A Comparison of the Effect of pH on the Biodegradation of Two Synthetic Absorbable Sutures

C. C. CHU, PH.D.

From the Department of Design and Environmental Analysis, Martha Van Rensselaer Hall, Cornell University, Ithaca, New York

The differences in hydrolytic degradation of two size 2-0 synthetic absorbable sutures, Polyglycolic acid (Dexon®) and Poly(glycolide-lactide) (Vicryl®), in the buffer media of three different pH levels ranging from 5.25 to 10.09, were compared in terms of the percentage retention of tensile strength. It was found that Vicryl sutures, in general, exhibited better retention of tensile strength than Dexon sutures within the studied pH range and extent of hydrolysis. When comparing Vicryl with Dexon sutures, the former was only slightly better than Dexon sutures, in the case of an acid environment. The former, however, retained better strength than the latter in a physiological pH (7.44) and under high-alkaline conditions (10.09). Among the three pH levels tested, Vicryl sutures retained the highest tensile strength in a physiological pH and showed a faster loss of tensile strength in both acidic and high-alkaline conditions. Dexon sutures, however, exhibited better retention of tensile strength in the acidic medium than in an alkaline medium. This pH dependent hydrolysis of Dexon and Vicryl sutures should command surgeons' attention in their selection of synthetic absorbable suture materials for particular needs.

THE DEVELOPMENT OF TWO biodegradable synthetic polymers, polyglycolic acid (PGA) and its lactide copolymer, has provided surgeons with the suture materials which elicit minimal tissue reactions, retain better strength than catgut under certain physiologic and pathologic conditions, and perform more consistently due to precise and reproducible manufacturing processes.[1-4]

The presence of aliphatic ester bonds in these suture materials renders them hydrolytically unstable; they degrade by hydrolysis from body fluids. As a result, the tensile strength of the suture materials decreases with an increase in the duration of immersion in a saline solution. Extensive research has been done in the past to evaluate how these suture materials degrade in a physiologic saline solution of pH = 7.4.[1-7] Experimental evidence shows that primary biodegradation of PGA sutures occurs independent of cellular activity; the only requirement for suture degradation is an aqueous environment.[5] Recent data, however, have shown that certain enzymes (such as esterase and carboxypeptidase) are able to influence the rate of hydrolysis in PGA.[8]

If the degradation mechanism of these suture materials is of a hydrolytic nature, then the questions to be addressed when considering polymer hydrolysis are as follows: 1) is the degradation reaction affected by the pH of the medium in the same way it is affected in the simple organic esters? 2) How does the tensile strength of the suture materials change with a difference in the pH of the immersion medium? Furthermore, it is important to understand the pH dependent degradation of these suture materials because surgical suture materials should be able to retain adequate strength under all possible physiologic and pathologic conditions. It is known that the pH of gastric juice in the stomach can reach as low as 0.9–1.5, while pancreatic juice in the duodenum ranges from 7.5 to 8.2.[9-10] The urinary pH often ranges from 4.5 to 8.0.[11] In the latter case, although the reported data are in conflict, absorbable sutures should be used. Nonabsorbable sutures cannot be used in the urinary tract because their presence incites the formation of urinary calculi.[12] This peculiar requirement in urologic surgery further indicates the importance of studying the pH dependent degradation of synthetic absorbable sutures.

This paper thus reports the comparison of the effect of various levels of pH on the hydrolytic degradation of polyglycolic acid and poly(glycolide-lactide) suture materials. A better understanding of the hydrolytic degradation under various pathologic and physiologic conditions for these particular suture materials must be achieved in order to facilitate future improvement of the suture materials.

Supported in part by The J.M. Foundation Grant in New York City, New York.

Reprint requests: C. C. Chu, Ph.D., Department of Design and Environmental Analysis, Martha Van Rensselaer Hall, Cornell University, Ithaca, NY 14853.

Submitted for publication: June 11, 1981.

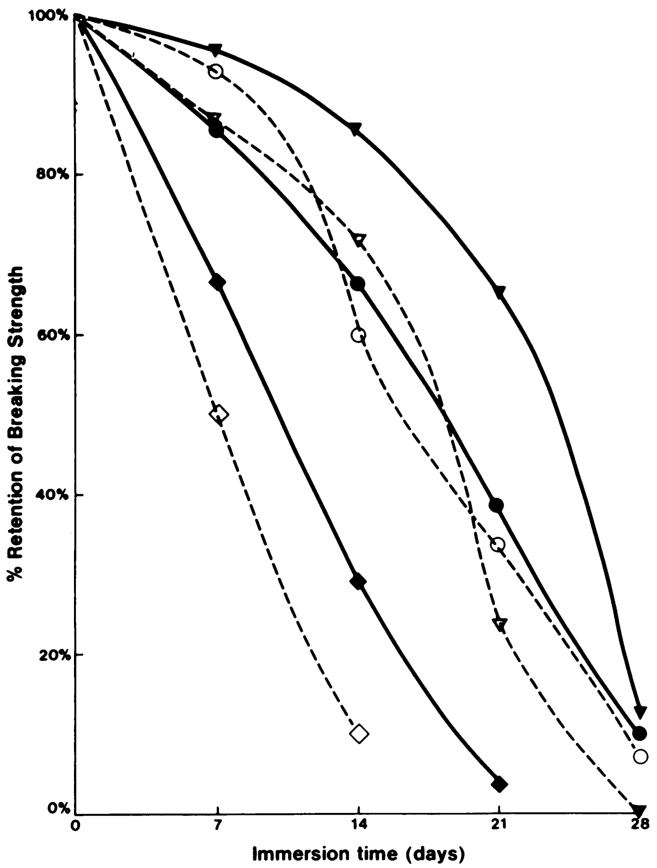

FIG. 1. The percentage retention of breaking strength of 2-0 Polyglycolic acid (Open symbol) and Poly(glycolide-lactide) (Solid symbol) absorbable sutures at various extents of immersion in buffer media of three different pH levels. ○—pH 5.25; ▽—pH 7.44; ◇—pH 10.09.

Materials and Methods

Size 2-0 Dexon® (Polyglycolic acid) and Vicryl® (Polyglycolide-lactide) were used. Three buffer solutions were made: 1) HAc/NaAc, 2) KH_2PO_4/K_2HPO_4, and 3) $NaHCO_3/Na_2CO_3$. The corresponding pH levels of the buffers were 5.25, 7.44, and 10.09. Due to the reported influences of bacteria on the degradation of these sutures,[13] three types of antibiotics were added to the buffers before immersion. These were, respectively, bacitracin, polymixin B, and cycloheximide, at concentrations of 7.5 IU, 1.8 IU, and 0.03 mg per ml. This composition of drugs covers microorganisms of Gram positive, Gram negative, and fungi. All buffers and glassware were autoclaved before immersion. Nine strands of suture, each 17 inches long, were immersed in 75 ml of each of the above-prepared buffer solutions. The solutions were sealed septically in flasks and placed in a hot-air circulating oven at 37 C ± 1 C for periods of 7, 14, 21, 28, 40, 60, 90 and 120 days.

Tensile properties of the immersed sutures were measured on a table model Instron immediately after they had been removed from the buffer solutions and washed in distilled water five times. The Instron pneumatic cord and yarn grip system Type 4D was used instead of the conventional grip. Detailed information about the cord and yarn grip and its influence on the stress–strain curves of several common sutures has been given very recently.[14] Testing was performed in a constant temperature (21 C ± 1 C) and humidity (65 ± 2%) room. The gauge length was eight inches, and the cross-head speed was one inch per minute. A total of five tests for each specimen was done. Both Q test and student's t-test (at 95% confidence level) were conducted for statistical purpose.

Results

Figure 1 summarizes the percentage of retention of original tensile strength of these two absorbable sutures as a function of the extent of immersion at various pH levels. The distinct difference in degradation behavior due to different pH levels becomes evident. In both suture materials, they degraded significantly faster in a highly alkaline buffer solution than in an acidic or physiological buffer.

In Dexon sutures there was, however, no significant differences in degradation behavior between physiologic (pH = 7.44) and acidic (pH = 5.25) buffers, particularly before 21 days of immersion. At day seven, the Dexon sutures at pH = 10.09 buffer lost almost half of their original tensile strength, while the corresponding sutures at pH = 5.25 and 7.44 buffers still retained more than 85% of their original tensile strength. As the duration of immersion decreased to 21 days, sutures at pH = 10.09 had no measurable strength, while those specimens at physiologic and acidic buffers still retained more than 20% of their original strength. The sutures at pH = 7.44 lost their strength slightly faster than the specimens at pH = 5.25 after 21-day immersion. Both exhibited no measurable strength at the 40-day immersion. The sigmodial curve in Dexon sutures exhibited three distinct regions: a concave initial section, an accelerated portion and a tail region. There was a small decrease in strength before 14 days, then an acceleration between 14 and 21 days. Most of the strength was lost during this period of degradation. For example, almost 40% of the original strength was lost during this period of immersion in both buffers. No sigmodial curve, however, could be detected in the pH level of 10.09. Instead, a rapid, continuous, and nearly linear loss of strength was found during the 14 days of immersion. There was only 10% strength left after 14 days, which was significantly lower than that of the specimens at lower pH levels.

In Vicryl, the suture specimens exhibited the best retention of breaking strength at pH = 7.44 while the specimens at pH = 10.09 showed the fastest loss of tensile strength. The specimens from pH = 5.25 fell between these two pH levels. For example, on day seven, more than 95% tensile strength was retained at pH = 7.44, about 85% at pH = 5.25, and 66% at pH = 10.09. On day 28, suture specimens at pH = 10.09 had unmeasurably small strength while those at pH = 5.25 and pH = 7.44 still retained about 10% of their original tensile strength. This difference in the retention of tensile strength due to pH became greater with an increase in the duration of immersion in the buffer medium. In other words, the percentage retention of tensile strength decreased the slowest at pH = 7.44 and the fastest at pH = 10.09 relative to the extent of immersion. As the duration of immersion increased from the seven to 14 days, changes in the percentage retention of tensile strength were highest (66% − 29% = 37%) at pH = 10.09, 19% at pH = 5.25, and lowest (10%) at pH = 7.44. On day 21, the sutures at pH = 7.44 still retained more than half their original tensile strength (65%), whereas the same sutures at pH = 10.09 lost almost all their tensile strength (4%). Thus, the suture specimens retained 61% more in tensile strength at pH 7.44 than at pH = 10.09. The sutures at pH = 5.25 had 37% tensile strength remaining.

The pH dependence of the hydrolytic degradation of Dexon and Vicryl sutures are further examined in Figure 2 in which the percentage retention of tensile strength was plotted against the pH levels at different periods of immersion. This plot not only illustrates the pH dependence of the hydrolytic degradation of these synthetic absorbable sutures but also shows how this pH dependence changes with the duration of immersion.

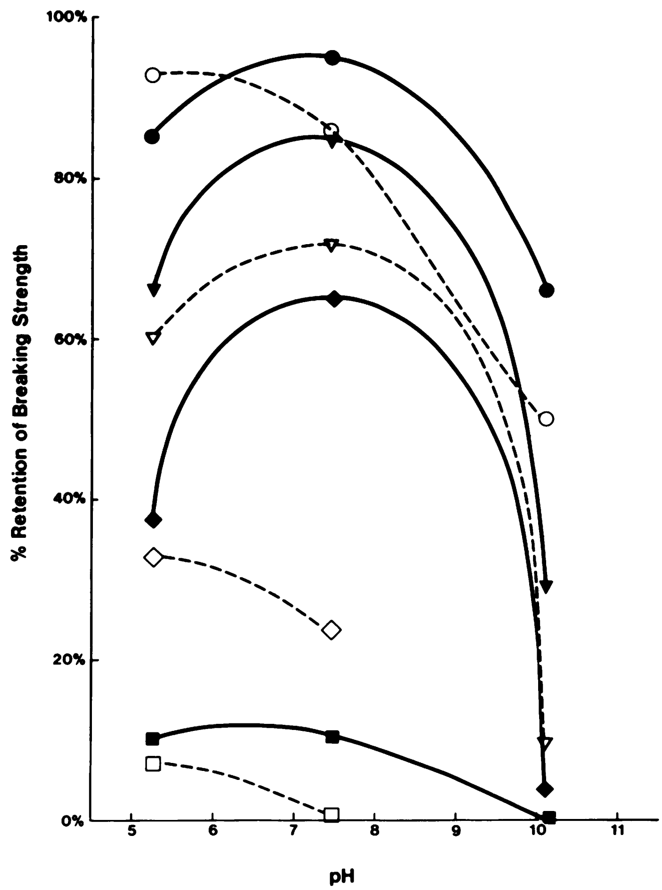

FIG. 2. The percentage retention of breaking strength of 2-0 Polyglycolic acid (Open symbol) and Poly(glycolide-lactide) (Solid symbol) absorbable sutures at various pH levels. ○—Day 7; ▽-Day 14; ◇—Day 21; □—Day 28.

In Vicryl sutures, all the curves have one common character—a convex shape. The maximum retention of tensile strength occurred around the pH level of 7.0, whereas smaller percentages of retention of tensile strength were observed at both acidic and strong alkaline solutions. The shape of the convex curves depended on the duration of immersion. The curves became sharper as the duration of immersion increased from seven days to 21 days, and then became broad at 28 days.

In Dexon sutures, a continuous decrease in the percentage retention of tensile strength was observed with an increase in the pH level from 5.25 to 10.09 at day seven. Therefore, Dexon sutures retained the highest amount of tensile strength at a pH level of 5.25 at day 7. The data indicate a change, however, at day 14 when sutures from the physiologic pH (7.44) exhibited better retention of tensile strength than Dexon sutures from the acidic and high alkaline buffers. Thus, a similar convex curve shape as for Vicryl sutures is found in Dexon sutures at day 14. As degradation proceeded to day 21, no measurable strength could be detected at the pH level of 10.09 and Dexon sutures retained better strength in acidic conditions than in slight and strong alkaline conditions. This tendency was also observed at day 28.

From Figure 2, Vicryl sutures, in general, exhibited better retention of tensile strength than Dexon sutures at all three pH levels and immersion times, except at pH = 5.25 on day 7. The magnitude of the difference in the retention of tensile strength between Vicryl and Dexon sutures depended on the pH level and the extent of immersion. The differences were the smallest at the acidic pH level (5.25) and were the largest at the physiologic pH level (7.44). In the latter case (pH = 7.44), the difference increased with the extent of immersion and reached a maximum at day 21, decreasing thereafter. For example, the difference increased from 9.5% (95% − 86%) at day seven, to 13% (85% − 72%) at day 14, and 42% (65% − 23%) at day 21, then decreased to 10% at day 28. Similar observations were found in the pH level of 10.09.

The pH effect on the tensile properties of these two synthetic absorbable sutures can also be examined by

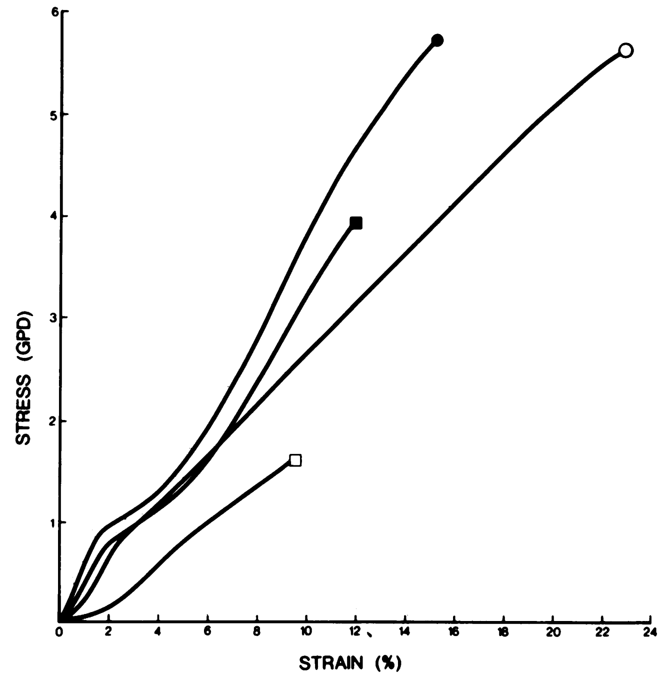

FIG. 3. Stress-strain curves of 2-0 Polyglycolic Acid (Open symbol) and Poly(glycolide-lactide) (Solid symbol) absorbable sutures at the pH level of 7.44. O—Day 7; □—Day 21.

comparing the stress-strain curves of the corresponding suture specimens. This comparison could provide additional important basic mechanical data for the investigation of the pH influence on the degradation of these suture materials. Figures 3 and 4 show this pH effect on the stress-strain curves of the suture specimens at various durations of immersion.

Figure 3 shows the stress-strain curves of both Dexon and Vicryl sutures after seven and 21 days of immersion at the pH level of 7.44. At day seven, Dexon sutures extended 8% more than Vicryl sutures and were more compliable (less stiff) than the latter even though the two sutures exhibited very similar tensile strength. At day 21, Vicryl sutures were much stiffer and stronger than Dexon sutures. The typical sigmodial shape of the stress-strain curve of Vicryl sutures still retained, whereas the one from Dexon sutures was barely visible. In both periods of immersion, Dexon sutures were easier to be stretched than Vicryl sutures in the physiologic pH. Similar observations have been found in the pH level of 10.09 as shown in Figure 4. Vicryl sutures were more resistant to extension than Dexon sutures and generally broke at a shorter elongation than the latter.

Discussion

The results obtained in this study have indicated that both Dexon and Vicryl sutures exhibit quite different hydrolytic degradation at various pH levels and immersion times. They degrade significantly faster in a high-alkaline buffer than in acidic and physiologic buffers. Vicryl suture specimens at the physiologic pH, however, retained the largest amount of tensile strength of the three buffers studied. Dexon suture specimens retained the best strength at the acidic condition. Vicryl sutures, in general, showed better hydrolytic resistance than Dexon within the studied pH range. The observed bell-shaped, pH-influenced, strength retention profiles associated with all Vicryl sutures and some Dexon suture specimens apparently suggest that hydrolysis of these suture materials is catalyzed by either hydrogen or hydroxy ions, as are many simple monomeric organic esters.[15]

These observations, however, were quite different from Holm-Jensen's Dexon data[16] in which the hydrolysis of Dexon sutures was reported to be insignificantly affected within the pH range of 2–11. The reasons are not clear for the lack of agreement between these findings and those of Holm-Jensen.

The need for having stress-strain data of these suture materials for the comparison of their degradation rates is illustrated by the stress-strain data of Vicryl and Dexon sutures after seven days of immersion at the pH level of 7.44 (Fig. 3). The shapes of the stress-strain curves of these two sutures were quite different from each other despite their very close tensile strength. Therefore, the stress-strain curves are particularly useful for revealing a literal and overall discrimination of suture materials that are difficult to obtain by comparing tensile strength alone. This approach, previously suggested by Holmlund and the authors,[14,17] of examining the degradation of synthetic suture materials could provide a better ground to distinguish their different responses to hydrolysis.

The importance of recognizing the pH dependence of hydrolytic degradation of these two synthetic absorbable sutures is illustrated by the fact that absorbable sutures are considered better suture materials than nonabsorbable ones when they are used in the urinary tract.[12,18,19] Despite these findings, it has been suggested that Dexon sutures are unsuitable for use in urogenital surgery because of the risk of calculus formation and accelerated hydrolysis.[20] The accelerated hydrolysis of synthetic absorbable sutures is particularly noticeable in certain pathologic conditions. Milroy reported that the presence of infection within the bladder enhanced the dissolution of Dexon sutures.[18] This early dissolution was tentatively attributed to an increase in bladder pH level to as high as 8.39 as a result of a urea splitting microorganism (*e.g.*, Proteus) degrading the urine to ammonia. This speculation on the pH dependence of the hydrolysis of these synthetic absorbable sutures is further confirmed in the present study of the effect of pH on the degradation of synthetic absorbable sutures.

The reported pH dependent hydrolysis of Dexon and Vicryl sutures in this study deserves the attention of surgeons in their selection of these absorbable suture

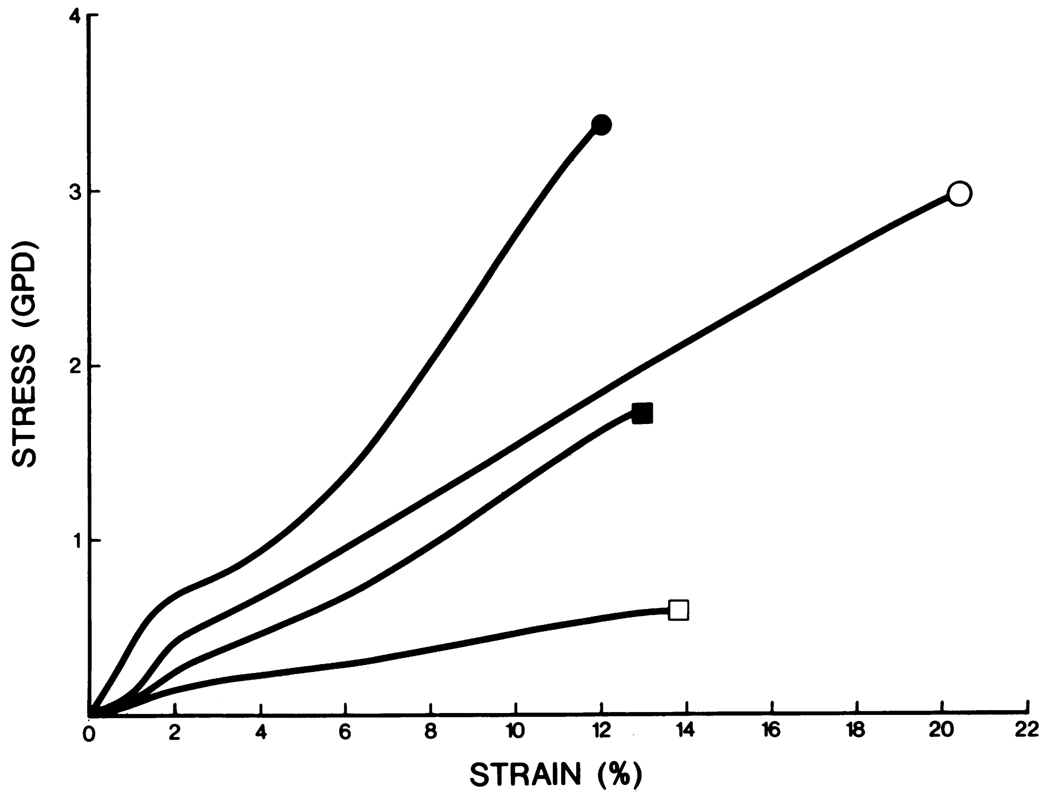

FIG. 4. Stress-strain curves of 2-0 Polyglycolic Acid (open symbol) and Poly-(glycolide-lactide) (Solid symbol) absorbable sutures at the pH level of 10.09. O—Day 7; □—Day 21.

materials for their particular needs. In the case of an acidic environment such as the stomach, there is very little difference in hydrolysis rate between Dexon and Vicryl sutures; the latter is only slightly better than the former. In the case of an alkaline environment, such as physiologic pH, or a Proteus-infected urinary track, Vicryl sutures appear to retain much better tensile strength than Dexon sutures, and hence are the better choice in that circumstance. This difference in strength retention should be considered along with the capability of the suture materials to elicit the formation of urinary calculi in the selection of proper suture materials for urologic surgery.

References

1. Craig PH, Williams JA, Davis KW, et al. A biologic comparison of polyglactin 910 and polyglycolic acid synthetic absorbable sutures. Surg Gynecol Obstet 1975; 141:1-10.
2. Katz AR, Turner RJ. Evaluation of tensile and absorption properties of polyglycolic acid sutures. Surg Gynecol Obstet 1970; 131:1-14.
3. Pavan A, Bosio M, Longo T. A comparative study of poly(glycolic acid) and catgut as suture materials: histomorphology and mechanical properties. J Biomed Mater Res 1979; 13:477.
4. Frazza EJ, Schmitt EE. A new absorbable suture. J Biomed Mater Res 1971; Symp. #1:43.
5. Salthouse TN, Matlaga BF. Polyglactin 910 suture absorption and the role of cellular enzymes. Surg Gynecol Obstet 1976; 142:544.
6. Herrmann J, Kelly J, Higgins GA. Polyglycolic acid sutures. Arch Surg 1970; 100:486.
7. Postlethwait RW. Polyglycolic acid surgical suture, Arch Surg 1970; 101:489-494.
8. Williams DF, Mort E. Enzyme accelerated hydrolysis of polyglycolic acid. J Bioeng 1977; 1:231.
9. Houssay BA. Human Physiology. New York. McGraw Hill, 1951; 318.
10. Cantarow A, Schepartz B. Biochemistry, 4th edition. Philadelphia. W. B. Saunders, 1967; 262.
11. Guyton AC. Textbook of Medical Physiology. Philadelphia. W. B. Saunders, 1976; 496.
12. Kaminski JM, Katz AR, Woodward SC. Urinary bladder calculus formation on sutures in rabbits, cats, and dogs. Surg Gynecol Obstet 1978; 146:353.
13. Williams DF. The effect of bacteria on absorbable sutures. J Biomed Mater Res 1980; 14:329.
14. Chu CC. Mechanical properties of suture materials: an important characterization. Ann Surg 1981; 193:365.
15. Maugh T, II, Bruice TC. The role of intramolecular bifunctional catalysis of ester hydrolysis in water. J Am Chem Soc 1971; 93(13):3237.
16. Holm-Jensen S, Agner E. Syntetisk absorberbart suturmateriale (PGA) sammenlignet med catgut. Ugeskrift Laeger, 1974; 136(32):1785.
17. Holmlund EW. Physical properties of surgical suture materials: stress-strain relationship, stress-relaxation, and irreversible elongation. Ann Surg 1976, 184:365.
18. Milroy E. An experimental study of the calcification and absorption of polyglycolic acid and catgut sutures with the urinary track. Invest Urol 1976; 14:141.
19. Branan W, Ochsner MG, Pond HS, et al. Laboratory and clinical experience with polyglycolic acid suture in urogenital surgery. J Urol 1973; 110:571.
20. Bergman FO, Borgstrom SJH, Homlund DEW. Synthetic absorbable surgical suture materials (PGA): an experimental study. Acta Chir Scand 1971; 137:193.