

Linear Polyethylene Sutures

AN EVALUATION OF TISSUE REACTION

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IN a recent report, Phelan [1] showed that linear polyethylene sutures were used to advantage in small artery anastomoses. He was impressed with the handling qualities, strength and nontoxic properties of linear polyethylene sutures. Histopathologic evaluation was carried out for periods up to thirty days. It was noted that cellular proliferation, particularly of fibrous elements, and acute inflammatory reactions due to the use of linear polyethylene were substantially less than reactions observed when arterial anastomoses were made using surgical silk.

Usher and Wallace [2] showed that when pellets of linear polyethylene were placed into the peritoneal cavities of dogs, the ensuing foreign body reaction as measured by appearance and degree of adhesion formation was slight. Pellets of nylon caused greater adhesion formation. These observations were made from seven day implantations.

No information, pertaining to tissue reactivity to linear polyethylene sutures over long time periods is available in the literature. The present report will present the histopathologic responses to embedded linear polyethylene for periods up to one year and will compare these reactions with those observed with surgical silk.

MATERIALS AND METHODS

*Physical Characteristics of Linear Polyethylene.** It must be made clear at the outset, that linear polyethylene is a complete and separate entity from conventional polyethylene; wide differences in physical characteristics exist between the two types of poly-

* Linear polyethylene sutures used in this study were manufactured by Surgical Products Division, American Cyanamid Company.

ethylenes. These differences are incorporated into the material at the time of polymerization and are reflected by alterations in the molecular structure of the compounds [3,4].

Conventional polyethylene is polymerized with nonspecific organic catalysts at high temperature and pressure, whereas linear polyethylene is formed with specific metal-organic catalysts at low temperature and pressure. The linear polyethylene molecule shows a high degree of orientation with respect to side branches on the main carbon chain. That is, the length, number and stereospecificity of the side chains and the length of the main carbon atom backbone are predetermined so that the end product will exhibit prescribed physical properties. This is not true of conventional polyethylene. Here nonspecific and random distribution of side chains of varying lengths are distributed on the main carbon chains of differing lengths. This results in a polymer which exhibits physical characteristics which may vary from one lot of material to another.

By extrusion of linear polyethylene at temperatures below its melting point, specific molecular chains are oriented parallel to the filament axis. The lineation of the molecular components, all of which are the same, increases the strength of the polymer by a factor of from six to eight times that of conventional polyethylene treated in the same manner [5,6]. The addition of crystalline regions in the linear polyethylene molecule further enhances the strength of the material during the orientation process.

This highly sophisticated type of polymer affords a broad pattern of finished end products each of which possesses specific characteristics. The linear polyethylene filament is strong, flexible, inert and has great stability. A com-

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TABLE I
COMPARISON OF THE PHYSICAL PROPERTIES OF LINEAR POLYETHYLENE, CONVENTIONAL
POLYETHYLENE AND NYLON

Property	Conventional Polyethylene	Linear Polyethylene	Nylon
Specific gravity.....	0.92	0.95-0.96	1.14
Melting range (°C.).....	107-210	130-138	212-252
Molecular weight.....	19,000-25,000	60,000-130,000	47,000-361,000
Tenacity (gm./denier).....	1.0-2.3	5.5-8.0	4.5-6.0
Stiffness modulus (lb./sq. in.).....	25,000-65,000	83,000-150,000	400,000-650,000
Tensile strength (lb./sq. in.).....	15,000-23,000	80,000-90,000	80,000-105,000

parison of the physical properties among linear polyethylene, conventional polyethylene and nylon are given in Table I.

Animal selection: Determination of short term tissue effects were carried out in the white New Zealand rabbit. In these studies eighteen rabbits were used. All were female and weighed 4.5 to 5 pounds at the time of suture implantation.

Long-term studies were carried out in the Swiss albino mouse. In these studies eighty-five mice were used; all were female and weighed 25 to 30 gm. at the time of suture embedment.

All animals were maintained on the usual laboratory diet.

Acute studies: Rabbits were anesthetized with pentobarbital sodium, 30 mg./kg.; abdomens shaved and prepared for aseptic embedment of several strands of linear polyethylene, one strand of monofilament nylon and two strands of serum-proofed surgical silk.

All sutures were placed into the ventral abdominal wall at right angles to the main body axis. The sutures were about 8 cm. in length and were placed 3 cm. apart. The animals were maintained for periods of three to forty days. At scheduled intervals, the animals were sacrificed, the suture embedded tissue visualized and removed en bloc and prepared for histopathologic examination.

Chronic studies: One strand of linear polyethylene, approximately 3 cm. in length, was placed into the ventral abdominal wall of the mouse. Conventional surgical silk was placed in a similar manner and served as the control. The animals were sacrificed at intervals from one month to one year. The embedded tissues were resected and prepared for histopathologic examination.

Histopathology: All tissues were fixed in Bouin's fixative for twenty-four hours and the usual dehydration and clearing methods were employed. Several slides of each bloc were made of which half were stained with hematoxylin and eosin; the other half were stained with Mallory's connective tissue stain.

No attempt was made to assign specific grade numbers to variations in tissue reactivity [7]. Direct comparisons were made between linear polyethylene and control sutures. Comparisons were based on the following criteria: exudate and edema, leukocytes (polymorphonuclear), lymphocytes and macrophages, foreign body giant cells, fibroblast invasion and fibrosis, organization (invasion of the suture, *per se*, by fibroblasts, foreign body giant cells, neovascularity),* vascular reaction (proliferation of new vessels in the perisuture tissues).

Microscopic examination was carried out at 50, 100 and 440 times. Comparative values were made on the basis of assigning (+) values to cellular appearance, degree of cellular proliferation and the relative density of each tissue type. Table II shows details of the evaluation of each criterion.

All suture materials used in these studies were size 2-0. They were sterilized with ethylene oxide gas and stored in individual packages.

RESULTS

The reactions of tissues to linear polyethylene embedded from three to forty days are summarized in Table III. Slight differences in cellular reactions were observed when linear polyethylene sutures are compared with nylon

* Organization is limited to those sutures which have interstices, i.e., braided silk. Linear polyethylene and nylon are solid monofilament materials.

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TABLE II
HISTOPATHOLOGIC EVALUATION OF TISSUE REACTIONS TO EMBEDDED SUTURE MATERIAL

Criterion	Magnification (X)	±	1 Plus	2 Plus	3 Plus	4 Plus
Edema and serous exudate	100	Some edema of perisuture tissues (slight)	Moderate edema, some exudate in the perisuture space	Marked edema, marked exudate in perisuture space	...	...
Polymorphonuclear (PMN)	440	Few PMN (trace)	Some PMN (slight)	Moderate leukocytosis	Marked leukocytosis (abscess)	...
Phage, lymphs and macrophage	440	Few lymphs and macrophage (trace)	Some lymphs and macrophage (slight)	Moderate lymphocytosis; moderate macrophage invasion	Marked lymphocytosis; marked macrophage invasion	...
Foreign body giant cell (FBGC) (multinuclear cells)	400	None, 1 FBGC (slight)	1-2 FBGC (moderate)	More than 2 FBGC (marked)	...	...
Fibroblasts	400	Few (trace)	Some fibroblast invasion (slight)	Moderate fibroblast invasion; suture surrounded	Marked fibroplasia extension of fibroblasts beyond 1 X radius of suture	...
Fibrotic capsule (collagen scar)	100	Very thin capsule; 1-2 cells thick; pro- or sclerocollagen	Thin capsule, 3-4 cells thick either procollagen or sclerocollagen (slight)	Moderately heavy capsule less than one-half radius of suture; sclerocollagen usually	Markedly thick fibrous capsule greater than one-half suture radius; mixed pro- and sclerocollagen	...
Intrasuture organization	100	...	Occasional fibroblast in suture matrix, no sclerocollagen formation	Moderate intrasuture fibroplasia, some sclerocollagen	Marked intrasuture fibrosis, sclerocollagen blood vessels; suture fairly well integrated with surrounding tissues	Complete organization; all suture fibrils individually surrounded by sclerocollagen, no active fibroplasia; reduction of blood vessels within suture
Vascular reaction	400	Occasional capillary in perisuture tissues (slight)	Moderate vascularity around suture; invasion of suture boundary	Marked vascularity	...	...

material. The variations between linear polyethylene and regular braided silk are more apparent. The acute inflammatory reaction with linear polyethylene does not extend much beyond three days. Some serous exudate and small numbers of leukocytes were observed at three days. Braided surgical silk causes slight to moderate exudate and leukocytic infiltration from three to ten days. A slight difference in fibroblastic and fibrotic response was also observed at ten and twenty days. Surgical silk shows a more dense proliferation of fibrotic elements at these intervals than does linear polyethylene. The zones of fibrotic activity appear larger and fibroblastic elements are more numerous. The suture appears somewhat enlarged. At this stage, this is probably due to separation of the suture fibrils by water absorption. An occasional foreign body giant cell was observed in the perisuture fibrotic capsule or within the interstices of the suture at forty days.

The reactions to linear polyethylene sutures embedded in tissues for one to twelve months are summarized in Table IV. The variations in tissue reactivity between the two types of suture material are apparent. The linear polyethylene sutures are encapsulated by a moderately thin, dense ring of fibrous elements and collagen. No foreign body giant cells are observed and proliferation of new blood vessels is not apparent. Surgical silk, on the other hand, becomes exceedingly well organized, both around and within the suture. It is observed that by the end of six months, each fibril was embedded within a lake of collagen and fibrous material.

Suture organization begins at about thirty to forty days as ingrowing cords of fibroblasts, isolated indwelling foreign body giant cells and small invasive new blood vessel elements. These tissues appeared to originate from the inside margin of the fibrotic capsule, a finding which, to our knowledge, has not previously been

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TABLE III

HISTOPATHOLOGIC EXAMINATION OF TISSUE REACTIONS TO EMBEDDED LINEAR POLYETHYLENE, NYLON AND SILK SIZE 2-0

No. of Days Embedment	Exudate and Edema	Polymorpho- nuclear	Phage		Fibro- blasts	Fibrotic Capsule	Foreign Body Giant Cell	Intra- suture Organiza- tion	Vascular Reaction
			Lymph	Macro					
Linear Polyethylene									
3	±	±	+	-	-	-	-	...	-
7	-	-	+	+	+	±	-	...	-
10	-	-	+	-	+	+	-	...	-
20	-	-	+	-	+	+	-	...	-
30	-	-	-	+	±	+	-	...	-
40	-	-	-	+	±	+	-	...	-
Nylon									
3	±	+	+	+	+	-	-	...	-
7	-	-	+	+	+	++	-	...	-
10	-	-	+	-	+	+	-	...	-
20	-	-	+	+	+	+	-	...	-
30	-	-	+	+	+	+	-	...	-
40	-	-	-	+	±	+	-	...	-
Braided Silk									
3	±	+	++	+	-	-	-	-	-
7	±	±	++	-	+	±	-	-	-
10	+	++	++	+	++	++	-	-	-
20	-	-	-	+	++	++	-	-	±
30	-	-	-	-	+	+	-	-	+
40	-	-	-	-	+	+	+	++	+

reported. Suture organization became progressively more complete until each suture fibril is encompassed by collagen and fibrocytes. Vascularity developed within and around the suture concurrent with fibrotic organization and is observed throughout the twelve month period. The thickness and density of the fibrotic capsule around linear polyethylene and surgical silk sutures does not appear to be markedly different although linear polyethylene showed a somewhat thinner capsule up to forty days. Inflammatory cells were absent after the first month with both suture types.

The photomicrographs show the progressive tissue responses to embedded linear polyethylene and silk. (Figs. 1-6.) In Figure 6A, the suture was removed just prior to sectioning in order to retain the fibrous envelope. It can be seen that with the linear polyethylene embedded sutures, the inflammatory responses

are negligible and fibrotic encapsulation is reduced from that which is observed with silk. The differences in tissue response to embedded linear polyethylene and surgical silk are obvious.

COMMENTS

An examination of the histopathologic data for time intervals up to forty days reveals a pattern of cellular response to embedded surgical silk and linear polyethylene which is strikingly similar to earlier reports [1]. Small variations between these two sets of data are most probably due to variations in suture diameter. Phelan used linear polyethylene and silk size 5-0, whereas the data reported herein are established on size 2-0.

Pattern of Reaction to Surgical Silk (the "Norm" Reaction). Tissue responses to embedded silk observed through seven days are,

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TABLE IV
HISTOPATHOLOGIC EXAMINATION OF TISSUE REACTIONS TO EMBEDDED LINEAR POLYETHYLENE
AND BRAIDED SURGICAL SILK SIZE 2-0

No. of Mo. of Embedment	Exudate and Edema	Polymorpho- nuclear	Phage		Fibro- blasts	Fibrotic Capsule	Foreign Body Giant Cell	Intra- suture Organiza- tion	Vascular Reaction
			Lymph	Macro					
Linear Polyethylene									
1	—	—	—	±	+	+	—	...	—
3	—	—	—	+	+	++	—	...	—
6	—	—	—	—	±	+	—	...	—
9	—	—	—	—	±	+	—	...	—
12	—	—	—	—	±	+	—	...	—
Braided Silk									
1	—	—	—	—	++	++	+	++	±
3	—	—	—	—	+	++	+	+++	+
6	—	—	—	—	±	+	+	++++	+
9	—	—	—	—	++	+	+	++++	—
12	—	—	—	—	+	+	+	++++	+

in the main, those produced by the *nonfixed* tissues (fluid tissues). Exudate containing predominantly leukocytes, lymphocytes, some macrophages (wandering cells), tissue debris and red cells are observed in this time interval. Exudative reactions of nonfixed tissues are accompanied by edema of the tissue and vascular dilatation. These early changes are very similar, although much less extensive, to the characteristic responses to injury [8-11].

Starting at about seven to ten days, *fixed* tissue responses (nonfluid tissues) become manifest, while exudative reactions are greatly reduced. At this time, the first moderate proliferations of fibroblasts are observed. Later, fibroplasia becomes more pronounced as fibroblasts deposit a collagen capsule around the suture. The numbers of acute exudative inflammatory cells becomes much reduced. In the typical response, edema and exudate are absent after twenty days.

Foreign body giant cells are observed at about forty days and persist for long periods of time in the perisuture capsule and in the organized granulation tissue within the suture. The appearance and degree of foreign body giant cell proliferation observed in this study coincides with earlier reports [12].

The formation of granulation tissue con-

tinues and becomes intimately associated with the suture. Invasion and penetration of the suture is apparent from one to two months onward.

Between three and six months the numbers of fibroblasts becomes greatly reduced and other cellular proliferations cease. After six months active tissue responses to embedded silk halt, although even at one year some fibroblasts are observed within the suture or in the suture capsule.

Pattern of Reaction to Linear Polyethylene. Within the first year after embedment, the pattern of reaction to linear polyethylene is similar to that observed with silk with regard to most of the cell types observed. The major difference in response is seen in the *degree* of reaction. With linear polyethylene, the amount of cells and new formed tissues are well reduced in comparison with surgical silk. Linear polyethylene, unlike silk, does not change shape or increase in volume. Further, the smooth contiguum tends to minimize cellular reactivity. This is an important point, especially in the early phases of healing. Compared with the surface of linear polyethylene, silk presents a roughened exterior which causes more cell trauma as it is being drawn through the tissues. Because of the small amount of cellular damage

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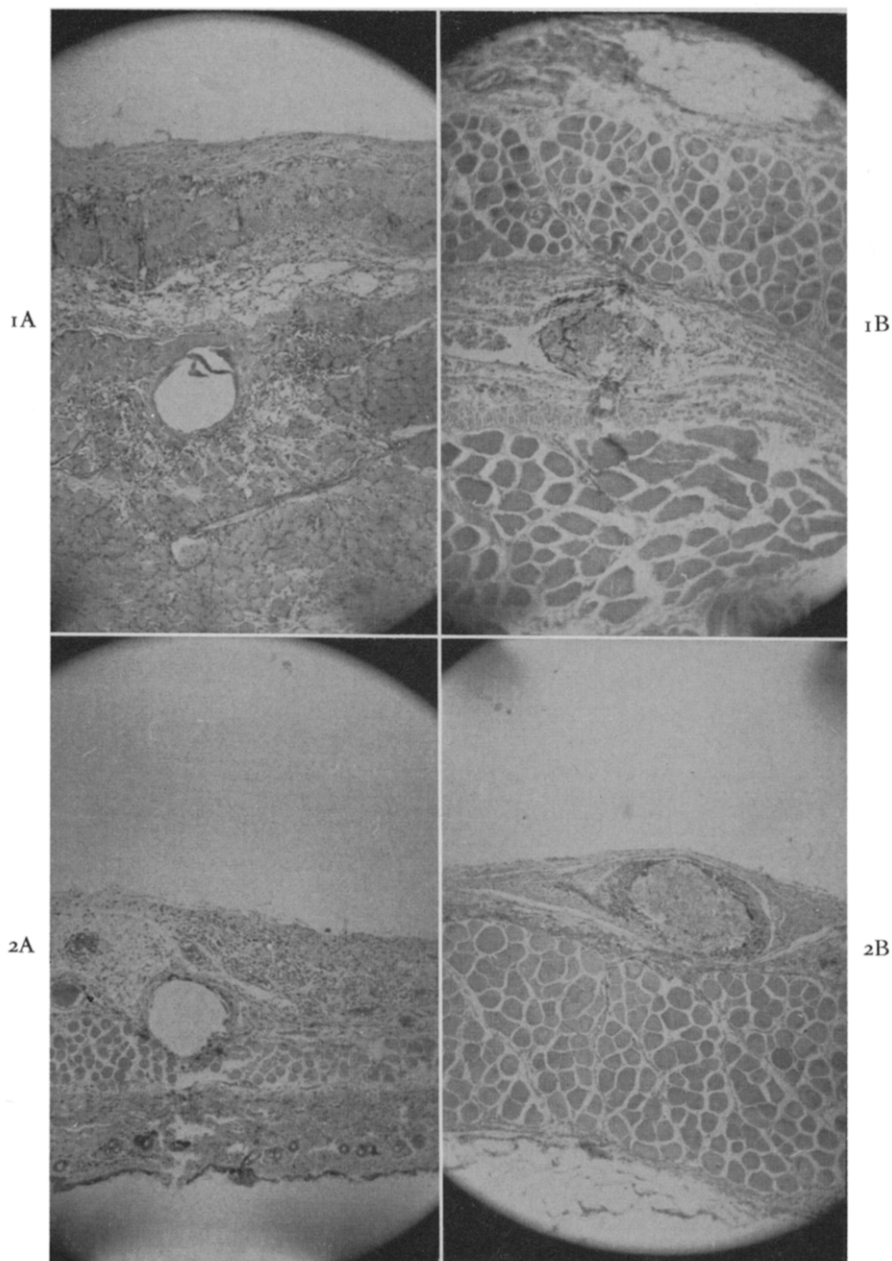


FIG. 1. Three day embedment in rabbits. A, linear polyethylene. Over-all acute inflammatory reaction is slight. Little exudate, few inflammatory cells and little tissue debris are present. B, surgical silk. Moderate exudate containing leukocytes and cellular debris is observed. Apparent edematous response is artifact. Hemotoxylin and eosin stain, 7μ , original magnification $\times 100$.

FIG. 2. Thirty day embedment in mouse. A, linear polyethylene. A thin fibrotic capsule is observed. Moderate numbers of fibroblasts are invading the suture tract from the right and left. B, surgical silk. Acute inflammatory cells are absent. The suture is surrounded by a capsule of fibrocytes and fibroblasts. At this stage little collagen is present. No alteration of the shape of the suture or its volume is present. Hemotoxylin and eosin stain, 7μ , original magnification $\times 100$.

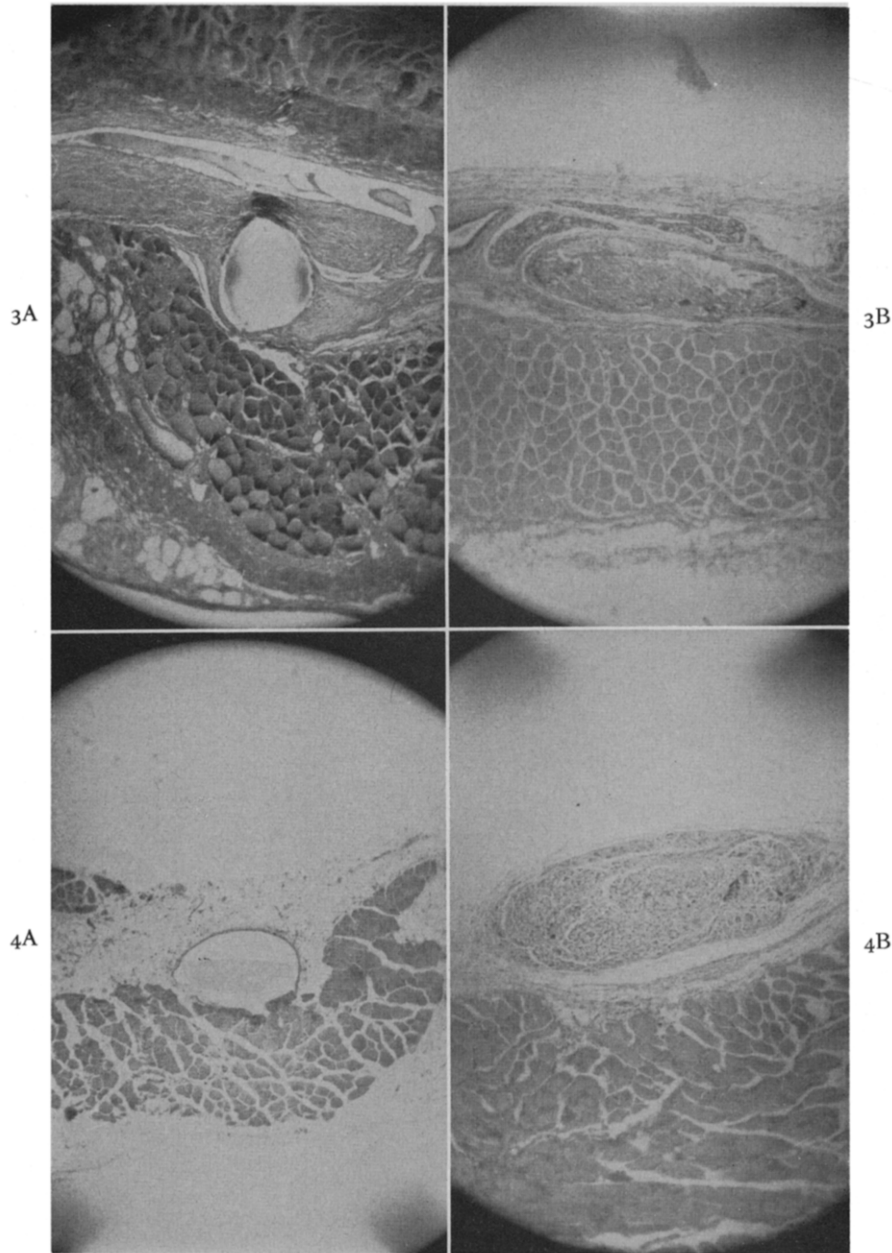


FIG. 3. Three month embedment in mouse. A, linear polyethylene. Deposits of collagen are seen surrounding the suture. No vascular reaction is observed and the numbers of fibroblasts are reduced. B, surgical silk. Cellular elements consist of fibrocytes and moderate numbers of fibroblasts. Invasion by organization tissue has begun. An occasional foreign body giant cell is observed as the small darkly stained areas at the right and lower center of the suture. A thin collagen capsule is present. The suture is moderately flattened and elongated. It is about twice its original diameter. Compare the size with Figures 1B and 2B. Hematoxylin and eosin stain, 7μ , original magnification $\times 100$.

FIG. 4. Six month embedment in the mouse. A, linear polyethylene. A thin, dense collagen capsule is present. No fibroblasts are observed. B, surgical silk. The suture is completely organized. Moderate numbers of foreign body giant cells are observed within the suture. The numbers of fibroblasts are reduced. The suture has increased in volume by about four times that observed at three and thirty days. Hematoxylin and eosin stain, 7μ , original magnification $\times 100$.

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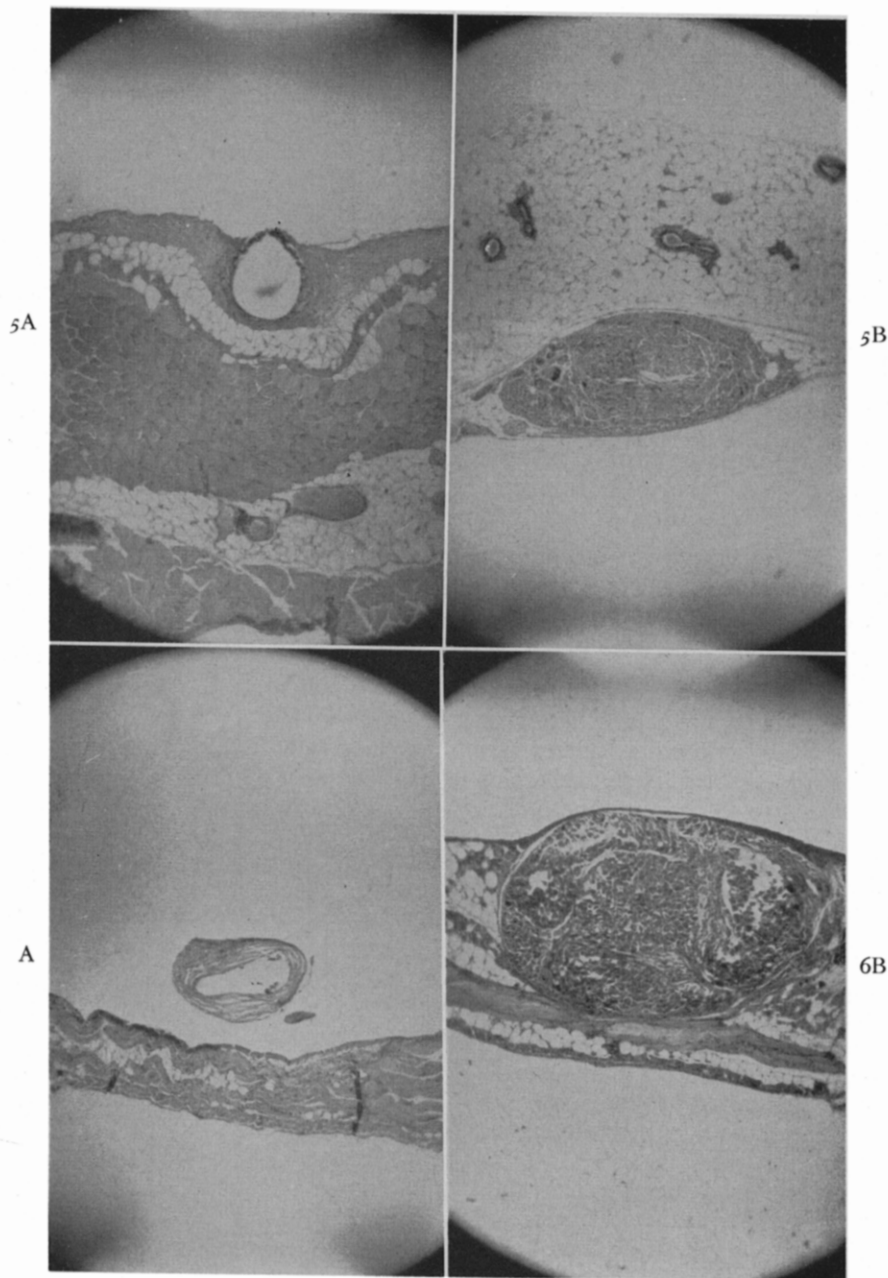


FIG. 5. Nine month embedment in the mouse. A, linear polyethylene. Some fibroblasts are present in the upper one third of the suture tract. B, surgical silk. No apparent alterations are observed when compared with Figure 4B. Hematoxylin and eosin stain, 7μ , original magnification. $\times 100$.

FIG. 6. Twelve month embedment in the mouse. A, linear polyethylene. Concentric rings of dense collagen are observed. The suture was removed prior to sectioning in order to preserve the suture tract. This accounts for the flattened appearance of the tract. B, surgical silk. Cords of fibrous tissue are observed invading the inner core of the suture. The suture volume has increased about six times over that seen in Figures 1B and 2B. Hematoxylin and eosin stain, 7μ , original magnification $\times 100$.

occurring with linear polyethylene, the exudative inflammatory response is reduced. This is demonstrated by the degree of leukocytosis, tissue debris and exudate in Figure 1A with Figure 1B. Figure 1A shows slight exudate and little cell damage whereas Figure 1B shows 2-plus exudate with moderate numbers of leukocytes and moderate amounts of cellular debris.

In the later phases of healing, linear polyethylene embedment causes limited cellular activity because its shape and volume are not altered. A simple, thin, dense encapsulation by fibrous tissue completes the reaction to embedded linear polyethylene.

It is believed that a single, solid strand of silk would show the same pattern of reaction as does linear polyethylene. The increased tissue reaction to silk is caused by the morphology of the silk not by its chemistry. Because of the nature of the multistrand braid, the tissue reaction is magnified by the reaction around each of the fibrils; first by the reaction around the fibrils making up the outer coat of the suture and later by the reaction around the individual fibrils of the entire strand. In effect, the suture presents an environment of a tightly wound cable of many sutures each of which contributes to the over-all tissue response. The integrity of the braid is attacked first by the invasion of water at three to seven days, and then by the invasion of fibroblasts from seven days onward. An examination of the figures shows these progressive changes.

The reduced tissue responses to small size silk sutures as compared with responses to large sizes, is well known [13]. This follows expectation since small sizes cause an over-all effect of less tissue damage as the suture is drawn through the tissue and less water swell after the embedment.

Linear polyethylene as a suture material thus produces minimal cellular trauma. Absence of alteration of suture shape or volume contributes largely to this effect. These factors coupled with the physical qualities of great tensile strength and pliability indicate linear polyethylene to have many of the properties of a superior suture material.

SUMMARY AND CONCLUSIONS

Histopathologic data are presented. Tissue reactions are examined at time intervals from three days to twelve months and evaluation of the tissue reactivity to linear polyethylene is made on the basis of a comparison with the norm reaction established with surgical silk. A discussion of tissue and cellular alterations as a result of suture embedment is presented. The role of suture size and texture is discussed.

The data presented in this report leads to the following conclusions:

The norm reactive pattern established with surgical silk indicates responses similar to those observed in normal wound healing.

Linear polyethylene sutures embedded in animals for twelve months show tissue reactive patterns which are much less extensive than those observed with surgical silk.

Linear polyethylene provides superior characteristics as a surgical suture material.

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