An In vitro *Evaluation of the Stability of Mechanical Properties of Surgical Suture Materials In Various pH Conditions*

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The effects of pH on the tensile properties of eight commonly used 2-0 suture materials—plain catgut, Dexon®, Vicryl®, silk, Nurolon®, Ethilon®, Mersilene®, and Prolene®—were examined. The pH level ranged from 3.0 to 10.0 In general, absorbable suture materials were more sensitive to pH than non-absorbable suture materials; within the same suture materials, a strong alkaline condition would have a more adverse effect on the strength of suture materials than physiologic and acidic pHs. Plain catgut sutures lost relatively significant amounts of strength at both acidic and alkaline conditions when compared with Dexon and Vicryl sutures; hence, precaution should be taken when they are used in closing tissues in contact with acidic environment like the stomach. Among the non-absorbable suture materials, silk and Nurolon exhibited the largest loss of strength in both alkaline and acidic environments after one month, while other sutures retained almost all of their original strength. Physical configuration of the suture materials seemed also to contribute to the sensitivity of suture materials toward pH. A comparison of Nurolon and Ethilon sutures demonstrated this point of view.

WOUND CLOSURE BIOMATERIALS, like sutures, concern every surgeon. Virtually every operation requires the use of materials to close the wound for subsequent successful healing. Many complications, such as infection, wound dehiscence, and sinus formation, occur in the wound closure line. The complexities involved in wound healing, such as the involvement of more than one type of tissue in the wound, the various degrees of wound strength during the process of healing, the exposure of the materials to body fluids, and the variety of surgical wounds each with its own healing problems, call for different types of wound closure materials.

Since the function of a suture is to hold several tissues in apposition until the healing process has resulted in the wound with sufficient strength to withstand stress, it is important to know how the different chemical components of the body fluid, particularly the pH level, can affect the retention of strength of suture materials. It is known that the pH of gastric juice in the stomach can go as low as 0.9 to 1.5, while pancreatic juice in the duodenum ranges from 7.5 to 8.2.[1] Urinary pH often ranges from 4.5 to 8.0.[2] Under certain pathologic conditions, the pH of body fluids could change also. For example, Proteus, a urea splitting bacterium, elevates the pH of the urine by dissociating urea to ammonia.[3] Furthermore, it is asserted that the suture implantation site, which is always accompanied by inflammation, is generally on the acidic side of the pH scale.[4] Thus, a study of the pH effect on the retention of tensile strength of suture materials will provide a better ground for the selection of suture materials for specific end use.

So far, the study of the pH effect on the retention of tensile strength of suture materials has been sparse and focuses on synthetic absorbable sutures.[5] This paper will categorize and summarize the effectiveness of pH on eight different absorbable and non-absorbable suture materials, based on an *in vitro* immersion study.

Experiments

Eight commonly used suture materials of size 2-0 differing in chemical structures were used. They were Dexon® (polyglycolic acid), Vicryl® (polyglycolide-lactide copolymer), plain catgut, surgical silk, Nurolon® (multi-filament Nylon 65), Ethilon® (monofilament Nylon 66), Mersilene® (Dacron), and Prolene® (polypropylene). The denier was calculated by taking precisely precut lengths, weighing them, and then multiplying by 9000 meters per length of suture specimen in meters. The average of five weighings constituted the denier.

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TABLE 1. *Tensile Properties of Suture Materials of Size 2-0 at Various pH Levels after 7 Days**

	Breaking Strength (GPD)			Breaking Elongation (%)			Specific Work Rupture		
	pH 3.0	pH 7.4	pH 10.0	pH 3.0	pH 7.4	pH 10.0	pH 3.0	pH 7.4	pH 10.0
Plain catgut	0.77 ± 0.08	1.28 ± 0.43	0.49 ± 0.29	26.9 ± 8.8	17.5 ± 9.3	6.1 ± 2.2	7.8×10^{-3}	1.7×10^{-2}	1.1×10^{-3}
Dexon	6.26 ± 0.12	5.94 ± 0.73	1.25 ± 0.06	22.8 ± 2.0	23.2 ± 2.0	16.6 ± 3.4	6.0×10^{-2}	6.4×10^{-2}	7.4×10^{-3}
Vicryl	6.10 ± 0.06	6.23 ± 0.10	2.44 ± 0.06	18.6 ± 1.0	17.1 ± 1.4	19.0 ± 1.7	4.8×10^{-2}	4.6×10^{-2}	2.0×10^{-2}
Silk	2.64 ± 0.23	2.6 ± 0.23	2.16 ± 0.03	18.4 ± 1.6	20.1 ± 0.40	17.5 ± 8.3	2.5×10^{-2}	2.6×10^{-2}	1.9×10^{-2}
Mershilene	4.15 ± 0.64	4.24 ± 0.25	4.12 ± 0.35	9.2 ± 1.5	9.1 ± 1.5	9.2 ± 0.7	1.5×10^{-2}	1.6×10^{-2}	1.5×10^{-2}
Nurolon	3.58 ± 0.15	3.81 ± 0.17	3.33 ± 0.27	18.2 ± 1.1	19.2 ± 0.6	19.8 ± 2.7	2.8×10^{-2}	3.0×10^{-2}	2.9×10^{-2}
Ethilon	5.42 ± 0.18	5.32 ± 0.58	5.48 ± 0.12	32.7 ± 1.3	31.7 ± 5.2	35.4 ± 1.3	7.7×10^{-2}	7.4×10^{-2}	8.5×10^{-2}
Prolene	5.30 ± 0.59	5.61 ± 0.39	5.53 ± 0.15	34.7 ± 10.3	36.4 ± 13.8	43.0 ± 8.8	1.2×10^{-1}	1.3×10^{-1}	1.5×10^{-1}

* Calculated at 95% confidence limit.

The immersion solutions consisted of three different pH range (3.0, 7.4, 10.0) saline buffer solutions. The consituents of the corresponding pH solutions were H_3PO_4/KH_2PO_4, KH_2PO_4/K_2HPO_4, and H_3PO_4/K_2HPO_4. All of the sutures to be immersed were cut into uniform lengths of 18 inches each. The eight different materials were immersed for two different immersion periods (7 and 28 days) in three separate buffer solutions. There were four strands of each material per trial. Groups of these four sutures were placed in individual vials containing the respective physiologic buffer solution. They were placed in a hot air circulating oven at 37.0 ± 1.0 C. At the end of these immersion periods, the sutures were removed, rinsed with distilled water, and then tested.

Tensile testing was performed using a table model Instron equipped with a type 4D yarn grip under standard conditions of 21.0 ± 1.0 C and 65.0% ± 2.0% relative humidity. The Instron settings were identical to those previously reported.[8] The testing procedure utilized an immersion tank that is attached to the Instron. Each suture was placed in the jaws, the tank was filled to a predetermined mark with distilled water, the sutures were immersed for 5 minutes, and then the load was applied. Once the suture broke, the tank was emptied and the suture was removed.

From the results of this testing the tensile properties of the suture specimens were calculated in the usual manner.

Results

Tables 1–3 show tensile properties and their percentages of retention of the original unimmersed specimens of the eight absorbable and non-absorbable suture materials tested at three different pH levels.

It is evident from the tables that a wide range of tensile properties-pH relationships were observed in the eight tested suture materials. In general, absorbable suture materials were more sensitive to the pH effect level than non-absorbable suture materials; within the same suture material, a strong alkaline condition would have a more adverse effect on the strength of suture materials than physiologic and acidic pHs.

Within the absorbable suture materials, the two synthetic ones (*i.e.*, Dexon and Vicryl) showed overall better retention of breaking strength than natural ones (*i.e.*, plain catgut). This is particularly true at the acidic and physiologic pH levels. For example, after a 7-day immersion, both Dexon and Vicryl sutures retained more than 90% of their original unhydrolyzed specimens at the pH levels of 3.0 and 7.4, while plain catgut retained

TABLE 2. *Tensile Properties of Suture Materials of Size 2-0 at Various pH Levels after 28 Days**

	Breaking Strength (GPD)			Breaking Elongation (%)			Specific Work of Rupture		
	pH 3.0	pH 7.4	pH 10.0	pH 3.0	pH 7.4	pH 10.0	pH 3.0	pH 7.4	pH 10.0
Plain catgut	-0-	-0-	-0-	-0-	-0-	-0-	-0-	-0-	-0-
Dexon	-0-	-0-	-0-	-0-	-0-	-0-	-0-	-0-	-0-
Vicryl	-0-	-0-	-0-	-0-	-0-	-0-	-0-	-0-	-0-
Silk	2.16 ± 0.21	2.44 ± 0.13	1.26 ± 0.19	14.4 ± 0.8	17.9 ± 0.8	9.2 ± 1.2	1.5×10^{-2}	2.3×10^{-2}	4.9×10^{-3}
Mersilene	4.13 ± 0.13	4.12 ± 0.15	4.08 ± 0.44	11.2 ± 4.3	10.2 ± 0.8	10.6 ± 1.2	1.9×10^{-2}	1.7×10^{-2}	1.7×10^{-2}
Nurolon	3.29 ± 0.43	3.55 ± 0.22	3.21 ± 0.14	18.6 ± 2.0	19.6 ± 0.3	20.2 ± 0.7	2.5×10^{-2}	3.0×10^{-2}	2.9×10^{-2}
Ethilon	5.01 ± 0.87	5.00 ± 0.47	5.22 ± 0.21	30.8 ± 9.3	30.8 ± 6.2	32.6 ± 3.3	6.6×10^{-2}	6.6×10^{-2}	7.0×10^{-2}
Prolene	5.59 ± 0.27	5.59 ± 0.19	5.80 ± 0.01	39.9 ± 7.4	39.2 ± 3.7	39.5 ± 2.7	1.4×10^{-1}	1.4×10^{-1}	1.3×10^{-1}

* Calculated at 95% confidence limit.

only 37% at the pH level of 3.0. Under a high-alkaline condition (pH = 10.0), Vicryl sutures exhibited the best retention of strength among the three tested absorbable sutures, whereas Dexon and plain catgut sutures showed similar results.

The breaking elongation of these absorbable sutures, except Dexon at all the three pH levels and plain catgut at pH = 10.0, however, increased from slightly to moderately after a 7-day immersion. Plain catgut sutures showed the widest range of change of breaking elongation within the studied pH levels. Breaking elongations were the highest at the acidic medium (175%) and the lowest at the high-alkaline medium (42%) in plain catgut sutures. Vicryl sutures, however, exhibited the smallest variation in breaking elongation with pH level. Dexon sutures showed a consistent decrease in breaking elongation, with an increase in pH from acidic to basic levels.

The specific work of rupture of these absorbable suture materials, which is a measurement of the ability of a material to withstand sudden shocks of a given energy and is defined as the amount of energy needed to break a material, was also found to depend on pH levels of the immersion medium. Again, plain catgut sutures were the most sensitive toward the change of pH levels (from 1.1×10^{-3} at pH = 10.0 to 1.7×10^{-2} at pH = 7.4). The specific work of rupture of Vicryl sutures, however, showed the least change with pH levels, and Dexon sutures were between Vicryl and plain catgut sutures. These absorbable sutures, in general, had the largest reduction in the specific work of rupture in the high alkaline buffer (pH = 10.0). Relatively little change of this specific work of rupture with pH level was observed in the physiologic and acidic buffers, particularly with synthetic absorbable sutures. No measurable tensile property data could be obtained with the three absorbable sutures at the 28-day immersion in all of the three pH levels studied.

Within the non-absorbable sutures, the tensile property data can generally be divided into two groups, depending on their sensitivity toward pH level. The first group, which included Mersilene, Prolene, and Ethilon sutures, exhibited the smallest change of tensile properties with the variation of pH level at both 7- and 28-day immersions. For example, the percentages of retention of breaking stress of these three non-absorbable sutures after 7 and 28 days remained relatively constant and very close to the value of unimmersed specimens at all the three pH levels. Similar observations were found in breaking elongation and specific work of rupture. There was virtually no change of tensile properties with pH and duration of immersion.

The second group, which included silk and Nurolon sutures, however, showed quite significant effects of pH on tensile properties. For silk sutures, a loss of about 13% of original unimmersed tensile breaking stress was found after 7-day immersion in both acidic (3.0) and physiologic pH levels, whereas within the same period, an amount of 27% loss of tensile breaking strength was observed under the high-alkaline condition (pH = 10.0). When the length of immersion was increased to 28 days, the difference in percentage of retention of tensile breaking strength due to pH levels became more pronounced. Silk sutures in the physiologic pH solution showed the best retention of strength among the three pH solutions, while more than half of their original strength was lost under the high alkaline condition. The breaking elongation of silk sutures, however, initially increased significantly after the 7-day immersion, and then decreased after the 28-day immersion.

Nurolon sutures showed a more significant dependence of their tensile properties on pH. The loss of tensile breaking strength was the greatest during the initial 7 days, and ranged from 33% (at pH = 10.0) to 23% (at pH = 7.4). There was no drastic loss of property after this period until the 28th day. In contrast, the tensile breaking strain of Nurolon sutures showed relatively little change with pH levels at both 7- and 28-day periods. Again, a better retention of strength was observed in the physiologic pH, followed by acidic and high alkaline pHs.

Among the non-absorbable sutures tested, silk sutures showed the largest decrease in the specific work of rup-

TABLE 3. *Per cent of Retention of Tensile Breaking Strength and Elongation of Suture of Suture Materials of Size 2-0 at Various pH Levels after 7 and 28 Days*

		Breaking Strength (%)			Breaking Elongation (%)		
	Day	pH 3.0	pH 7.4	pH 10.0	pH 3.0	pH 7.4	pH 10.0
Plain catgut	7	37	61	20	175	132	42
	28	-0-	-0-	-0-	-0-	-0-	-0-
Dexon	7	96	91	20	93	91	68
	28	-0-	-0-	-0-	-0-	-0-	-0-
Vicryl	7	93	95	40	114	106	116
	28	-0-	-0-	-0-	-0-	-0-	-0-
Silk	7	88	87	73	150	164	143
	28	72	81	42	117	146	75
Mersilene	7	99	101	98	104	103	104
	28	98	99	98	123	115	120
Nurolon	7	72	77	67	94	99	103
	28	66	72	65	96	102	105
Ethilon	7	104	102	105	104	100	112
	28	96	96	100	98	98	103
Prolene	7	97	103	102	95	102	120
	28	103	103	106	111	109	105

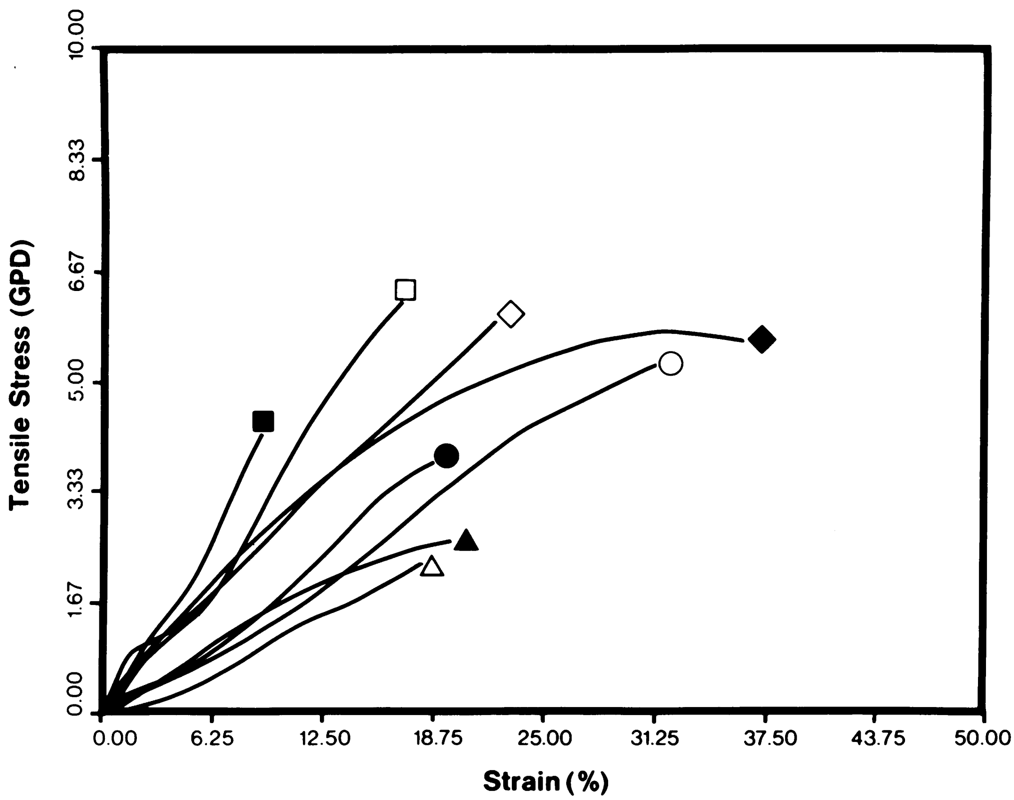

FIG. 1. Stress-strain curves of 2–0 suture materials after 7 days *in vitro* immersion in saline buffer solution of pH = 7.4. ■—Mersilene, □—Vicryl; ●—Nurolon, ○—Ethilon; ▲—silk, △—plain catgut; ♦—Dexon, ◇—Prolene.

ture, with time at both acidic and high alkaline conditions. At a fixed duration, this suture material also exhibited the largest change in the specific work of rupture with pH levels, particularly at high alkaline conditions. This pH dependence of specific work of rupture was more pronounced at the longer duration of immersion. Other non-absorbable sutures, however, showed relatively little pH and time dependence of the specific work of rupture.

The pH influence on the tensile properties of these sutures can also be examined by comparing the stress-strain curves of the corresponding suture specimens. This comparison could provide additional, important information on scrutinizing the pH effect on the performance of these sutures. Figures 1 and 2 show this pH effect on the stress-strain curves of the suture specimens after 7 days of immersion.

The major difference between synthetic and natural absorbable suture materials lies in their sensitivity toward pH. In synthetic absorbable sutures, the shape of the curves were very similar to each other at pH = 3.0 and 7.4 levels. Catgut sutures, however, showed quite different stress-strain behavior than Dexon and Vicryl sutures at the corresponding pH levels. There was no similarity in the three curves at the three different pH levels. Except for silk sutures, pH levels had very little influence on the stress-strain curves of the rest of the non-absorbable sutures.

Discussion

The results obtained from this study have indicated that pH levels are able to influence the performance of absorbable sutures more than non-absorbable sutures. Both acidic and alkaline environments are able to accelerate the degradation of natural absorbable sutures (*i.e.*, catgut), while only alkaline conditions have this adverse effect on man-made absorbable sutures (*i.e.*, Dexon and Vicryl). Within the non-absorbable sutures, silk is the most vulnerable in various pH conditions. Nurolon sutures are the next most sensitive to pH levels. Ethilon, Mersilene, and Prolene sutures have very similar pH dependence.

The observed pH dependence of Dexon and Vicryl sutures was consistent with the previous reports,[5–7] but it was quite different from Holm-Jensen's Dexon data and the work of Gilding, et al.[9,10] The former concluded that the degradation of Dexon sutures was not significantly affected within the pH range of 2–11. The latter has recently reported that there is no significant difference in the degradation rate of PGA and poly (glycolide-lactide) copolymer of compositions of 50/50 and 70/30 mol per cent within the pH levels of 5.0 and 9.0. This discrepancy between our data and their data was surprising, as these man-made absorbable sutures are of linear aliphatic polyesters whose hydrolytic degradation should be pH dependent. It is speculated that the coating

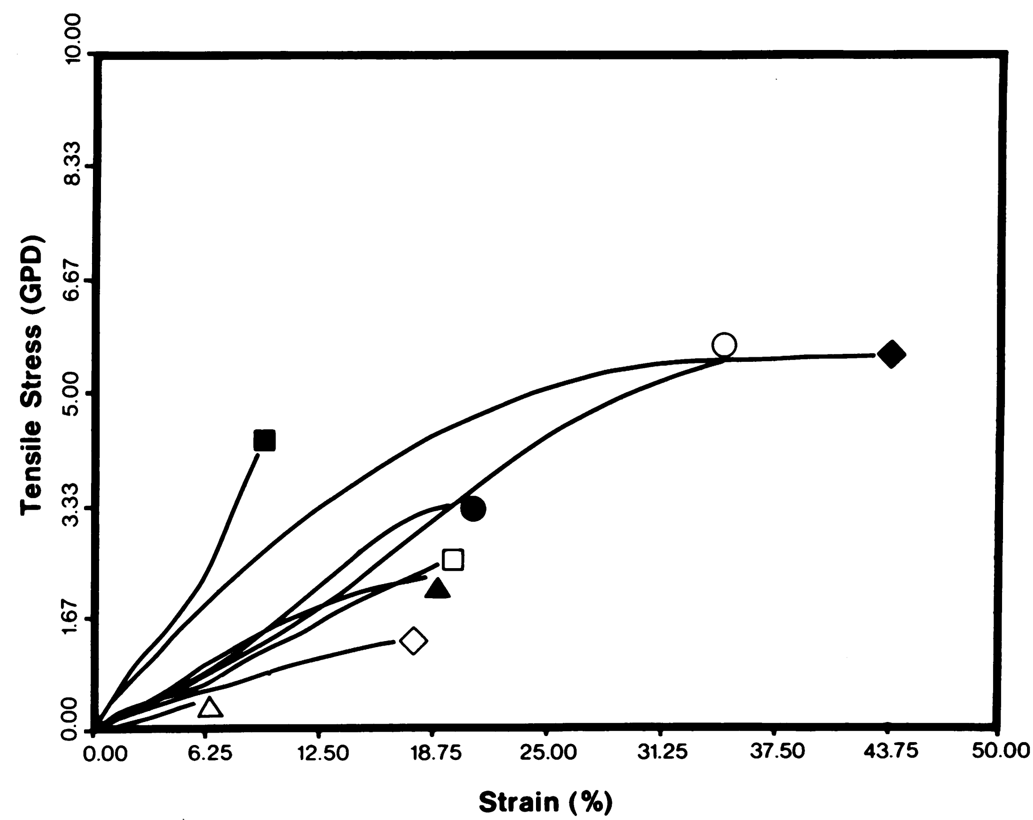

FIG. 2. Stress-strain curves of 2–0 suture materials after 7 days *in vitro* immersion in saline buffer solution of pH = 10.0. ■—Mersilene, □—Vicryl; ●—Nurolon, ○—Ethilon; ▲—silk, △—plain catgut; ♦—Dexon, ◇—Prolene.

materials and/or the level of crystallinity may contribute to this discrepancy.

In the natural absorbable sutures, a definite association between hydrolytic and proteolytic enzyme activity and tensile strength loss and absorption of catgut sutures was reported.[11,12] Accelerated degradation of catgut sutures could be observed in the presence of enzymes. In this study, it was also found that the *in vitro* degradation of the suture could be influenced by pH levels. This accelerated loss of strength in both acidic and alkaline environments may be related to the reported loss of tensile strength of catgut sutures in the gastrointestinal tract.[13–15]

In spite of free hydrochloric acid, bacteria of varying pathogenicity, and potent proteolytic enzymes, the stomach heals rapidly because of ample blood supply, rapidly regenerating epithelium, and external defense mechanisms.[16] Seventy-five per cent of the normal wound breaking strength of the stomach wall is achieved after the twenty-first day of post operation. This implies that suture materials for closing stomach wounds should be able to carry the 25% of unhealed wound strength after 3 weeks of post operation. Plain catgut sutures have only 37% of strength left, while both Dexon and Vicryl sutures have more than 90% of strength remaining after 7 days in pH = 3.0. This clearly suggests that plain catgut sutures are highly inappropriate to suture the wounded tissues containing low pH fluids such as HCl. In situations such as the transfixion of a bleeding ulcer, early premature loss of suture strength might be disastrous. All non-absorbable sutures maintained adequate strength at this low pH level, even after 4 weeks. Thus, from the strength retention point of view, these absorbable sutures are a good choice for stomach wounds, particularly in debilitated patients. Obviously, many other important technical factors such as wound infection, tissue reaction, and postoperative ulcers must be considered along with the sutures' strength retention. Suture-line ulceration is rare among the types of postoperative ulcers. It is almost always due to the exposure of a portion of a continuous non-absorbable suture in the lumen of the anastomostic site. The use of absorbable sutures with adequate strength retention during the first few weeks can prevent such complications.

When considering the closing of small and large intestines, absorbable sutures are preferred, particularly because they will not restrict the lumen diameter and because they leave no trace for bacterial migration. It is known that the pH of pancreatic juice in the duodenum is toward the alkaline side (7.5–8.2). Thus, the ability of sutures to retain adequate strength in this condition is important. Among the non-absorbable sutures, Prolene, Mersilene, and Ethilon sutures are better than silk and Nurolon sutures. Among the absorbable sutures, Vicryl is the best; however, further improvement in strength retention is highly desirable, particularly when considering the slow healing rate and high population of bacteria of the colon (*e.g.*, only 50% of normal strength is gained after 4 weeks post operation).

The importance of recognizing the pH dependence of sutures is also illustrated in the urologic and biliary tract surgery. The contents of the fluids present certain special aspects in relation to suture use. Absorbable sutures are considered better suture materials than non-absorbable ones when they are used in the urinary tract. The accelerated degradation of absorbable sutures is particularly noticeable in certain pathologic conditions. Milroy[18] reported that the presence of infection within the bladder enhanced the dissolution of Dexon and catgut sutures. 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 degradation of these absorbable sutures is further confirmed in the present study.

The reported pH dependent degradation of sutures in this study deserves the attention of surgeons in their selection of these suture materials in various physiologic and pathologic conditions.

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