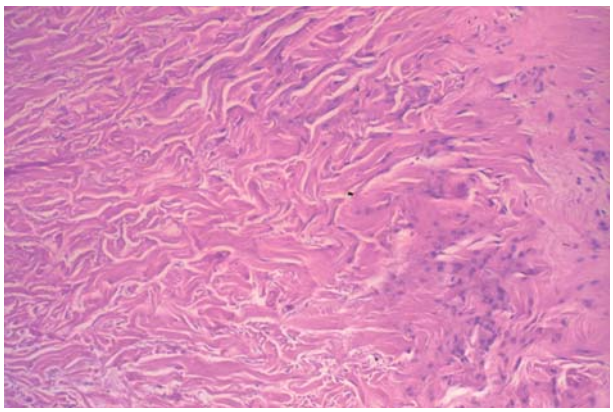

Fig. 5. — Fibroblastic infiltration deeper into the dermal matrix graft (at left of image). Eight weeks survival, H & E OM 100 ×.

implant but appeared to be confined to areas adjacent to suture material (fig 6).

No foreign body or immune cell infiltrate was noted in either specimen group. Over time, a trend towards infiltration of fibroblast like cells was noted in the dermal graft and the autologous tendon interposition groups. The autologous tendon specimens appeared to have much greater cellular infiltration at each time period, with nearly uniform and complete infiltration by the 8 week time point. In contrast, cellular infiltration was noted in the acellular dermal matrix group specimens with increasing cellularity at the 8 week mark ; however, even at this final time point, the majority of the graft remained acellular.

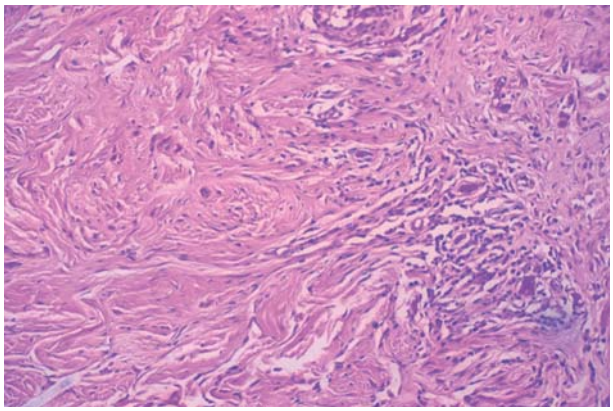

Fig. 6. — Infiltration of cells is nearly complete at 4 weeks survival in the autologous tendon interposition arthroplasty. Giant cells associated with suture material are seen in the right of the field. H & E OM 100 ×.

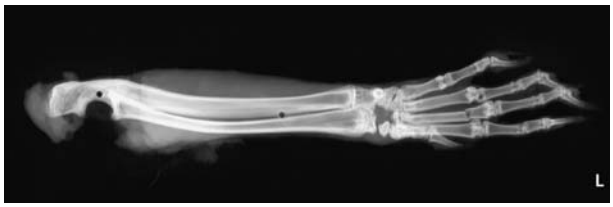

Fig. 7. — Radiograph of the dermal matrix graft interposition arthroplasty at 8 weeks survival.

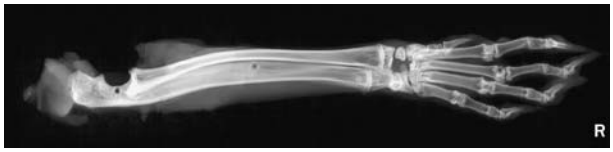

Fig. 8. — Radiograph of the autologous tendon interposition arthroplasty at 8 weeks survival.

Radiographic findings

High resolution radiographs were obtained in the anteroposterior plane of all specimens. Radiographs were examined for maintenance or subsidence of the interposition space ; the latter manifested by gross subsidence of the graft or shifting of the remaining carpal bones.

No overt shifting or collapse of the remaining carpal bones was noted ; all specimens in the control and experimental interposition groups demonstrated a preserved clear space representing the interposition site (figs 7, 8).

Vascular

Vascular studies were performed according to the methods outlined previously in this manuscript. Due to difficulty with cannulation of the brachial artery and injection of sufficient dye, only four experimental (n = 3 ; n = 1 with partial infusion only at 4 weeks and n = 3 at 8 weeks) and 3 control specimens underwent vascular analysis (n = 1 at 4 weeks, n = 2 at 8 weeks).

Analysis of the specimens infused with India ink dye revealed a blush of dye most prominent about the periphery of the interposition material. Closer analysis revealed presence of dye infusion in a centripetal fashion. This pattern was noted in both the control autologous interposition material as well as the acellular dermal matrix interposition material. It is difficult to interpret the results of this analysis due to the small numbers of specimens and the difficulty in infusion, however, a trend towards increasing dye infiltration with increasing survival time (from the 4 to 8 week survival groups) was noted (figs 9, 10). This suggests that the interposition material may become vascularised over time with neovascularisation occurring with increasing survival time. Again, small numbers of specimens preclude the ability to make a strong conclusion, but when comparing the acellular dermal matrix graft interposition to the autologous tendon graft interposition, the autologous tendon arthroplasty specimens appeared to have greater dye infiltration at each time point.

DISCUSSION

No foreign body or immune cell infiltrate was noted in either specimen group. Over time, a trend towards infiltration of fibroblast like cells was noted in the dermal matrix graft and the autologous tendon interposition groups. The autologous tendon specimens appeared to have much greater cellular infiltration at each time period, with nearly uniform and complete infiltration by the 8 week time point. In contrast, cellular infiltration was noted in the acellular dermal matrix group

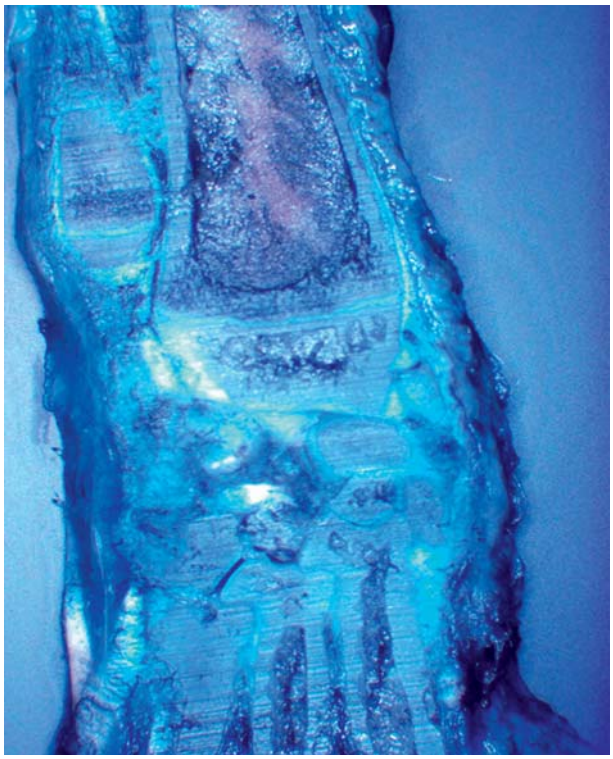

Fig. 9. — Photograph of the autologous tendon interposition arthroplasty at 8 weeks survival.

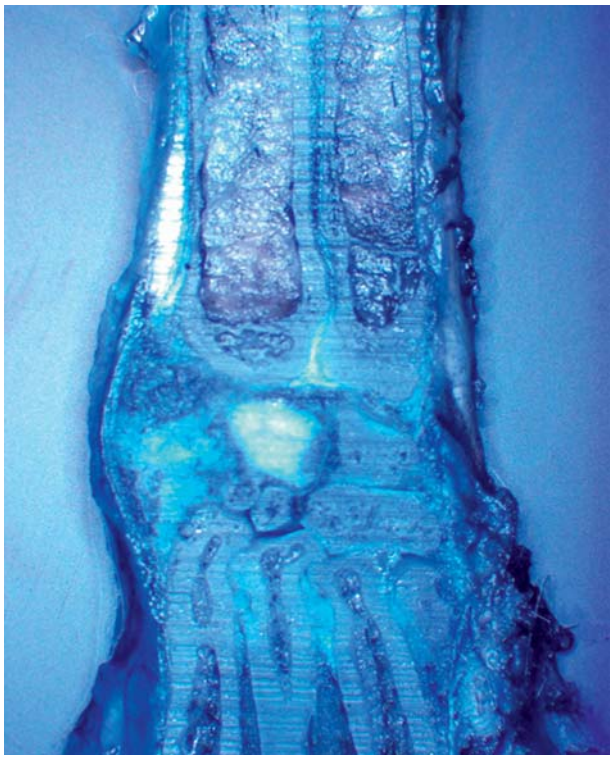

Fig. 10. — Photograph of the dermal matrix graft interposition arthroplasty at 8 weeks survival.

specimens with increasing cellularity at the 8 week mark ; however, even at this final time point, the majority of the graft remained acellular.

It appears that both the acellular dermal matrix and the autologous tendon grafts are well tolerated in this model of interposition arthroplasty. Both appeared to maintain the post-lunate resection space and appeared to promote cellular ingrowth without provoking adverse immune response. From the vascular infusion portion of the study, it appeared that vascular infiltration occurred in both arthroplasty groups, perhaps to a greater extent in the autologous tendon group.

No adverse immunological infiltration was observed. One case of septic arthritis was noted on the control (autologous tendon) side in a single animal. This was thought to be secondary to infection at time of surgery.

Multiple studies have been performed upon tendon interposition arthroplasty of the carpometacarpal joint with a high rate of patient satisfaction and successful clinical outcomes. As such, tendon interposition arthroplasty has become the gold standard by which other, more novel procedures for the treatment of first carpometacarpal joint arthritis should be measured. In this study, we compared interposition arthroplasty using an autologous tendon graft to interposition with an acellular dermal matrix graft. This study evaluated the histological, vascular, and radiographic findings following the procedure. Satisfactory and equivalent outcomes were noted clinically and radiographically ; histologic and vascular studies revealed more favourable characteristics in the autologous tendon graft group. However, this study did not address donor site morbidity occurring with tendon interposition. Likewise, the advantages of arthroscopic treatment of carpometacarpal arthritis with use of an allograft rather than an autograft, requiring donor site morbidity, are not investigated by this study. It is likewise unclear what ultimate clinical effect, if any, the less robust cellular and

vascular infiltration in the dermal graft group would have relative to that of the autologous tendon group. Our study is limited due to the small number of animals in the series and the difficulty with vascular infusion. However, the utility of our series is in the documentation of satisfactory outcomes and the absence of adverse events in this animal series, information that had previously been lacking.

Despite the possibly more favourable histological and vascular characteristics of the autograft relative to the dermal matrix graft, it is possible that use of an arthroscopic technique and allograft to minimise disruption of ligamentous structures and to obviate donor site morbidity inherent in the tendon interposition techniques would result in a more clinically favourable outcome. Further study is indicated and is underway to investigate the outcomes of interposition arthroplasty using an arthroscopic technique and acellular dermal matrix allograft. Until such data is available, treatment of symptomatic first carpometacarpal joint arthritis will remain a subject for much discussion. However, several facts are evident : both the autologous tendon and acellular graft materials were viable interposition arthroplasty materials in this model. Both tended to preserve the neo-joint space, and both became incorporated with neovascularity and cellularity over time. The dermal matrix graft demonstrated somewhat less cellular infiltration relative to the autologous tendon graft over time, perhaps indicating that remodelling and cellular infiltration occurred more readily in the autologous material. From this study, it is apparent that the acellular dermal matrix material is effective in maintaining joint space, allows for neo-vascularity and cellular infiltration, and has minimal adverse effects *in vivo*.

Previous studies have demonstrated similar finding in canines and humans when the material has been utilised for other purposes. Likewise, limited use in humans for interposition arthroplasty has been associated with successful clinical outcomes and a high degree of patient satisfaction, with outcomes comparable to tendon interposition arthroplasty. Only further investigation will define the role of this procedure in treating symptomatic first carpometacarpal joint arthritis.

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