IMPLANTABLE MATERIALS AND GRAFTS IN TENDON SURGERY

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INTRODUCTION

Tendon injuries are frequently seen in the lower extremity and are often challenging injuries to the podiatric physician. If total disruption occurs, primary repair of the tendon is often difficult due to the inadequate remaining tissue or need for resection of frayed tendon ends. Autogenous tendon grafts have been utilized for reconstruction of tendon injuries. However, a normal functioning musculo-tendinous unit must be sacrificed. Autogenous tendon grafts are successful even though the graft initially weakens and may take months to regain tensile strength.

Ruptured or lacerated tendons heal primarily through extrinsic rather than intrinsic means. The nutrition received via the synovial fluid is one of the key factors in tendon healing. Potenza and Skoog concluded that the tenocyte did not have the ability to heal a tendon juncture. They emphasized that a tendon would heal by the ingrowth of tissue from the wound itself. Peacock shortly thereafter developed the concept of "one wound, one scar", stating that every part of the wound is continuous by permeation of a proteinaceous fluid. Thus, the ideal tendon graft or implant would not only allow, but promote the ingrowth of tissue from the wound. It would combine the high strength of synthetic polymer fibers with the scaffold for cellular invasion provided by autogenous grafts. This ideal implant would slowly dissolve, gradually transferring the load to the newly formed collagen. The generation of the neotendon would be faster than that of an autogenous graft, thereby shortening the required protection or immobilization period.

The major problem with attempted tendon grafts or implants is the formation of adhesions restricting free tendon glide. Many of the materials that will be presented in this paper were developed in an effort to solve this problem. Other concerns with materials for tendon grafting are their biological reactivity, lack of strength, and ease of handling and implantation.

This paper will present an overview of tendon bio-prosthetics used in the past, those in current use, and those under investigation. These materials can be divided into two major categories. The absorbable materials are those which act as scaffold for fibrous ingrowth. The nonabsorbable materials act as true prosthetic devices as a substitute for the injured tendon.

ABSORBABLE IMPLANT MATERIALS

Polyglactin Mesh

Roberts et al. compared the tensile and histologic characteristics of acutely transected Achilles tendon in rabbits treated by cast immobilization, primary surgical repair, and surgical repair reinforced with polyglactin mesh. All modes of tendon repair resulted in tensile failure at significantly lower loads than the contralateral control tendons. The primarily repaired tendon and the polyglactin mesh repaired tendon more closely approximated the load tolerance of the control side than the non-repaired, casted tendons. The polyglactin mesh reinforced tendon exhibited no mechanical superiority to the suture repaired tendon. Unlike previous studies of tendons reinforced with polyglactin, Gore-Tex, and Dacron, their study

exhibited no discernible increase in fibrous ingrowth in the repaired tendons. Roberts theorized that the polyglactin mesh dissolved too rapidly to stimulate either a fibrous or a cellular reaction.

Howard et al. utilized polyglycolic acid (Dexon) as a replacement for the Achilles tendon in sheep. They found uniformly good results with the induction of a thick neo-tendon with very little foreign body reaction.

Polylactic Acid Implant

Liem et al. reported on the MR imaging of repairs of Achilles tendon ruptures repaired with polylactic acid implant. A polymer of lactic acid (PLA) is currently undergoing multi-center clinical trials. The advantages of PLA include high tensile strength and the induction of proliferative tissue response. In current surgical techniques for repair of Achilles tendon rupture, the integrity of repair is dependent on the mechanical strength of the suture and the stress imbalance between the suture and the surrounding healing tendon.

The PLA implant acts as a scaffold for soft-tissue ingrowth and reduces the stress imbalance by distributing tissue growth over a larger surface area. The tendon repaired with PLA is markedly thickened in a diffuse, fusiform manner, whereas tendon thickening in a conventional repair is usually localized to the site of repair. The diffuse hypertrophy of the PLA repaired tendon persists as long as 35 months after repair, which may be a significant factor in the continued strength and integrity of this type of repair.

Carbon Fiber Implant

The major work in absorbable tendon implants has been with carbon fiber. Since Jenkins et al. reported the use of carbon fiber as a method of inducing a neo-tendon in 1977, much interest and research have been conducted with this material. Carbon fiber has been repeatedly reported to have the ability to induce a neo-tendon. Jenkins et al. believed that the filamentous carbon implant has the power of attracting connective tissue within their interstices with the subsequent laying-down of deposits of strong collagenous fibers. These collagen fibers gradually orient themselves so that after eight to twelve weeks, a structure very closely resembling a natural tendon results. The carbon fibers act as an implant only for the first few weeks. Thereafter the newly induced tendon takes over the action of the implant and the implant becomes progressively less necessary for normal function.

Parsons et al., in their study of 52 Achilles tendon repairs using carbon fiber composite, found that continuity of the tendon was immediately restored with bridging of gaps and restoration of length. Howard et al. reported that the average muscle power obtained with a carbon fiber implant for late Achilles tendon rupture was 88% of normal, and the thickness of the neo-tendon was 148% of that on the normal side. Mendes et al., utilizing carbon fiber in the quadriceps tendon of dogs, found that the tensile strength was 88% of the dog's natural tendon. However, it was only 60% of the tensile strength of the unused carbon fiber. Mendes attributes this to the gradual takeover of the load by the collagen fibers along with the gradual failure of the carbon fibers.

Several disadvantages with carbon fiber have been reported since its introduction. The carbon fibers are brittle and must not be subjected to twisting, bending, or knotting. Smooth entrance and exit holes in bones must be ensured to prevent fraying. Metal anchoring devices should not be used with carbon fiber since metal reacts with the carbon causing a degradation in the metal. Mendes et al. also found an ongoing inflammatory reaction that coincided with the constant production of collagen. They found a constant turnover of macrophages which surrounded the carbon fibers, thus preventing the tendon structure from maturing even after one and one-half years of implantation.

Amis et al. discovered that the tissue reaction with carbon fiber continued, leading to a steady decrease in the network of collagen fibers and producing large edematous areas. They also found carbon particles in the lymph nodes. They postulated that the large number of phagocytes seen with carbon fiber implants would inhibit rather than stimulate fibroblast activity and the subsequent formation of collagen.

NONABSORBABLE IMPLANT MATERIALS

Teflon Graft

Roger Williams suggested using teflon as a tendon substitute in 1960. The major problem with prosthetic materials was frequent adhesions yielding poor functional results. Teflon might be used to develop a strong, non-reactive graft with satisfactory function. Williams used closely-woven teflon grafts to replace the extensor communis of anterior tibial tendons of 18 dogs. Examination of the grafts revealed a well-developed pseudo-sheath within which the teflon would glide easily. Microscopic examination showed that this sheath was composed of fibrous tissue with a thin layer of cells having the appearance of mesothelium. Williams reported good functional results with minimal tissue reaction.

Silicone Rubber Sheeting

Bader et al., in 1968, used reinforced silicone rubber sheeting which were bonded over dacron suture material. This prosthetic device yielded similar results as the teflon implant. A vascularized fibroblastic membrane surrounded the silicone implant which glided through tissues with little resistance.

Dacron Graft

Lieberman et al. utilized Dacron grafts in seven patients with Achilles tendon ruptures. They felt the Dacron graft facilitates the approximation of the frayed tendon ends, decreases the tension on the repaired tendon, and allows for early mobilization. Amis et al. also used a polyester implant on one limb and carbon fiber on the contralateral limb to replace the Achilles tendon in 30 sheep. They found that the polyester implants had several advantages over carbon. The polyester implants were not liable to disintegrate during implantation, since polyester does not fragment. The implant also has similar stiffness as the structure being replaced, and is easier to remove in the event of an infection. The neo-tendon associated with the polyester implant was denser, more collagenous and more closely adherent than that in the carbon implanted extremity.

Surgical Mesh

A number of surgical meshes have been used in tendon repair. A polyester (Dacron, Mersilene) mesh and more recently a polypropylene (Marlex, Prolene) mesh have both been used in Achilles tendon repairs. Hosey et al. reported on repairing the Achilles tendon of rabbits with Marlex mesh. They demonstrated that the biosynthetic tendon complex very closely approximated the physical properties of the normal tendon with no significant difference in tensile strength between the two groups. Histologically, this material forms a bridgework for ingrowth of normal, orderly, collagen bundles, similar to those found in the original tendinous units, and with minimal foreign body reaction. Ozaki et al. reported similar favorable results using Marlex mesh with six neglected Achilles tendon ruptures with an additional note of less adhesions with the mesh than with primary repair.

Bovine Tendon Xenograft

The majority of recent work in nonabsorbable tendon bio-prosthetics has been with bovine tendon xenografts. McMaster performed the initial investigation with animal collagen in the form of tendon homografts. As a result, glutaraldehyde-treated bovine tendon xenografts came into clinical use in 1980. Dockery has reported on several occasions on the use of the bovine tendon xenograft in lateral ankle stabilization procedures. The commercially available xenograft has been shown to possess comparable properties to the human peroneus longus tendon. The bovine xenograft is treated with glutaraldehyde to stabilize and preserve the collagen structure within the graft. Since glutaraldehyde is potentially toxic, the more recent commercially available grafts are packaged in sterile saline to eliminate the need for extensive washing. The collagen molecules appear to be sufficiently similar from species to species that antigenicity is not a major consideration.

Dockery states that initially, the bovine xenograft functions as a true prosthetic, but undergoes a transformation to a composite implant with a fibroblastic response around the exposed tendon. The advantages of the bovine xenograft in lateral ankle stabilization is minimal dissection and maintenance of the lateral ankle

myotendinous units. The major disadvantage is a longer period of immobilization to allow the bioprosthetic time to anastomose to bone.

Goldstein et al. performed experiments with the Achilles tendon of rabbits comparing an autogenous graft, a xenograft treated with glutaraldehyde, and a xenograft treated with carbodiimide. The autogenous grafts were infiltrated with fibroblasts and capillaries at ten weeks postoperatively, and partially replaced with repair tissue at twenty weeks. Fibrous tissue infiltration was noted at three weeks on both collagen-treated implants. At ten weeks, the xenograft treated with carbodiimide had been resorbed and replaced with a normally-appearing neo-tendon. The glutaraldehyde treated xenograft was resorbed and replaced much more slowly and with more inflammatory cells noted. The strength of the carbodiimide-treated xenograft was less than the autogenous after initial implantation, but at 20 weeks surpassed the autogenous strength. The glutaraldehyde-treated xenograft showed the greatest strength initially, but at 20 weeks showed approximately equal strength to the autogenous graft. Allen et al. found that xenografts do not contribute to the neo-tendon, but merely remain unaltered within their surrounding fibrous envelopes. Fibrous tissues eventually bypass the load-bearing action by the tendon xenograft.

CONCLUSION

Tendon implant surgery, although still in its infancy, will continue to receive the attention of medical research institutions, as the need for an ideal replacement material persists. Absorbable tendon grafting materials seem to be the most promising to date. Their scaffolding effect appears to induce the ingrowth of fibrous tissue and subsequently replace the structure and function of the implant. Bovine xenograft and polyester (Dacron) grafts are promising as true bio-prosthetic replacements for lost or severely damaged tendons. It is important for the podiatric physician to stay abreast of this relatively new field of musculo-tendinous surgery, as the full potential benefit and expanded spectrum of applicable procedures will be realized through continued utilization and study.

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