THE ULTRASTRUCTURE OF NORMAL DIGITAL FLEXOR TENDON SHEATH AND OF THE TISSUE FORMED AROUND SILICONE AND POLYETHYLENE IMPLANTS IN MAN

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Three normal digital flexor tendon sheaths and the corresponding tissue formed around five silicone rod tendon implants, two silicone rubber mammary prostheses and one polyethylene tubing implant have been examined by light microscopy and by transmission and scanning electron microscopy. No principal difference in morphology was found. The surface facing tendon or implant was almost invariably covered with an irregular layer of amorphous material and filaments; only occasionally were collagen fibrils or cells exposed. Beneath the surface there were abundant collagen fibrils and some cells; besides fibroblasts, cells rich in filaments and often with numerous glycogen granules, mitochondria and peripherally located vesicles were found. These cells were frequently surrounded by a thick layer of an amorphous matrix. The results indicate that the implants caused remarkably little tissue reaction.

Silicone rubber implants have found numerous applications in reconstructive surgery as substitutes for tissues and organs (Mullison 1964). In tendon transplantation, silicone rods have been used as stents in a first stage (Bassett and Carroll 1963; Hunter 1965; Hunter and Salisbury 1970). When the stent is replaced by an autogenous tendon graft, fewer adhesions are formed than usual after primary or delayed tendon transplantation (Nicolle 1969; Conway, Smith and Elliot 1970; Hunter and Salisbury 1970; Kessler 1972; Urbania, Bright, Gill and Goldner 1974). The functional results of the two-stage tendon replacement have also been gratifying, especially after untidy, complex or crushing injuries in which excessive scar formation tends to jeopardise the results of conventional tendon suture or transplantation (Chong, Cramer and Culf 1972). After a two-stage tendon replacement it seems that the fluid within the sheath around the graft provides its nutrition (Hunter and Salisbury 1971).

A silicone rubber implant with a smooth and non-porous surface causes very little tissue reaction. A thin fibrous capsule forms around the implant, which remains free within the cavity. To the naked eye the inner layer of this tissue capsule is smooth and shiny, and has a striking similarity to the surface of a serous cavity or tendon sheath. Several investigators have studied the tissue of the new capsule by light microscopy. The outer layer has been found to consist of fibroblasts and collagen (Imber, Schwager, Guthrie and Gray 1974), and the inner lining of cells like endothelium, synovium or mesothelium (Neuman, Ben-Hur and Tritsch 1966; Nicolle 1969; Padula, Zeok, Pupi and Camishion 1969; Conway et al. 1970; Hunter and Salisbury 1970; Chong et al. 1972; Kessler 1972; Farkas, McCain, Sweeney, Wilson, Hurst and Lindsay 1973; Hernández-Jáuregui, Esperanza-García and González-Angulo 1974; Wilflingseder, Propst and Mikuz 1974). Light microscopy, however, offers little possibility of distinguishing cells of these types (Eskeland and Kjaerheim 1966).

In an electron microscopical study of biopsies taken after the implantation of silicone rods into the digital flexor mechanism of chickens, Farkas and his colleagues found that the capsule formed around the implant had no inner cell lining; the inner surface consisted of large amounts of amorphous material, with underlying fibroblasts and abundant collagen fibrils. In contrast, Hernández-Jáuregui and his co-workers, using subcutaneous silicone rubber implants in dogs, observed by the electron microscope an inner lining of histiocytes arranged in several rows.

The present study is an effort to reach a better understanding of the tissue formed around silicone implants in clinical situations.

MATERIAL AND METHODS

In three patients the normal flexor tendon sheath of a finger was examined (Table I). The biopsies were obtained from an unaffected digit of a patient with an injury to a neighbouring flexor tendon (Case 4); from the ring finger of a man with Dupuytren's contracture of the little finger only (Case 9); and...
from a normal finger of a kidney donor (Case 10). This patient was a man, aged forty-five and previously healthy, who suddenly lost consciousness from subarachnoid haemorrhage. A few hours later he suffered another attack, ceased to breathe, and was artificially ventilated. Investigations led to the diagnosis of unquestionable cerebral death, whereas the peripheral circulation was good. The biopsy was taken while both kidneys were being removed for transplantation.

Five patients (Cases 1 to 5) with implants of silicone rod (Silastic) had all suffered an injury of the flexor tendon of a finger. The biopsies were taken when the implants were replaced by tendon grafts.

In two patients mammary implants were removed because of unsatisfactory cosmetic results. In Case 6 each prosthesis (Mammatech 310-IT) had been implanted in a cavity beneath the pectoralis major muscle. In Case 7 the prosthesis (Sima-plast, small type) had been inserted between the mammary gland and the pectoralis fascia. In this patient, after collapse

JEM 100 B transmission electron microscopes. Sections for light microscopy were stained with toluidine blue, and sections for electron microscopy were stained with either uranyl acetate or lead citrate or both. Dehydrated specimens were also prepared for scanning electron microscopy. They were dried in liquid CO₂ (Sorvall critical point drying system). The specimens were then coated with a thin layer of carbon and gold-palladium in an Edward’s vacuum coating unit and examined with a Jeol JSM-50 scanning electron microscope.

RESULTS

Normal tendon sheath—Under the light microscope the sheaths consisted of dense connective tissue (Figs. 1 and 2). The cells were evenly distributed throughout the tissue and some appeared to be located on the surface. The concentration of cells and small vessels seemed

| Table I |
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| Case number | Sex | Age at time of operation (years) | Interval between tendon injury and operation (months) | Type of implant | Interval between implantation and biopsy (months) |
| 1 | M | 22 | 3 | Silicone rod | 2.5 |
| 2 | M | 45 | 0 | Silicone rod | 2.5 |
| 3 | M | 33 | 3 | Silicone rod | 3 |
| 4* | F | 60 | 9.5 | Silicone rod | 3 |
| 5 | F | 17 | 14 years | Silicone rod | 13 |
| 6 | F | 34 | — | Silicone rubber | 9 |
| 7 | F | 29 | — | Silicone rubber | 16 |
| 8 | F | 18 | — | Polyethylene tubing | 16 years |
| 9* | M | 60 | Biopsy from ring finger. | Polyethylene tubing | 16 years |
| 10* | M | 45 | Biopsy from kidney donor | Polyethylene tubing | 16 years |

* Three normal tendon sheath biopsies were obtained—in Case 4 during operation for a tendon injury to a neighbouring finger, and in Cases 9 and 10.

of the right implant, both implants were removed and a biopsy taken from the fibrous capsule on the left side.

A single patient (Case 8) had an implant of polyethylene tubing. This girl was born in 1956 with a malformation of the right lower limb, which was then twice the size of the left leg and dark blue in colour. Angiography at the age of fourteen months revealed multiple arterio-venous communications. A month later fifteen thin polyethylene tubes were implanted subcutaneously from the distal part of the foot to the proximal part of the thigh. The post-operative course was uneventful and the limb gradually decreased in size. In 1974, sixteen years after the implantation, a piece of subcutaneous tissue with a segment of tube in situ was excised.

Histological examination—All the biopsy specimens were immediately fixed at 4 degrees Celsius for one to sixteen hours in either 2.5 per cent glutaraldehyde or in 2.5 per cent glutaraldehyde and 1:8 per cent formaldehyde, and post-fixed for one to two hours in 1 per cent osmium tetroxide. The fixatives were buffered with 0.15 M sodium cacodylate or 0.1 M sodium hydrogen phosphate, pH 7.4. The specimens were dehydrated in ethanol or acetone and embedded in Epon or Araldite. Sections were cut on an LKB ultratome in a direction vertical to the inner surface of the specimen, and were examined by light microscopy and by Siemens 1A or higher in the biopsy from the female patient, Case 4 (Fig. 1), than in the biopsies from Cases 9 (Fig. 2) and 10, whereas the collagen appeared more dense in the two latter specimens.

Transmission electron microscopy showed that the surface mostly consisted of an amorphous substance and aperiodic filaments with diameters of 7 to 10 nm (Figs. 3, 4 and 5). Sometimes the filaments seemed to be a part of the amorphous substance (Fig. 4). Fibroblasts and collagen fibrils were occasionally seen on the surface (Figs. 3 and 5). The fibroblasts had a relatively dark cytoplasm, a well-developed granular endoplasmic reticulum, and long slender cytoplasmic processes. The collagen fibrils showed typical periodicity (Figs. 3, 4 and 5).

Below the surface collagen fibrils predominated (Figs. 3, 4 and 5), and appeared to be orientated mainly in two directions (Fig. 3). The cells among the collagen bundles were of at least two types. The principal type appeared to be fibroblasts, which were found in all three biopsies (Cases 4, 9 and 10). The other cell type was

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found in the specimens from the kidney donor and from the patient with Dupuytren's contracture. These cells were rich in glycogen particles and mitochondria with a relatively dense matrix and few cristae (Fig. 6). The cells also contained numerous peripherally located vesicles and invaginations of the cell membrane. Abundant filaments about 10 nm in diameter were often packed in thick bundles. The microvilli of the cells were embedded in a thick amorphous matrix (Figs. 3 and 6).

By scanning electron microscopy at low power the normal tendon sheath showed a wavy surface, with minor folds running across the major waves (Fig. 7). At higher magnification, however, the surface was highly irregular, consisting of varying amounts of non-filamentous material and of filaments orientated in different directions (Fig. 8).

**Tissue around silicone rod implants**—The capsules formed at three months consisted of a cellular connective tissue when examined under the light microscope (Fig. 9). The outer cells were more elongated than the inner cells close to the implants, and the inner cells stained more heavily with toluidine blue. At thirteen months (Case 5), the capsular tissue was less cellular and very similar to normal tendon sheath.

Transmission electron microscopy revealed that in capsules formed at three months the inner surface was usually lined by an amorphous material, but occasionally cells, filaments, or collagen fibrils were found (Figs. 10 and 12). Below the surface, cells and collagen fibrils were seen (Fig. 9). Most of the cells resembled fibroblasts, but another cell type was rich in filaments, contained glycogen particles and showed microvilli (Fig. 11). Invaginations of the cell membrane and vesicles close to it were also observed. Minor amounts of an amorphous matrix surrounded the cells (Fig. 11). At thirteen months the amorphous surface layer was much thinner.

Scanning electron microscopy of the surface at three months revealed a coarse and irregular surface (Fig. 14); single exposed cells were only rarely observed.

**Tissue around silicone rubber mammary prostheses**—At nine and twenty-four months this consisted of dense connective tissue when examined under the light microscope (Fig. 15). The cells were evenly distributed. Electron microscopy showed that the surface was composed mostly of filaments and amorphous material with occasional collagen fibrils (Fig. 16). The deeper part consisted mostly of collagen fibrils, and the few cells examined were fibroblasts.
Tissue around polyethylene tubing—At sixteen years the capsule was thin and contained some fat cells, but otherwise resembled the capsules found around the two mammary implants (Fig. 17). Some of the sections examined by the electron microscope contained both capsule and tube (Fig. 18); nowhere were they adherent.

DISCUSSION

The main conclusion drawn from our investigations was that no principal difference could be demonstrated between the structure of normal tendon sheath and the capsule which had formed around any of the implants.

Both were made up of connective tissue rich in collagen fibrils. The inner gliding surface was almost exclusively covered with an amorphous material interspersed with filaments and only occasionally were collagen fibrils and cells exposed. No evidence of a continuous cell layer was found. The capsules formed at three months usually contained more amorphous substance on the surface and more fibroblasts than did the capsules formed after a longer period and normal tendon sheaths.

The nature of the amorphous substance and the filaments of 7 to 10 nm diameter are unknown. The amorphous material may be procollagen molecules, and the filaments early stages in the formation of collagen fibrils. It is established that the precursors of collagen are secreted from fibroblasts as procollagen molecules which do not polymerise to fibrils until peptides have been split off at both ends by proteolytic enzymes (Uitto and Lichtenstein 1976).

Most cells examined were fibroblasts, but in normal tendon sheath and in the capsules around silicone rods an unidentified cell type also occurred. These cells were often remarkably rich in glycogen particles, vesicles, surface invaginations, mitochondria and filaments. The filaments had a diameter of 10 nm, which seems to exclude their representing microfilaments (actin), which have a diameter of 6 to 7 nm. The amorphous matrix surrounding these cells may represent a basal lamina.

Apart from a short note by Farkas et al. (1973) on tendon sheath in the chicken, the normal ultrastructure has not previously been reported. The present observations correspond well with their findings.

There is some similarity between synovial membrane
and tendon sheath (Ghadially and Roy 1969). Both tissues have mostly collagen in the deeper part, while on the surface amorphous material, filaments and collagen fibrils are found. The main difference is in the number and arrangement of the cells on the surface. In the synovial membrane of most species the cells are numerous and arranged in two or more rows. This layer of cells is discontinuous and only some form specialised contacts (Barland, Novikoff and Hamerman 1962; Ghadially and Roy 1969; Groth 1975). In contrast to this, we found only an occasional cell exposed on the surface of the tendon sheath.

Three reports have been published on the ultrastructure of the tissue formed around silicone rubber implants. Farkas et al. (1973), who examined that tissue in chickens, made observations similar to ours. In contrast, Willflingseder et al. (1974), studying cases of constrictive fibrosis in the tissue around mammary prostheses, and Hernández-Jáuregui et al. (1974), using subcutaneous silicone implants in dogs, found that the surface facing the implants consisted of several rows of histiocytes. In other clinical situations the presence of macrophages and the development of fibrosis indicate a strong host reaction. The type and intensity of reaction are, of course, influenced by a number of variable factors, such as the physical and chemical properties of the implant, haematoma formation, contamination with bacteria or foreign bodies like particles of glove powder or cotton fibres from swabs, and individual variations in host response. On the other hand, the absence of macro-
Tissue capsule formed around a silicone rubber mammary implant. Figure 15 (inset above)—A light micrograph. Only scattered cells are located on the surface (right). \((\times 215.\)\)

Figure 16—An electron micrograph illustrating collagen fibrils (COL) and amorphous substance (AM) on the surface (right). \((\times 22,500.\)\)

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Figs. 17 and 18
Capsule formed around a polyethylene tubing implanted for sixteen years. Figure 17—A light micrograph showing numerous cells close to the tubing (T). \((\times 215.\)\)

Figure 18 (inset below)—An electron micrograph showing that only filaments and collagen fibrils (COL) are facing the tubing. \((\times 22,500.\)\)

Scanning electron micrographs from the tissue capsule formed at three months around a silicone rod tendon implant. Figure 13—Showing a coarse and irregular surface layer. \((\times 315.\)\)

Figure 14—Detail of the surface shown in Figure 13, demonstrating the appearance of a meshwork. A red blood cell (RBC) is seen. \((\times 6,300.\)\)

phage reaction and the development of a lining similar to that of normal tendon sheath lead to the conclusion that the implants used in the present cases caused very little tissue reaction.

It would be of great interest to study the tissue formed around silicone rods at a later date, namely after tendon transplantation and vascularisation of the graft. This would probably have to be done in animal experiments because in clinical practice such an opportunity is rare.
REFERENCES


