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I hereby recommend that the thesis prepared under my supervision by Herbert V. Weiss

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THE GENERAL NATURE OF THE MOLECULAR ALTERATION OF COLLAGENOUS SUTURE IN VIVO

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INTRODUCTION

It is the purpose of this study to investigate the general nature of the molecular changes which provide for the solubilization of collagen in an in vivo system. With the exception of the investigation of Haugaard, Thoennes and Hall (8), the results of which will be related subsequently, no attempt has been made to evaluate the fundamental processes involved in this transformation.

In previous studies attention has been devoted primarily to the absorption characteristics of collagenous sutures with a view toward furnishing the surgeon with a product which meets the requirements imposed by specific conditions. By following the change in tensile strength with in vivo digestion time, it has been shown by Bates (3) and Kraissl (12) that non-chromicized suture is digested more rapidly than chromicized suture. Furthermore a relationship between the rate of tensile strength decline and ultimate solubilization has been demonstrated by Jenkins (11). Suture which usually lost its tensile strength in less than ten days was rapidly absorbed in three to six weeks, whereas suture which remained intact beyond this period was generally solubilized within an interval of three weeks to three months.

The fact that the in vivo digestion of collagenous sutures a period of lengthy duration is observed in which the protein is refractory to solubilization suggests that the collagen is undergoing a preliminary conditioning reaction which is requisite for enzymatic attack. This interpretation is in accord with the views expressed by

Linderstrom-Lang to account for the accepted description of enzyme action. A conditioning reaction (denaturation), (15) or the cleavage of a number of "strategically" important peptide bonds (14) is assumed to occur prior to the enzymatic hydrolysis of many proteins. Evidence of denaturation and/or the fission of small numbers of peptide bonds in the stage preceding the onset of appreciable hydrolysis should be demonstrable in the present study.

Comprehensive reviews by Schmitt (21), Gustavson (7), and McLaughlin and Theis (17) on the structure and chemistry of collagen are readily available, and a discussion of the features germane to the problem need only be considered.

Interpretation of the x-ray diffraction pattern obtained for collagen indicates that a degree of order or crystallinity occurs in the basic structure. Thus, characteristic side-chain, back-bone and average residue spacings have been described. A repeating pattern of approximately 640 A° along the fibril has also been demonstrated with the use of x-ray by Bear (4) and corroborated by Schmitt (22) by electron microscope analysis. Within this unit a series of alternate light and dark bands are observed with the electron microscope, and these have been associated with the disordered and crystalline regions along the fiber axis.

The collagen fibril is regarded to be constituted of polypeptide chains which, more or less, traverse the fibril parallel with the long axis and these chains are considered to be in close proximity to each other in the crystalline areas.

The native configuration is maintained through the action of

inter and intramolecular forces. Probably the most important of these are hydrogen bonds, and salt-linkages. Rupture of these bonds results in a marked shrinkage and the fiber acquires a rubbery elasticity. The cleavage of these secondary forces may be induced by thermal treatment as well as by the addition of certain chemical reagents. In the shrinkage process the normally extended polypeptide chains fold upon themselves to achieve a more thermodynamically stable configuration. Intermediate stages between the completely shrunken state and the native state are also possible, and this is manifested by a lowering of the shrinkage temperature. For example, as shown by Haugaard, Thoennes and Hall (8), when collagen is heated in a non-aqueous medium at temperatures insufficient to produce shrinking, the shrinkage temperature in water is reduced. This reduction is a reflection of the partial loss in lateral cohesion induced by heat. These investigators also showed that during the course of the in vivo digestion of collagenous suture a progressive depression of the shrinkage temperature is apparent.

It appears likely, however, that more than the rupture of secondary forces is involved in the preliminary stages of in vivo digestion. For reasons which will be discussed later the profound change in tensile strength prior to the period of solubilization cannot be entirely explained on the basis of loss of lateral cohesion when the probable mechanism of rupture under stress is considered.

Meyer (18), and Alfrey (1) discuss a number of defined factors which influences the tensile strength characteristics of fibers.

Fibers which are composed of long primary valence chains are characterized by high tensile strength, although the value obtained experimentally is usually considerably lower than that which is calculated from theory. This discrepancy may be accounted for by the fact that in practice not all the chains within a fiber are put under stress simultaneously, and the force required for rupture is obviously influenced by the number of chains which bear the stress. Hence, fibers in which the degree of orientation is high more nearly approach the tensile strength which is predicted from purely theoretical considerations.

In collagen the polypeptide chains are arranged, more or less parallel with the fiber axis. Despite this alignment it is found by Highberger (9) that the theoretical tensile strength is thirty times greater than the observed tensile strength, if rupture of the weakest primary valence force in the chain (the C-N bond) is assumed. It was, therefore, concluded that the most probable mechanism of rupture in collagen consists of breaking the lateral cohesive forces. This type of cleavage then permits one chain to slip over another with consequent fracture. Other arguments will be advanced later in support of this mechanism.

Since in a mechanism of this nature the cleavage of relatively few peptide bonds may have a pronounced influence on tensile strength, evidence for such cleavages will be sought. Of further interest is the qualitative appraisal of the contribution of reduction in lateral cohesion to the loss of tensile strength, as well as the examination of the changes in hydration potential.

EXPERIMENTAL METHOD

A series of implantation studies was conducted on a variety of sutures for the purpose of evaluating the general pattern of the changes which sutures undergo with digestion time. The types of sutures studied were:

1. Plain, size 2-0
2. Medium chromic, size 2-0
3. Medium chromic, size 1
4. Extra chromic, size 2-0

(Size 2-0 and size 1 sutures have approximate diameters of 0.35 mm. and 0.65 mm. respectively. The chrome content of medium chromic suture is about 0.4 per cent and that of extra chromic about 0.55 per cent).

Implantations were performed on white male rabbits, the weights of which ranged between five to ten pounds. The operative procedure was carried out under strict aseptic conditions. An area approximately five inches wide extending from the shoulder to the tail region of the animal was cleanly shaven. Following shaving, the skin was cleansed with "pHisoderm", and the lather was subsequently removed with sterile saline. Tincture of iodine, alcohol, and ether were then applied in the order named. The animal was finally prepared by draping with sterile sheets. Satisfactory anaesthesia was obtained by the intra-peritoneal injection, one-half hour before incision, of one to two cc. of nembutal (60 mg./cc.) diluted with an equal volume of isotonic saline.

The implantation technique comprised drawing a seven inch stilet threaded with suture through two incisions four inches apart. The knot binding the suture to the stilet was cut on the side proximal to the incision, and the stilet was withdrawn. All implants were imbedded in

the subcutaneous tissue. In the case of Medium Chromic Suture, Size 2-0, the first type studied, the suture protruding through the skin at each end of the implant was secured to the skin by means of silk sutures. Six portions of the same suture were introduced into each rabbit. The remainder of each strand was reserved for control analyses.

The implants were removed at periodic intervals; only one implant was removed at a time from a given rabbit. The protruding ends of the suture and the areas close to the surface were cut off and discarded. Occasionally, sutures could not be found protruding through the skin. If probing was unsuccessful, the animal was sacrificed, the subcutaneous area exposed, and the remaining implants removed.

Because of the difficulties encountered in this procedure, as well as the possibility of infection spreading from the exposed ends of the suture into the tissues, the suture was completely embedded in the subcutaneous tissue in subsequent implantations. At predetermined intervals the animals were sacrificed and the six implanted sutures removed.

Each implant was subjected to tensile testing and either weight or nitrogen determinations. The chrome content was evaluated for all of the chromicized implants. Shrinkage temperature analyses were performed on three of the four types of sutures listed. (Medium chromic, size 2-0 implants were not subjected to shrinkage study).

In a subsequent phase of this investigation the extent of peptide bond hydrolysis was determined in a stage of the in vivo process prior to solubilization. Further, another series of implantation studies were conducted to examine the tensile strength of implants

under different test conditions.

Since large quantities of implant were desired for these analyses, the implantation procedure was modified to meet these requirements. This generally involved making two transverse incisions about four inches apart. The suture was threaded through the subcutaneous layer by passing the stilet to which it was attached through one incision and out of the other. The path was retraced in the opposite direction when the free end or loop of the suture approximated the line of the incision. In this manner it was possible to implant two sutures (about 100 inches) into a rabbit.

ANALYTICAL PROCEDURES

A. Chrome Analysis

A titrimetric method for the determination of chromium in collagenous sutures, using 1 to 2 gram samples, has been reported by Smith (23). Since samples weighing only 3 to 6 mg. could be conveniently reserved in the present study for this analysis, another method was sought.

The highly sensitive diphenylcarbazide method has been adapted by Lollar (16) to the determination of chromium in leather. The described procedure was not within the working range for the minute quantities of chromium to be determined in sutures. Modifications of this procedure have, however, afforded the accurate determination of chromium in 3 to 4 mg. samples of suture. The results of recovery experiments and accuracy of the procedure are recorded elsewhere (26).

To avoid weighings, the change in chrome content per unit length of suture was studied. This method was possible since the length of the implant did not alter perceptibly during the course of digestion. To permit accurate measurement of the sample, the implant was thoroughly wetted. A sample one-half to one inch in length was cut off and transferred to a 12 X 75 mm. test tube. Two drops of concentrated sulfuric acid and 4 drops of concentrated nitric acid were added, and the mixture was boiled gently on a hot plate until carbonization occurred. The sample was cooled, and one drop of hydrogen peroxide (30%) was added.

The mixture was heated again to charring, removed from the hot plate, and cooled, and the treatment with a drop of hydrogen peroxide was repeated. Usually 3 drops of hydrogen peroxide were required to

effect complete digestion of the sample in this manner. Following clearing the sample was allowed to remain on the hot plate for 0.5 hour to remove traces of unreacted hydrogen peroxide.

After cooling, 2 drops of constant boiling perchloric acid (70 to 72%) were added to the digestion tube. The test tube was inserted about 15 mm. below the surface of a constant temperature bath adjusted to 200° ± 2° C. and oxidized for 15 minutes. After oxidation, the tube was immediately inserted into a cold water bath and diluted with distilled water to a volume of approximately 3 ml. The solution was transferred into a 25 ml. volumetric flask. About 10 ml. of water were used for the transfer. The volumetric flask was placed on a hot plate and the solution was boiled for several minutes to remove liberated chlorine. After cooling, one drop of concentrated phosphoric acid and 10 ml. of an HCl-KCl buffer, pH 1.6 were added. One ml. of diphenylcarbazide (0.25% in 1 to 1 acetone-water) was transferred to the flask, water was added to the mark, and the solution was shaken. The color was allowed to develop for 15 minutes. Readings were made in an Evelyn colorimeter using a No. 540 Evelyn filter. The results were expressed as micrograms of chromium/inch of suture.

B. Solubilization

Solubilization was determined either by weight or nitrogen analysis of a known length of implant. On removing implants from an animal, frequently a mucoid-like deposit was observed to surround the suture. This was carefully removed prior to analysis. The portion of implants used for either of these analyses was that which had been previously subjected to tensile tests.

Nitrogen was determined by the standard micro-Kjeldahl procedure. The measured length of sample, usually 2 to 3 inches, was digested overnight. Titrations were carried out with 0.02 N HCl in the presence of a mixed indicator. Although the titration values were only of the order of about 2 ml., satisfactory reproducibility was obtained. The results were expressed as mg. nitrogen/inch of suture.

Where weighings were substituted for nitrogen determinations, the measured length of suture was air-dried for 48 hours. The sample was weighed to 0.01 mg. on a micro-balance. Results were expressed as mg./inch of suture.

C. Tensile Strength

A Scott IP-4 Serigraph was used in the tensile strength determinations. The sample was secured between the jaws of a stationary clamp and a movable clamp, the latter being attached to a carriage. The carriage rested on rails, the plane of which changed at a constant rate when the instrument was in operation. The instrument was so designed that the full load of the carriage was transferred to the sample 20 seconds after the initiation of incline. A mechanism for automatically recording on a chart the point at which rupture occurred was also provided. The breaking strength was calculated from the known load on the carriage.

It was found necessary to alter the rate of loading during the course of an experiment because of the drastic change in the tensile strength of implants with progressive digestion. The rate of load was usually restricted to a one and one-half change and never exceeded three-fold. The error incurred because of this variation was, however, not

considered serious. Midgley and Pierce (19) have found that the breaking strength of a yarn increased only about 10% for every tenfold increase in the rate of loading.

Implants subjected to this test were prepared under various conditions. In the preliminary phase of this study, 2 to 3 inches of implant, accurately measured, were soaked in water for about an hour prior to testing.

In order to characterize the contribution of reduction in lateral cohesion to the loss of tensile strength, a portion of implant was tested under wet conditions and compared with another segment of the same implant which was shrunk at 70° or 100° C. In conjunction with this phase of the study another section of implant was reserved for dry testing to determine the changes in hydrophilic character during digestion by comparing these values with those obtained for the wet-conditioned implant.

For this purpose two sutures were implanted into each of fourteen rabbits. To afford closer observation of events, the digestion process was impeded by implanting suture within a relatively confined area. The sutures used were medium chromic, size 1. The animals were sacrificed at various intervals over a period of 17 days to obtain a wide range of residual tensile strength values. Upon removal of the implants, three segments of each were cut of sufficient length to allow for at least four replicate analyses. The segments were prepared for dry, shrunken, and wet testing. Dry conditioning comprised air-drying at about 70° C. for 48 hours. The shrunken samples were obtained by subjecting previously soaked implants for 45 seconds to water maintained

at 70° C. or boiling water for 30 seconds. The tensile strength was recorded in pounds.

D. Shrinkage Temperature.

Three methods were employed in the evaluation of shrinkage temperature. An electronic shrinkage meter constructed by Kremen and Lollar (13), and similar in principle to the one described by Theis and Serfass (24), was first used to determine the shrinkage temperature of Plain Suture, Size 2-0 and Medium Chromic Suture, Size 1 implants which were embedded up to 10 days.

A strain gauge was embodied in the instrument, and the force applied to the gauge was reflected by a change in electrical resistance. By means of a Wheatstone Bridge arrangement, the change in voltage was measured. The voltage change was expressed in terms of force by calibrating the scale with known weights. A linear response between voltage and force prevailed in the operating range. The instrument was sensitive to a change of one gram.

The sample, usually about one-half inch in length, was clamped between the jaws of two holders. One of the holders was firmly fixed to the frame of the instrument; the other was attached to the lower end of the strain gauge and could be adjusted by means of a screw thread so that any desired initial tension could be exerted on the fiber. An initial tension of 7 to 8 grams was found to be adequate, since the sample did not exhibit extension during the course of determination.

The sample was wetted for one hour prior to testing. It was then clamped to the instrument and immersed in a beaker of water which was at

room temperature. An electric stirrer and heating element were built into the instrument. The rate of heating was adjusted at 3° C. per minute. The force which developed as the temperature was raised was recorded every two degrees. Force was plotted against temperature, and extension of the straight-line part of the curve to the temperature axis was arbitrarily designated as the shrinkage temperature.

Implants which were embedded for more than ten days frequently became fragmented under the test conditions. Since the force developed is a function of the integrity of the fiber, it was necessary to supplant this method by visual techniques.

In a microscopic technique the sample was placed in a water-filled concavity of a glass slide and protected against evaporation with a coverslip. The slide was placed on a Walton microscope hot stage, and the rate of heating was controlled at 3° C./min. by means of a variable transformer.

The sample was cut of such size that it exactly spanned the field of the microscope objective. The temperature at which the ends of the sample were seen to shrink away from the border of the field was recorded as the shrinkage temperature.

In a macroscopic technique a sample about one inch in length was inserted into the arm of an "L" glass tube of 1/4" diameter. The tube was affixed to a thermometer and inserted into a water bath provided with a stirrer. The bath was heated at a rate of about 3° C. per minute. The temperature at which curling and shrinking were first observed was recorded. Since subjectivity is inherently involved in visual procedures, these analyses were performed by an unbiased observer.

E. Free Amino Nitrogen Analysis

For the purpose of determining the extent of peptide bond hydrolysis at a stage of the digestion process prior to solubilization, amino nitrogen analyses were performed. The method adopted for free amino nitrogen analysis was the Van Slyke procedure, as modified for application to insoluble proteins by Doherty and Ogg (6).

The sample was ground in a Wiley Mill to 60 mesh size. The moisture content of a portion of this sample was determined by drying under vacuum for 16 hours at 90° C. Another portion weighing approximately 140 mg. was transferred to an auxiliary chamber, which contained about 2 ml. of water. The chamber was evacuated and left under vacuum overnight. This preliminary treatment was suggested by Bowes and Kenten (5), in order to ensure thorough wetting. The following morning the chamber was re-evacuated, and the reagents were added. The liberated gases were withdrawn at 10 and 30 minutes, 1, 2, 3 and 4 hours after the start of the reaction. The gas was purified, transferred to the Van Slyke manometric apparatus, and the volume measured. The amino nitrogen was calculated by plotting the nitrogen evolved against time. The slope and intercept of the secondary part of the curve were determined by the method of least squares. The liberation of gas in the secondary phase is due to the reaction of the guanidine group on arginine. Correction for this reaction is obtained by extrapolating to the amino nitrogen axis. The results were expressed as per cent amino nitrogen/gram moisture free protein.

RESULTS

The average per cent tensile strength which is retained during digestion for the four types of sutures which were studied in the preliminary phase of this study is shown in Table I. This summary of results was computed from the individual tensile strength values which appear in Table A of the appendix.

Figure 1 shows the relationship between the per cent of tensile strength retained and digestion time for these sutures. Each point represents an average of the tensile strength retained for implants, which were removed at the designated intervals.

Plain suture is digested more rapidly than the chromicized variety. Further, the chrome content of the suture influences the rate of digestibility, as is evident by the fact that size 2-0 extra chromic implants retain a greater tensile strength throughout the course of digestion than the same gauge of medium chromic suture. The latter in turn decay less rapidly than plain suture.

As in previous investigations the rate of digestibility is also found to be a function of suture gauge. Medium chromic, size 2-0 implants are digested less rapidly than size 1 medium chromic implants.

A marked decrease in tensile strength occurs in the early stage of digestion. Following this period the change is more gradual. The initial reaction is generally less pronounced with increased chrome content. The size of the suture also influences this phase of the reaction significantly.

A summary of the nitrogen determinations of plain and medium Chromic suture, size 2-0 are shown in Table II. The weight determina-

tions of medium chromic, size 1 and extra chromic size 2-0 sutures are given in summary form in Table III. The complete data for nitrogen and weight appear in Tables B and C of the appendix, respectively.

Figure 2 shows the relationship of solubilization and digestion time for medium chromic suture size 1. In the first 10 to 12 days of implantation the suture is refractory to solubilization. Following this period, a gradual loss in weight is manifested. On the 26th day about 50 per cent of the implant is solubilized.

The general characteristics of the solubilization curve are essentially the same for the other types of suture investigated, whether examined by weight or nitrogen analyses. Differences, however, are apparent with respect to the rate of solubilization. Extra chromic suture is most resistant to attack, although solubilization is initiated after approximately the same interval of implantation (12th day). In the case of plain suture, a slight decrease in weight is observed at an earlier period (8th day).

The shrinkage temperature data of medium chromic sutures, size 1 and plain sutures, size 2-0 as obtained with the shrinkage meter are shown in Tables IV and V, respectively. The results are variable, and no definite conclusions regarding the influence of digestion time on this factor can be deduced. For reasons which were previously discussed, this technique is found to be unsuitable for measuring the shrinkage temperature of implants which are embedded for periods exceeding 10 days.

These sutures were re-examined by visual techniques; and the data are shown in Tables VI and VII for medium chromic, size 1 and plain, size 2-0 sutures, respectively. From the beginning of implantation, a

difference in the shrinkage temperature between the control and implant is discernible. With the exception of the implant removed on the first day following implantation, a difference of 1 to 3 degrees between implants and controls is noticeable for the plain suture. The greatest deviation from the control usually occurs in the later stages of the digestion period. With regard to medium chromic, size 1 implants, the shrinkage temperature is 3 to 4 degrees lower than corresponding controls in the initial phases of digestion. As digestion proceeds, the shrinkage temperature declines progressively; and a maximum difference of 10 degrees is observed on the 24th day. Similar results are obtained for extra chromic implants (Table VIII), although the disparity in this case between controls and implants is not so pronounced. In the later stages of digestion (20 to 30 days) the difference is of the order of 7 degrees.

A summary of the changes in the chrome content for the three types of chromicized sutures studied is shown in Table IX. The complete data are shown in Table D of the appendix. As before, the average per cent of chromium which is retained at a specified interval was computed and plotted against the implantation time. The relationship is shown in figure 3 for medium chromic suture, size 1. The curve is characterized by a more or less rapid loss of chromium to about 80 per cent of the original chrome content within the first days of implantation. This period is followed by one in which the loss is less rapid. By the 26th day the residual chrome content is approximately 60 per cent of the control.

Essentially the same results are obtained for the other varieties of chromicized sutures studied. If differences in the chrome content as affected by implantation time exist, such differences are not demonstrable because of the variability of the results.

The free amino nitrogen analyses of medium chromic suture, size 1 controls, and eight day implants are shown in Table X. The range of six control analyses is 0.41 per cent to 0.49 per cent amino nitrogen. Because of this variability, comparatively small changes in the free amino nitrogen content are not detectable. The per cent amino nitrogen in the implants is not significantly different from that of controls.

The tensile strength data for implants which were examined under different test conditions are shown in summarized form in Table XI. The experimental values appear in Table E of the appendix.

In figure 4 the dry tensile strength values are plotted against the wet tensile strength values of the same implant. Each point represents an average of the separate values (usually four) obtained.

A general correspondence exists between the tensile strength and digestion time. That is, sutures which are removed in the early phase of the study usually possess greater tensile strength than those which are removed at a later period. However, the implantation time was neglected so that the fundamental change without the influence of biological variability could be more readily analyzed.

The tensile strength of wet and dry control suture was also determined. These data are shown in Table XII. The mean wet/dry was 88 per cent, and the maximum deviation from the mean for one of the

five sutures tested was 3 per cent. That this relation is constant, irrespective of the initial tensile strength of the control suture, may be reasonably assumed. The relationship is designated by a control line in figure 4.

Figure 4 shows that the relation between wet and dry tensile strength falls below that of the theoretical control value from the beginning of digestion. The $\frac{\text{Wet}}{\text{Dry}}$ (%) is indicated in the figure for each implant. As the tensile strength is dissipated this ratio diverges progressively from that of the control.

Figure 5 shows the relation between wet implants and implants shrunk at 100° C. Control sutures which are shrunk under these conditions retain 60 per cent of their wet tensile strength (Table XIII). This relation is indicated by the control line. The consideration previously mentioned with regard to the control line which was drawn for the wet-dry ratio applies in this case as well in justifying extrapolation of the experimentally determined control relationship.

The summarized data for the relation between wet implants and implants shrunk at 70° C. are shown in figure 6. Under these conditions of shrinking the control suture retains 77 per cent of its original wet tensile strength (Table XIV).

Figures 5 and 6 show the same general characteristics. In the early stages of digestion the experimentally determined values are concentrated below the control line. The relation appears to undergo transformation as digestion proceeds, particularly for the series in

which implants are shrunk at 100° C.

The statistical significance of the deviation of the experimental values from the control line was evaluated by student's "t" test. Each series was separated into two groups (designated by hollow and solid circles in figures 5 and 6). The separation was determined by the stage in which the relation to the control line appeared reversed. The experimentally determined values were computed as $\frac{\text{Shrunken}}{\text{Wet}}$ (%) and compared with the corresponding percentage values of the controls.

To justify the comparison of implants with controls by the statistical method, the extent of shrinkage of each was determined. Control fibers which are shrunk at 70° C. and 100° C. retain about 65 per cent and 58 per cent of their original length, respectively. Although error is involved in the measurement of the kinked and elastic shrunken fibers, gross differences are discernible. The length retained by implants following shrinking is not significantly different from that of controls (see Table XV).

In figure 6 the average $\frac{\text{Shrunken}}{\text{Wet}}$ (%) of the experimental points in the upper range (solid circles) is 70 per cent, whereas that of controls is 77 per cent. This difference is found to be statistically significant. The calculated "t" is 9.75 in contrast with the tabular "t" at the 0.01 probability level of 2.86. That is, this difference may have been the result of chance less than one time in a hundred. The variance ratio (F) test precludes the examination of the lower points in this figure by the "t" test.

With regard to the data presented in figure 5 in which shrinking was induced at 100° C., evaluation of the statistical results indicates that the experimental points in the upper, as well as in the lower range, are significantly different from the control values. The average difference of the points in the upper part of the curve from that of the average control ratio is 8 per cent. The calculated "t" is 7.05 as compared with the tabular "t" of 2.92 at the 0.01 confidence level. The lower points in the figure average 3.5 per cent greater than the average control value. The "t" which is computed for this difference is 2.074, which is very nearly equivalent to the tabular "t" (2.120) at the 0.05 probability level.

DISCUSSION

A depression in the shrinkage temperature as determined by the visual techniques occurs during digestion for the three types of suture analyzed (Tables VI, VII, VIII). The shrinkage temperature of the chromicized implants declines more rapidly than that of plain sutures.

The positive correlation between the chrome content of collagen and the shrinkage temperature is commonly recognized. That is the shrinkage temperature of collagen is found to decrease with decreasing concentrations of chrome. Therefore the decline in the shrinkage temperature which is observed for chromicized implants is partially ascribable to the dechromicization which occurs during digestion (see figure 3). However, chromicized implants which are removed in the later stages of digestion retain significant quantities of chrome; yet, these implants exhibit a lower shrinkage temperature than that of plain suture. For example the shrinkage temperature of control medium chromic suture, size 1 is about 58° C. After 24 days of implantation the shrinkage temperature drops to 48° C. (Table IV). The shrinkage temperature of control plain suture exceeds the latter temperature by 4 degrees (Table VII). Therefore, the decline in the shrinkage temperature of chromicized implants is not wholly attributable to a decreasing chrome composition.

Shrinkage is regarded to occur when the thermal agitation of the polypeptide chains is sufficiently strengthened to rupture the lateral cohesive bonds. If the number of lateral bonds is reduced, then the

temperature at which shrinkage is induced is lowered. The results of the shrinkage temperature analyses, therefore, indicate that the rupture of these secondary valence forces occurs in the in vivo process.

The discrepancy in the results between instrumental analysis in which no change in the shrinkage temperature was observed (Table IV and V) and the visual methods of analysis is not clearly understood, particularly since the shrinkage temperatures of control suture when examined by these methods are essentially identical. The possibility exists that under the conditions employed with the shrinkage-meter in which the fiber is not permitted to shrink, the initially applied tension and the restraint may in some manner be sufficient to obscure the changes in lateral cohesion incident to the in vivo process. That tension has an inhibitory effect on the solution of crystallites in collagen (crystallites dissolve on shrinkage) is borne out by the investigation of Wright and Wiederhorn (27). Furthermore, Weir (25) has shown that with increased tension the rate of shrinkage decreases; and the induction period is prolonged.

The progressive decline in lateral bond strength as indicated by the shrinkage temperature measurements may explain the change in the wet-dry tensile strength relationship during the in vivo process. The wet-dry ratio diminishes more or less regularly as the tensile strength declines (see figure 4) indicating that the tensile strength of implants increases in sensitivity to wet testing as digestion proceeds. Since the rupture of secondary forces may be expected to

produce a less firm structure, the quantity of water imbibed may be augmented from purely this physical consideration. Further, if the secondary forces ruptured involve hydrogen bonds, the carbonyl groups liberated are available for water binding. The introduction of water into the side-chain spaces as the result of either or both these effects may weaken the existing lateral cohesion and thereby induce the sensitivity to wet testing conditions which is observed.

When the mechanism of rupture under stress is considered, the reduction in lateral bond strength during the in vivo process partially explains the decline in tensile strength (figure 1). As previously discussed the concept of slipping when collagen is ruptured under stress was proposed by Highberger (9) because of the vast difference between the tensile strength value which is obtained in practice and that which is theoretically computed, when the rupture of primary bonds is assumed. Evidence to support this mechanism may be advanced from other observations in which modification of the lateral bond character is found to alter the tensile properties significantly. Jacobson and Lollar (10) have shown that, when treated with mercuric acetate, which is considered to be a bridging agent, collagen fibers exhibit a significant increase in tensile strength. Furthermore, reduction of lateral bonding by shrinking (Table XIV) causes a marked decrease in tensile strength. Since the shrunken fiber is stretched to approximately its initial length during the tensile test, with consequent realignment of polypeptide chains, the decrease in tensile strength is not attributed solely to a modification in the orientation.

A comparison of sutures tested following wet and dry conditioning (Table XII) further shows that the wet fiber is approximately twelve per cent weaker than the dry fiber. If the mechanism of rupture in collagen involved the cleavage of primary forces along the polypeptide chain, the influence of the factors enumerated would have no, or at most slight effect on the tensile strength. Practical demonstration of this fact may be cited. Sakurada (20) has shown that with well oriented bast fibers, which rupture by cleavage of primary valence forces, the load at which the fiber breaks is uninfluenced by nitration or acetylation, although this treatment is known to modify the secondary valence bonds. The evidence, then, strongly favors the mechanism of rupture by slipping.

The fact should be emphasized that the cleavage of cross-links which occurs in the in vivo process does not proceed to the extent of spontaneous shrinkage. The length of implant removed is the same as that which is implanted. Apparently sufficient lateral bond strength remains intact in the early stage, as well as in the subsequent stages of digestion, for retaining the metastable configuration.

The decline in tensile strength which occurs in the in vivo system cannot be attributed merely to the lessened lateral cohesion when the extent of loss is considered. Shrunken suture, which undoubtedly possesses less lateral bonding than implants which are removed in any stage of digestion retains 60 per cent to 80 per cent of its original tensile strength, depending upon the conditions of shrinking (Table XIII and XIV). These values exceed that of implanted suture

considerably, even prior to the period of the in vivo process in which solubilization is initiated. As an example, on the eighth day of implantation medium chromic suture size 1 retains only 25 per cent of its original tensile strength (see figure 1).

Since the rupture of lateral bonds does not adequately describe the extent to which tensile strength is lost, some other factor is obviously involved. The cleavage of peptide bonds could explain the results. If, by the application of physical stress, collagen is ruptured by a slipping mechanism, then the cleavage of only a few peptide bonds could have a profound effect on the tensile strength. The influence of peptide bond fission on tensile strength is demonstrated diagrammatically in figure 7. The horizontal and vertical double lines represent polypeptide chains and secondary valence bonds, respectively. The path of rupture is shown by (1) in the intact fiber. For rupture to occur in this hypothetical case, twelve lateral units are required to break. If on the other hand a peptide bond is cleaved at position A the number of lateral bonds which must rupture is reduced by 75 per cent since slipping has the natural tendency to follow the path of least resistance. (path 2). It is realized that cleavage in the position shown is ideal; however, that cleavages in even less favorable positions significantly influence the tensile characteristics is clear.

Evidence of peptide bond fission is not demonstrable by the free amino nitrogen analyses (Table X). However, when the variability attendant to the Doherty and Ogg procedure is recognized a difference of

only 0.05 per cent free amino nitrogen is discernible. Calculations show that this difference represents one peptide bond cleavage in about 225 amino acid residues.

The polypeptide chains in collagen contain very large numbers of amino acid residues (see Bowes and Kenten (5)). It is then entirely conceivable that the cleavage of small numbers of peptide bonds may result in split products of molecular dimensions which are not detectable by the analytical procedure. Therefore, notwithstanding the results of this analysis, peptide cleavage is assumed to occur. This assumption is found to be necessary in order to account for the extent to which tensile strength declines, particularly in the early stages of digestion in which the rate of decline is rapid (see figure 1).

The assumption that peptide bonds are cleaved in the early stages of the in vivo process also affords an explanation for relationship between shrunken and wet tensile strength of an implant.

The results of the shrunken-wet tensile strength ratio show that in the initial stages of the in vivo process the values range below the control line and above the control line in the later stages of digestion. (figures 5 and 6). The length retained after shrinking is the same for both controls and implants (Table XV). Since the type of heat treatment influences the extent of shrinkage, the conclusion that shrinking implants and controls under specified conditions reduces both to essentially the same basic constitution is considered valid.

If the loss in lateral strength were the sole reaction involved in the reduction of tensile strength prior to solubilization, the

shrunken-wet ratio would be expected to exceed that of the controls. This conclusion follows from the fact that the lateral forces which contribute to the tensile characteristics are diminished. Because fewer numbers of lateral bonds are ruptured in transforming sutures subjected to the in vivo process to the shrunken state, a smaller difference in the tensile strength between wet and shrunken implant as compared with that of the control should be reflected.

Since the shrunken-wet ratio of implants removed in the early stage of digestion falls below the control line, a factor other than the rupture of secondary valence bonds is involved. Peptide fission in this stage of digestion may be responsible for the apparent anomaly. As already noted, when shrunken suture is subjected to the tensile test, the fiber extends to essentially its original length as the load is applied. Presumably the polypeptide chains become realigned in the process. The fact that the high angle x-ray pattern of collagen reappears unaltered upon stretching shrunken collagen (2) supports this view.

If the longitudinal continuity of the polypeptide chains is interrupted by peptide bond fission, the tendency for re-alignment after shrinking may be so impaired that relatively fewer numbers of chains bear the load during the tensile test. As a consequence the shrunken implants in which peptide bond cleavage occurs are mechanically weakened to an extent which is greater than that induced by the mere rupture of lateral bonds. Since impaired re-alignment is not involved in the testing of wet implants the influence of peptide cleavage results in a lower shrunken-wet ratio. In view of the relation of

the shrunken-wet ratio of implants to the control line, the effect of peptide bond fission apparently outweighs the influence of lateral bond cleavages in the early stages of digestion.

Figure 1 shows that the decline in tensile strength is exponentially related to time for all of the sutures studied. A relationship of this nature suggests that more than one reaction is occurring simultaneously. The pronounced initial decline may be reasonably attributed to the profound influence of relatively few peptide bond fissions. If in a stage of the digestion process the number of peptide bonds which are susceptible to attack is diminished or exhausted, the influence of lateral bond cleavage is the dominating factor. The more gradual decline of tensile strength in the secondary phase of the reaction suggests that such a condition is attained. These circumstances may explain the reversal of the relationship between the shrunken-wet ratio with respect to the control line in the case of implants where the residual tensile strength is low. That is, the influence of lateral bond cleavages is sufficiently enhanced by prolonged digestion to overshadow the diminishing effect which is induced by the fission of peptide bonds.

SUMMARY AND CONCLUSIONS

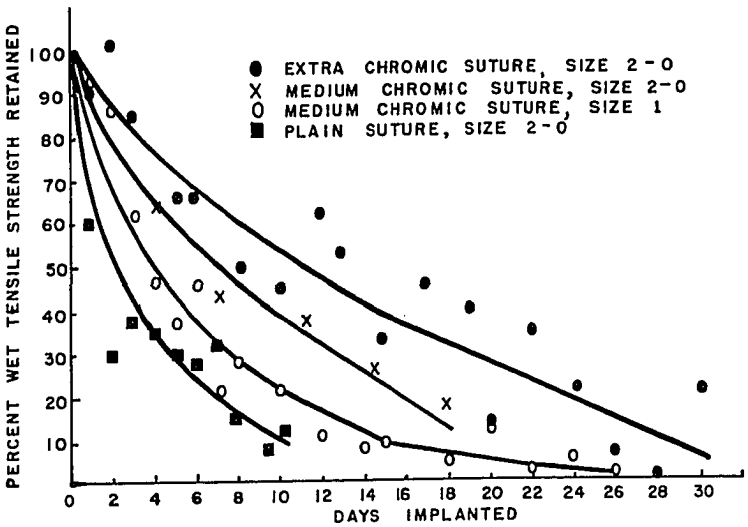
The tensile strength of implanted collagenous sutures declined exponentially with in vivo time. The pronounced decline in the incipient stage of the process was unattended by solubilization. Further the rate of decline was found to be a function of the chrome content of the suture.

Shrinkage temperature determinations as well as the comparison of wet and dry tensile strength of implants removed at various periods of digestion indicated that secondary valence bonds ruptured progressively. However, the loss of lateral cohesion incident to the in vivo process did not adequately account for the degree to which tensile strength was dissipated, particularly in the initial stages of implantation. Although peptide bond cleavage was not demonstrable by free amino nitrogen analyses, a small number of cleavages was assumed to have occurred in the early phase of the reaction to account for the extent to which tensile strength declined.

To characterize the contribution of lateral bond rupture to the loss of tensile strength, implants were tested under wet and shrunken conditions. Peptide bond fission afforded a possible explanation for the anomalous behavior of the shrunken-wet ratio which was observed in the incipient stage of digestion. The results also suggested that following the cleavage of the initially susceptible peptide bonds, the influence of lateral bond rupture predominated.

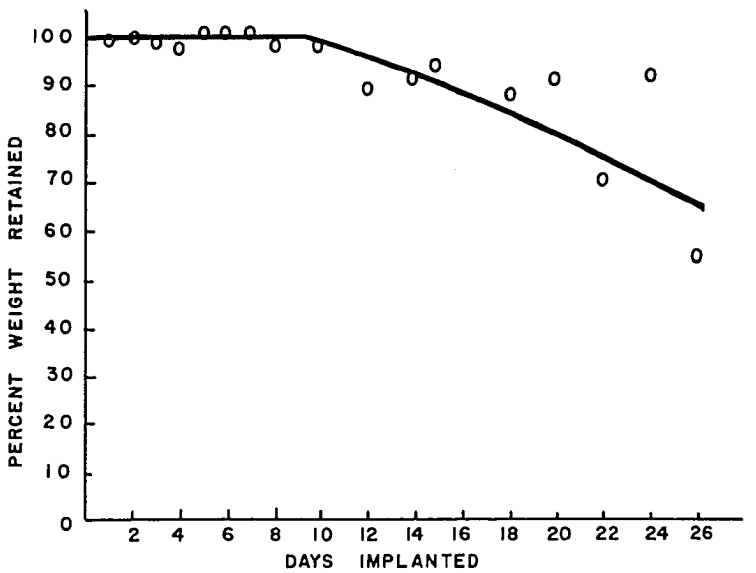
Since a period of lengthy duration was observed in which implants were refractory to solubilization, and in which only small numbers of

peptide bonds appeared subject to attack, the alteration in lateral bond character may be likened to the conditioning process which was postulated by Linderstrom-Lang (3, 4) to account for the enzymatic attack of metastable proteins.



CHANGE IN WET TENSILE STRENGTH OF FOUR TYPES OF SUTURE IN IN VIVO DIGESTION

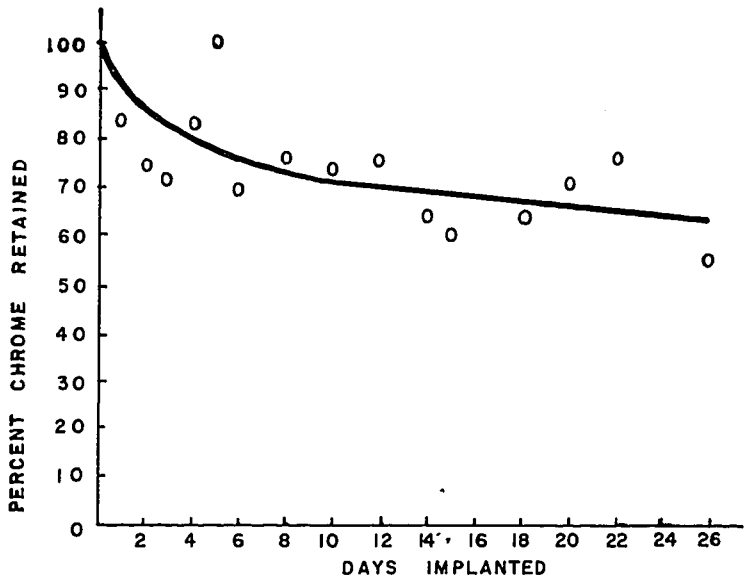
FIGURE 1



CHANGE IN WEIGHT OF MEDIUM CHROMIC SUTURES, SIZE 1 IN IN VIVO DIGESTION.

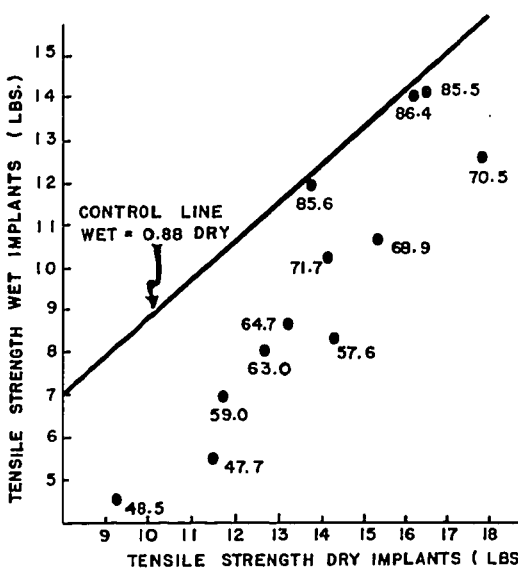
FIGURE 3

Figure 2.



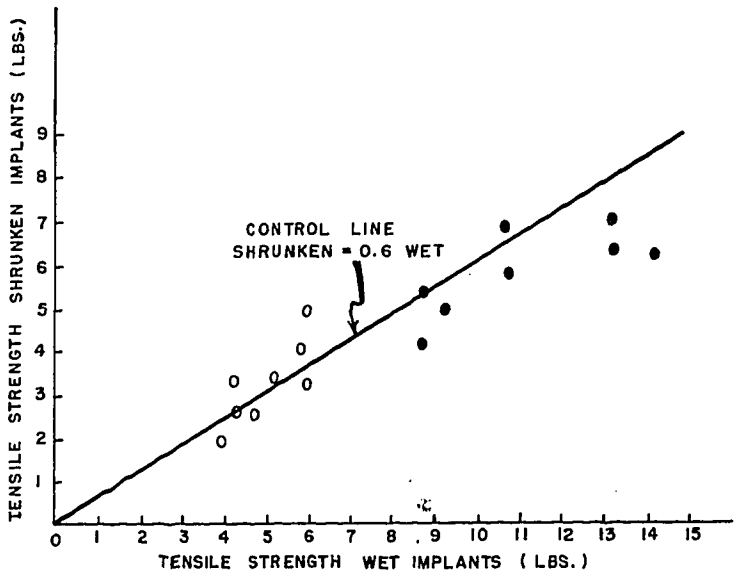
CHANGE IN CHROME CONTENT OF MEDIUM CHROMIC SUTURES, SIZE 1 IN IN VIVO DIGESTION

Figure 3.



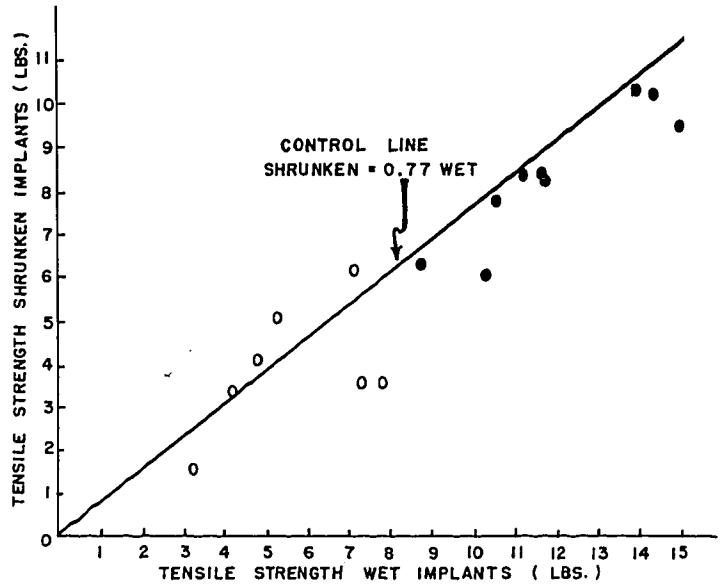
TENSILE STRENGTH DURING THE COURSE OF DIGESTION OF WET AND DRY CONDITIONED IMPLANTS SHOWING $\frac{WET}{DRY}$ (PERCENT) AT EACH EXPERIMENTAL POINT AND DEVIATION FROM AVERAGE CONTROL LINE.

FIGURE 4



TENSILE STRENGTH RELATION DURING THE COURSE OF DIGESTION OF WET AND SHRUNKEN (100° C., 30 SECONDS) IMPLANTS, AND AVERAGE CONTROL LINE.

Figure 5.



TENSILE STRENGTH RELATION DURING THE COURSE OF DIGESTION OF WET AND SHRUNKEN (70° C., 45 SECONDS) IMPLANTS, AND AVERAGE CONTROL LINE.

Figure 6.

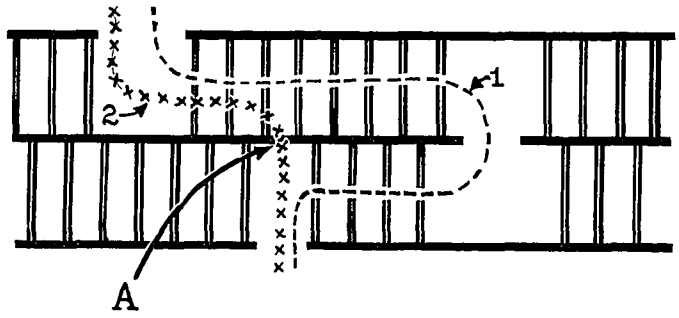


Figure 7. The mechanism of slipping and the influence of peptide bond fission. The horizontal lines and vertical double lines represent polypeptide chains and secondary valence forces, respectively. In the intact fiber the course of rupture follows path (1). By virtue of peptide bond cleavage at (A) the path is altered and proceeds by way of (2).

Table I

Average Tensile Strength Retained (%) in

In Vivo Digestion of Four Types of Suture

Days Implanted	Suture Type: Plain Size,2-0	Medium Chromic Size 2-0	Medium Chromic Size 1	Extra Chromic Size 2-0
1	61		93	90
2	28		87	102
3	39		61	85
4	35	64	47	
5	30		37	65
6	28		45	66
7	31	47	21	
8	16		27	49
9	9			
10	13		21	45
11		37		
12			11	62
13				53
14		26	8	
15			9	32
17				45
18		17	5	
19				39
20			12	13
21		16		
22			3	34
24			6	23
26			1	7
28				0
30				21

Table II

Average Nitrogen Retained (%) in In Vivo Digestion of Two Types of Suture.

Days Implanted	Suture Type: Plain Size 2-0	Suture Type: Medium Chromic Size 2-0
1	98	103
2	102	102
3	98	104
4	100	103
5	99	104
6	97	102
7	101	101
9	94	
10	93	
11		98
14		99
18		91
21		90

Table III

Average Weight Retained (%) in In Vivo

Digestion of two Types of Suture.

Days Implanted	Suture Type: Medium Chromic Size	Suture Type: Extra Chromic Size 2-0
1	100	100
2	100	101
3	99	100
4	94	
5	101	100
6	100	98
7	101	
8	99	97
10	97	98
12	90	93
14	91	
15	94	90
17		92
18	88	
19		94
20	90	86
22	70	94
24	92	86
26	53	69
28		65
30		83

Table IV

Shrinkage Temperature Analyses of Medium Chromic Sutures, Size 1 Controls and Implants as Determined with the Electronic Meter.

Rabbit	Shrinkage Temperature Control	Shrinkage Temperature Implant	Days Implanted
9970	56.0	59.5 59.0	1
9971	61.0	57.0 55.5	2
9972	60.0	54.0 57.0	3
9973	55.0	60.0 55.0 55.0	4
9969	56.0	55.0 55.5	5
9968	57.0	55.0 55.0	6
9974	55.0	53.0 57.0	7
9967	58.0	57.0 56.0	8
9966	57.5	53.0 56.5	10

Table V

Shrinkage Temperature Analyses of Plain Sutures, Size 2-0

Controls and Implants as Determined with the Electronic Meter.

Rabbit	Shrinkage Temperature Control	Shrinkage Temperature Implant	Days Implanted
9938	50.0	55.0 52.0	1
9936	54.5	54.0 53.0	2
9944	48.5	53.0 52.0	3
9945	52.0	55.0 54.0	4
9942	55.5	55.5 53.0	5
9940	52.5	56.0	6
9941	55.5	53.0 51.0	7
9939	54.5	53.5	8

Table VI

Shrinkage Temperature Analyses of Medium Chromic Sutures, Size 1 Controls and Implants as Determined by Macroscopic Technique.

Rabbit	Shrinkage Temperature Control	Shrinkage Temperature Implant	Days Implanted
9970	---	53.5	1
9971	57.5	54.0	2
9972	59.0	52.0	3
9973	56.0	51.0	4
9969	---	50.0	5
9968	---	50.0	6
9974	---	52.5	7
9967	---	52.0	8
9966	---	50.0	10
9965	---	48.5	12
9964	---	49.0	14
9963	58.5	48.5	15
9962	---	48.0	18
9960	58.0	47.5	20
9957	59.0	48.0	24

Table VII

Shrinkage Temperature Analyses of Plain Sutures, Size 2-0 Controls and Implants as Determined by Macroscopic Technique.

Rabbit	Shrinkage Temperature Control	Shrinkage Temperature Implant	Days Implanted
9938	51.0	54.0	1
9936	50.0	49.0	2
9944	51.5	50.5	3
9945	52.0	49.0	4
9942	50.5	48.0	5
9940	53.0	51.0	6
9939	54.0	51.0	8
9937	51.0	48.0	9
9943	52.0	49.0	10

Table VIII

Shrinkage Temperature Analyses of Extra Chromic Sutures, Size 2-0 Controls and Implants as Determined by Microscopic Technique.

Rabbit	Shrinkage Temperature Control	Shrinkage Temperature Implant	Days Implanted
213	60.5	57.5-59.5	1
214	58.5	57.5	2
215	59.5	55.5	3
216	60.5	55.0	5
217	61.5	54.0	6
218	59.0	53.0	8
212	59.0	56.0	12
211	59.0	54.5	13
210	62.5	53.0	15
209	60.0	53.0	17
208	59.0	54.5	19
201	59.0	52.0	20
202	60.0	54.5	22
203	61.0	52.0	24
204	60.0	52.5	26
205	60.0	53.0	28
206	59.0	52.0	30

Table IX

Average Chromium Retained (%) in In Vivo

Digestion of Three Types of Suture.

Days Implanted	Suture Type: Medium Chromic Size 2-0	Extra Chromic Size 2-0	Medium Chromic Size 1
1	88	84	84
2	87	102	75
3	81	95	72
4	80		83
5	70	83	99
6	64	76	69
7	71		
8		95	76
10		73	73
11	65		
12		65	75
13		75	
14	54		63
15		60	60
17		77	
18	61		64
19		68	
20		73	70
22		62	75
24		65	
26		47	54
28		51	
30		53	

Table X

Amino Nitrogen Analyses Medium Chromic

Sutures, Size 1, Controls and Implants

	Amino Nitrogen Per Cent by Gram
Medium Chromic Sutures, Size 1 Control	0.46
	0.41
	0.42
	0.41
	0.48
	0.49
Medium Chromic Sutures, Size 1 8 Day Implant	0.46
	0.43
	0.48

Table XI

Average Tensile Strength (pounds) of Dry, Wet and Artificially Shrunken Medium Chromic, Size 1 Implants Removed After Various Intervals of Digestion

Rabbit	Implants Removed (Day)	Implant	Wet Control	Wet Implant	Dry Implant	Shrunken Implant(70°C.)	Shrunken Implant(100°C.)
292	1	A	13.4	14.3	16.1	10.2	
		B	12.6	10.7	17.4		6.7
285	2	A	14.0	14.9	16.7	9.4	
		B	14.5	13.2	16.3		6.9
286	3	A	17.0	14.2	17.8		6.1
		B	12.5	13.8	14.5	10.3	
284	5	A	13.5	11.6	14.2	8.3	
		B	11.6	8.7	14.1		4.1
288	7	A	15.1	10.7	16.5		5.7
		B	16.6	10.5	14.2	7.7	
276	9	A	13.5	9.2	15.1		4.9
		B	15.3	7.3	13.6	3.5	
278	10	A	16.7	13.3	14.8		6.2
		B	15.4	10.3	12.7	6.0	
282	12	A	12.5	3.9	9.3		1.9
		B	17.1	7.1	13.7	6.2	
279	14	A	17.6	4.3	10.6		2.6
		B	17.1	11.7	14.8	8.2	
281	15	A	15.5	6.0	12.5		3.2
		B	18.0	11.1	14.0	8.3	
283	16	A	17.7	6.0	11.7		4.9
		B	15.7	7.8	11.7	3.5	
280	17	A	13.4	3.2	7.1	1.5	
		B	14.3	5.8	11.5		4.0
287	17	A	16.0	5.2		5.0	3.3
		B	14.5	8.7		6.3	5.3
291	17	A	12.7	4.2		3.3	3.3
		B	14.5	4.8		4.1	2.5

Table XII

Tensile Strength Determinations of Wet and Dry Non-Implante Medium Chromic Sutures, Size 1

Suture	Condition	Replicate Tensile Tests (pounds)								Average Per Cent Wet/Dry
1	Dry	12.8	16.0	16.8	18.8	20.0	20.3	20.5	20.8	
	Wet	15.1	15.7	15.9	16.2	16.8	16.8	17.6	18.8	91
2	Dry	17.5	17.8	18.0	18.5	19.0	20.5	21.0		
	Wet	14.4	15.8	16.3	17.0	17.1	17.1	17.4	17.8	88
3	Dry	14.0	14.3	19.8	20.5	20.5	20.5	20.8	21.8	
	Wet	15.2	15.5	16.1	16.8	16.9	17.3	17.4	18.3	88
4	Dry	15.8	18.8	18.8	18.8	19.3	20.3	20.5		
	Wet	14.9	15.0	15.0	16.2	17.0	17.7	17.0	17.3	86
5	Dry	15.3	15.8	17.3	17.8	17.8	18.3	18.5	18.5	
	Wet	14.4	14.5	15.2	15.7	15.9	16.1	16.3	16.9	89

Table XIII

Tensile Strength Determinations of Non-Implanted Wet and Shrunken (100 C, 30 seconds) Medium Chromic Sutures, Size 1

Suture	Condition	Replicate Tensile Tests (pounds)						Average Per Cent Shrunken/Wet
1	Shrunken	11.4	11.1	10.8	10.7	9.9		
	Wet	19.0	18.6	18.4	16.4	15.4	14.2	62.4
2	Shrunken	10.2	10.1	9.4	9.1	6.4	5.7	
	Wet	18.4	18.1	16.8	16.8	16.6	14.7	50.3
3	Shrunken	11.5	10.6	10.0	10.0	9.9	8.4	
	Wet	18.0	17.2	17.0	16.4	16.2	16.0	58.6
4	Shrunken	10.5	10.0	9.6	8.8	8.9		
	Wet	17.6	17.2	16.4	16.2	15.6	14.6	58.9
5	Shrunken	9.5	9.0	9.0	8.0	8.0	6.8	
	Wet	16.9	16.8	16.0	15.8	15.4	14.8	52.5
6	Shrunken	9.4	9.0	9.0	8.6	8.4	7.7	
	Wet	17.1	16.6	16.1	16.0	14.4	13.6	55.8
7	Shrunken	10.6	9.9	9.9	9.2	9.2	8.2	
	Wet	16.8	16.0	16.0	15.9	15.4	12.9	61.0
8	Shrunken	11.8	10.2	10.5	9.7	7.6		
	Wet	16.2	15.7	15.4	14.6	12.6	12.2	69.0

Table XIII (Continued)

Suture	Condition	Replicate Tensile Tests (pounds)						Average Per Cent Shrunken/Wet
9	Shrunken	10.9	10.2	9.5	8.9	8.6	8.1	
	Wet	16.3	16.1	15.9	15.2	14.4	13.9	61.4
10	Shrunken	9.0	8.6	8.0	7.8	7.8	7.3	
	Wet	14.2	12.6	11.2	11.0	10.6	10.1	69.8

Table XIV

Tensile Strength Determinations of Non-Implanted Wet and Shrunken (70°C, 45 seconds) Medium Chromic Sutures, Size 1

Suture	Condition	Replicate Tensile Tests (pounds)				Average Per Cent Shrunken/Wet
1	Shrunken	15.2	13.6	13.6	12.2	
	Wet	16.0	17.0	17.2	17.8	80.5
2	Shrunken	12.1	12.4	12.7	13.0	
	Wet	17.2	17.5	17.6	18.6	71.1
3	Shrunken	10.9	12.8	12.8	13.4	
	Wet	15.1	16.0	16.3	17.0	77.6
4	Shrunken	10.2	11.9	13.0	13.8	
	Wet	14.6	15.9	17.6	19.2	72.6
5	Shrunken	15.1	14.8	14.9	14.4	
	Wet	17.6	18.1	18.7		81.7
6	Shrunken	13.6	13.7	13.9	14.4	
	Wet	14.4	15.6	16.4	16.7	87.9
7	Shrunken	11.4	12.2	12.7		
	Wet	13.4	14.6	15.9	16.0	80.6
8	Shrunken	7.6	11.5	11.8	12.2	
	Wet	12.5	13.5	13.6	14.7	79.4

Table XIV (Continued)

Suture	Condition	Replicate Tensile Tests (pounds)				Average Per Cent Shrunken
9	Shrunken	9.2	9.2	10.8	11.7	
	Wet	12.7	12.7	14.0	14.1	76.1
10	Shrunken	9.8	10.2	10.7	11.1	
	Wet	15.8	15.2	14.9	13.2	70.9
11	Shrunken	10.1	10.1	11.2		
	Wet	12.8	13.8	14.8	15.2	73.2
12	Shrunken	11.2	11.6	11.8	13.6	
	Wet	15.2	15.5	16.1		76.9

Table XV

Length Retained (%) by Shrunken Controls and Implants. Implants Arranged in Order of Decreasing Wet Tensile Strength.

Shrunk at 70°C.		Shrunk at 100°C.	
Controls	Implants	Controls	Implants
66	67	59	55
64	70	56	57
66	72	59	60
64	64	59	55
66	67	55	60
69	65	57	62
69	65	63	59
62	65	57	58
66	65	59	56
70	62	57	57
62	67		57
69	64		55
	64		56
	65		56
	63		57
			63

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Table A

Tensile Strength Determinations in In Vivo Digestion (pounds)

A. Medium Chromic Sutures, Size 2-0

Rabbit	Original Suture	Implant Removed (days) 4	7	11	14	18	21
1S	5.8 6.8	2.9	2.5	3.3	2.4	1.7	---
2S	7.6 6.1	2.4	1.2	0.5	---	---	---
4S	7.3 6.0	4.6	1.0 2.0 3.0 1.7	---	---	---	---
5S	7.5 7.8	5.7	2.5	---	---	---	---
6S	7.5 7.0	6.1	4.9	---	---	2.0	---
13S	7.5 8.0	4.8	4.7	3.0	2.5	---	---
14S	6.3 7.0	4.2	3.3	2.6	1.7	1.1	1.1
15S	6.5 6.7	4.1	4.0	1.7	1.5	---	---

Table A (Continued)

Rabbit	Original Suture	Implant Removed (days) 4	7	11	14	18	21
16S	7.6 6.8	4.6	4.5	4.6	2.1 1.1	---	---
17S	7.1 5.6	2.6	2.9	0.3	0.7	0.5	---
18S	7.9 6.6	6.6	3.8	4.5	2.9	0.5	---
Average Per Cent Retained		64	47	37	26	17	16

Table A

B. Plain Sutures, Size 2-0

Rabbit	Day Implants Removed	Original Suture	Implant 1	2	3	4	5	6	Average Per Cent Retained
9936	2	8.4 8.1	1.4	3.0	1.8	2.3	3.2	2.1	28
9937	9	6.8 5.4	0.2	0.7	1.3	0.4	0.5	0.1	9
9938	1	6.0 6.1	3.3	2.1	5.0	2.4	6.2	3.5	61
9939	8	6.6 6.6	0.8	1.0	1.8	0.8	2.0	0.0	16
9940	6	5.3 6.3	2.2	0.8	1.0	1.8	2.3	1.6	28
9941	7	5.5 6.0	1.6	2.4	1.4	2.3	2.0	1.0	31
9942	5	7.1 7.2	2.3	1.6	3.3	1.7	1.7	2.5	30
9943	10	5.4 5.6	0.3	1.0	0.5	0.8	1.2	0.4	13
9944	3	5.1 6.5	2.1	1.4	2.7	3.1	2.3	1.9	39

Table A (Continued)

Rabbit	Day Implants Removed	Original Suture	Implant 1	2	3	4	5	6	Average Per Cent Retained
9945	4	6.5 6.0	2.2	2.8	2.3	1.4	2.0	2.5	35

C. Extra Chromic Sutures, Size 2-0

Rabbit	Day Implants Removed	Original Suture	Implant 1	2	3	4	5	6	Average Per Cent Retained
213	1	5.9 7.4	5.5	6.8	6.4	6.0	6.3	4.9	90
214	2	4.7 7.1	5.5	5.6	---	6.8	6.5	5.8	102
215	3	7.4 8.4	6.8	5.6	7.1	7.6	6.1	6.7	85
216	5	5.8 8.0	5.3	5.0	5.5	3.9	5.0	2.0	65
217	6	7.5 7.9	4.6	6.7	5.4	3.1	5.0	6.0	66
218	8	7.5 7.9	1.9	4.4	2.7	4.6	3.9	5.1	49

Table A (Continued)

Rabbit	Day Implants Removed	Original Suture	Implant 1	2	3	4	5	6	Average Per Cent Retained
5692	10	6.4 6.5	2.1	3.7	2.8	3.5	3.7	1.7	45
212	12	5.8 6.4	3.1	3.5	4.0	4.8	3.8	3.6	62
211	13	7.7 8.0	4.2	5.2	3.4	3.4	4.0	4.7	53
210	15	6.2 7.5	1.5	4.1	1.5	1.4	1.3	3.2	32
209	17	6.1 6.7	3.1	2.5	3.7	3.3	2.5	1.7	45
208	19	6.3 6.5	2.4	1.0	2.8	2.5	4.1	2.4	39
201	20	8.4 8.5	1.7	0.5	0.5	0.7	3.0	0.3	13
202	22	7.1 7.4	1.9	2.2	3.1	2.4	1.9	3.3	34
203	24	8.2 7.3	1.0	1.5	1.4	1.5	2.1	3.2	23
204	26	7.9 7.4	1.4	0.8	0.5	0.0	0.0	0.0	7

Table A (Continued)

Rabbit	Day Implants Removed	Original Suture	Implant 1	2	3	4	5	6	Average Per Cent Retained
205	28	5.9 6.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
206	30	4.7	1.9	1.3	3.3	0.7	0.7	0.0	21

D. Medium Chromic Sutures, Size 1

Rabbit	Day Implants Removed	Original Suture	Implant 1	2	3	4	5	6	Average Per Cent Retained
9970	1	15.2 13.4 15.2	14.4	15.4	13.0	12.8	14.4	11.2	93
9971	2	12.8 15.6 14.6	13.2	11.0	13.6	12.4	12.2	12.2	87
9972	3	14.4 15.2 14.0	10.0	12.6	8.8	6.8	4.8	10.2	61

Table A (Continued)

Rabbit	Day Implants Removed	Original Suture	Implant 1	2	3	4	5	6	Average Per Cent Retained
9973	4	11.6 13.0 13.0	7.0	7.2	6.0	2.0	6.6	6.6	47
9969	5	13.4 14.2 12.2	3.4	5.6	5.6	3.8	5.2	6.0	37
9968	6	14.0 14.6 14.4	12.0	6.6	7.0	4.4	5.0	4.2	45
9974	7	13.8 14.2 14.4	2.6	3.6	3.6	3.0	3.0	2.3	21
9967	8	14.4 14.2 14.6	4.2	4.8	3.2	3.3	3.6	4.1	27
9966	10	12.6 15.2 14.6	3.3	1.7	2.3	3.2	4.7	2.3	21
9965	12	12.6 14.0 13.4	0.6	1.9	1.8	1.7	1.5	1.0	11
9964	14	14.6 15.0 14.8	1.6	0.5	1.5	1.2	0.7	1.2	8

Table A (Continued)

Rabbit	Day Implants Removed	Original Suture	Implant 1	2	3	4	5	6	Average Per Cent Retained
9963	15	15.6 15.6	1.3	0.9	1.5	1.0	2.5	1.4	9
9962	18	12.4 16.4 11.2	0.5	1.2	0.7	0.2	1.2	0.3	5
9960	20	15.6 15.6	2.0	3.0	2.3	1.8	1.0	1.6	12
9952	22	14.5 15.4	0.3	0.7	0.5	0.3	1.2	---	3
9957	24	13.6 14.8	0.7	0.5	0.8	1.4	1.1	---	6
9959	26	12.2 14.6 16.6	0.1	0.5	0.1	0.4	0.2	0.0	1

Table B

Nitrogen Determinations in In Vivo Digestion (mg./inch suture)

A. Medium Chromic Sutures, Size 2-0

Rabbit	Original Suture	Implant Removed (days) 1	2	3	4	5	6	7	11	14	18	21
9976S	0.527 0.525	0.536	0.554	0.565	0.546	0.592	0.544					
9977S	0.513 0.512	0.536	0.538	0.547	0.534	0.536	0.527					
9978S	0.527 0.523	0.530	0.515	0.553	0.527	0.525	0.527					
9979S	0.524 0.526	0.527	0.521	0.523	0.537	0.539	0.525					
9980S	0.533 0.526	0.552	0.569	0.538	0.549	0.542	0.538					
9981S	0.536 0.537	0.554	0.553	0.549	0.555	0.564	0.537					
1S	0.520 0.524							0.553	0.523	0.524	0.472	
2S	0.523 0.508							0.536	0.512	0.501 0.526		
3S	0.521 0.521							0.532	0.504			

Table B (Continued)

Rabbit	Original Suture	Implant Removed (days) 1	2	3	4	5	6	7	11	14	18	21
4S	0.509 0.513							0.497 0.541 0.504 0.477				
5S	0.531 0.530				0.543			0.475				
6S	0.492 0.489				0.521			0.468			0.416	
13S	0.512 0.507				0.524			0.520	0.486	0.577		
14S	0.494 0.500				0.525			0.531	0.518	0.512	0.422	0.449
15S	0.461 0.492				0.494			0.488	0.469	0.433		
16S	0.498 0.502				0.498			0.519	0.485-	0.527	0.455	
17S	0.526 0.520				0.519			0.541	0.535	0.426	0.451	
18S	0.508 0.524				0.547			0.545	0.457	0.460	0.561	
Average Per Cent Retained		103	102	104	103	104	102	101	98	99	91	90

Table B

B. Plain Sutures, Size 2-0

Rabbit	Day Implants Removed	Original Suture	Implant 1	2	3	4	5	6	Average Per Cent Retained
9936	2	0.520 0.516	0.524	0.526	0.528	0.529	0.540	0.521	102
9937	9	0.508 0.513	0.475	0.494	0.477	0.491	0.450	----	94
9938	1	0.528 0.529	0.506	0.506	0.544	0.536	0.528	0.533	98
9940	6	0.530 0.526	0.506	0.500	0.512	0.512	0.521	0.505	97
9941	7	0.532 0.531	0.544	0.546	0.553	0.528	----	0.515	101
9942	5	0.520 0.515	0.521	0.507	0.502	0.518	0.514	0.505	99
9943	10	0.528 0.537	0.480	0.502	0.502	0.501	----	0.503	93
9944	3	0.535 0.530	0.527	0.507	0.537	0.527	0.504	0.517	98
9945	4	0.510 0.516	0.515	0.525	0.512	0.508	0.523	0.502	100

Table C

Weight Determinations in In Vivo Digestion (mg./inch)

A. Extra Chromic Sutures, Size 2-0

Rabbit	Day Implants Removed	Original Suture	Implant 1	2	3	4	5	6	Average Per Cent Retained
213	1	3.36 3.33	3.28	3.32	3.28	3.35	3.43	3.38	100
214	2	3.32 3.22	3.32	3.40	3.38	3.33	3.15	3.33	101
215	3	3.28 3.27	3.13	3.33	3.28	3.30	3.30	3.30	100
216	5	3.20 3.32	3.28	3.30	3.30	3.30	3.25	3.20	100
217	6	3.33 3.30	3.18	3.30	3.25	3.25	3.28	3.30	98
218	8	3.37 3.35	3.25	3.25	3.23	3.23	3.23	3.30	97
5692	10	3.33 3.32	3.25	3.33	3.23	3.30	3.23	3.23	98
212	12	3.35 3.27	3.08	3.10	3.08	3.05	3.05	3.10	93
211	13	3.27 3.17	3.28	3.23	3.25	3.00	3.18	3.20	99

Table C (Continued)

Rabbit	Day Implants Removed	Original Suture	Implant 1	2	3	4	5	6	Average Per Cent Retained
210	15	3.35 3.35	3.05	3.05	2.93	3.10	3.03	3.03	90
209	17	3.35 3.33	3.15	3.00	3.08	3.08	3.13	3.03	92
208	19	3.43 3.33	3.18	3.00	3.20	3.18	3.18	3.20	94
201	20	3.35 3.39	3.05	2.73	2.75	3.00	3.10	2.83	86
202	22	3.33 3.32	3.03	3.15	3.13	3.13	3.15	3.25	94
203	24	3.36 3.33	2.65	2.88	2.88	2.83	3.00	3.00	86
204	26	3.33 3.39	2.48	2.43	2.28	2.10	2.20	---	69
205	28	3.36 3.35	2.88	2.00	1.75	2.10	2.10	---	65
206	30	3.33 3.33	2.73	2.93	2.75	2.85	2.65	2.60	83

Table C

B. Medium Chromic Sutures, Size 1

Rabbit	Day Implants Removed	Original Suture	Implant 1	2	3	4	5	6	Average Per Cent Retained
9970	1	6.98	6.92	6.82	6.96	6.93	7.00	7.05	100
9971	2	6.89	6.97	6.93	6.89	6.93	6.93	6.85	100
9972	3	7.05	6.95	6.99	6.92	6.97	6.86	6.99	99
9973	4	6.87	6.83	6.74	6.78	6.69	6.89	6.83	97
9969	5	6.66	6.51	6.82	6.67	6.49	6.87	6.94	101
9968	6	6.91	6.99	6.87	7.00	6.83	7.04	6.91	100
9974	7	6.98	7.08	7.03	6.97	6.89	7.06	7.00	101
9967	8	6.74	6.67	6.83	6.60	6.57	6.50	6.65	99
9966	10	6.87	6.76	6.55	6.66	6.76	6.66	6.74	97
9965	12	6.65	5.69	6.59	6.05	4.92	6.18	6.20	90
9964	14	6.71	6.16	5.86	6.36	5.84	6.05	6.36	91
9963	15	7.10	6.72	6.65	6.67	6.49	6.78	6.60	94
9962	18	6.87	5.75	6.90	6.51	5.42	6.35	5.30	88

Table C (Continued)

Rabbit	Day Implants Removed	Original Suture	Implant 1	2	3	4	5	6	Average Per Cent Retained
9960	20	7.05	6.40	6.49	6.49	6.35	6.15	6.22	90
9952	22	6.91	4.32	5.43	4.92	4.49	4.69	----	70
9957	24	7.15	6.29	6.59	6.79	6.59	6.71	6.59	92
9959	26	7.01	3.80	4.25	3.54	3.84	3.20	----	53

Table D

Chromium Determinations in In Vivo Digestion (gamma/inch suture)

A. Medium Chromic Sutures, Size 2-0

Rabbit	Original Suture	Implant Removed (days) 1	2	3	4	5	6	7	11	14	18	21
9976S	7.2 8.2	5.7	5.8	6.4	6.5	6.8	5.2					
9977S	6.9 6.3	6.8	5.8	3.9	6.5	5.8	---					
9978S	7.7 8.1	7.0	7.0	7.0	6.5	6.3	4.7					
9979S	7.7 7.7	6.3	7.6	6.0	7.6	5.4	5.0					
9980S	9.4 8.6	7.2	7.6	6.8	6.8	5.0	5.8					
9981S	5.2 5.1	5.0	---	5.1	6.0	3.6	---					
1S	6.8 6.8				3.3			4.3	2.9	3.8	4.0	---
2S	7.7 8.9				5.4			4.8	5.1	4.6 4.3	---	---
3S	7.8 7.9				4.7			4.0	4.6	---	---	---

Table D (Continued)

Rabbit	Original Suture	Implant Removed (days) 1	2	3	4	5	6	7	11	14	18	21
4S	7.2				6.5			4.7 5.2 5.4 6.2				
5S	8.4 8.5				5.8			5.7				
6S	7.9 7.9				6.4			5.4			4.5	
13S	6.5 6.2				5.6			4.6	5.9	5.3		
14S	5.7 5.0				4.7			4.7		2.5	3.6	
15S	5.3 5.3				3.0			3.7		2.2		
16S	11.7 11.7				11.4			8.2	8.4	5.9		
17S	9.1 7.6							5.5	5.5	3.3	5.3	
18S	8.8 9.1				6.4			8.3		5.4		
Average Per Cent Retained		88	87	81	80	70	64	71	65	54	61	

Table D (Continued)

B. Extra Chromic Sutures, Size 2-0

Rabbit	Day Implants Removed	Original Suture	Implant 1	2	3	4	5	6	Average Per Cent Retained
213	1	11.9 12.2	8.3	11.2	14.4	8.7	8.8	9.9	84
214	2	9.3 9.7	8.6	9.0	10.5	10.5	9.6	10.1	102
215	3	8.2 10.3	8.9	11.0	9.6	8.8	9.0	5.5	95
216	5	10.0	7.0	8.6	8.9	8.3	10.5	6.5	83
217	6	11.6 11.1	8.6	8.9	8.0	10.1	8.0	8.4	76
218	8	9.7 10.5	9.6	9.5	9.5	10.0	9.8	9.1	95
5692	10	12.6 12.0	8.8	8.7	9.1	8.2	8.9	10.0	73
212	12	10.0 10.1	6.9	7.1	8.4	8.0	4.2	5.1	65
211	13	10.1 9.6	7.3	8.6	6.5	5.9	8.0	8.3	75

Table D (Continued)

Rabbit	Day Implants Removed	Original Suture	Implant 1	2	3	4	5	6	Average Per Cent Retained
210	15	11.9 13.8	6.4	9.0	6.4	7.2	7.1	9.9	60
209	17	11.4 12.4	10.5	9.3	10.1	8.5	8.6	8.3	77
208	19	11.7 8.6	8.7	7.7	6.4	5.6	7.7	6.2	68
201	20	9.3 8.6	6.5	4.3	7.2	7.2	7.0	7.2	73
202	22	10.5 11.5	6.6	4.2	7.8	6.4	7.5	8.0	62
203	24	13.2 12.6	7.7	7.5	9.2	7.1	9.1	9.8	65
204	26	12.3 11.0	6.5	5.7	5.3	5.8	4.4	---	47
205	28	9.6 10.5	6.6	3.8	4.3	5.7	---	---	51
206	30	11.6 10.5	7.2	5.5	6.2	5.3	6.4	5.1	53

Table D (Continued)

C. Medium Chromic Sutures, Size 1

Rabbit	Day Implants Removed	Original Suture	Implant 1	2	3	4	5	6	Average Per Cent Retained
9970	1	15.6 14.8 15.4	9.4	14.4	8.8	13.4	17.2	13.2	84
9971	2	23.2 25.0	18.4	21.6	11.2	16.0	22.4	18.4	75
9972	3	17.8 17.6	10.0	11.8	11.0	17.4	12.8	13.2	72
9973	4	14.2	12.6	12.0	11.8	12.2	11.4	10.6	83
9969	5	9.8 9.6 11.8	9.6	12.4	11.0	9.2	9.0	10.8	99
9968	6	16.0 14.6	10.6	7.8	10.6	11.2	11.8	11.8	69
9967	8	14.2 21.4 19.2	14.8	15.6	14.2	9.6	15.0	13.8	76
9966	10	17.2 19.6	11.0	10.0	15.8	14.6	16.0	12.2	73
9965	12	18.8 17.4	12.8	13.6	11.8	15.2	16.2	11.8	75

Table D (Continued)

Rabbit	Day Implants Removed	Original Suture	Implant 1	2	3	4	5	6	Average Per Cent Retained
9964	14	13.4 15.0	8.6	9.6	11.4	8.2	7.6	8.4	63
9963	15	15.4 11.6 18.0	9.0	8.2	10.2	---	8.2	9.4	60
9962	18	15.0 16.0	6.8	10.8	11.4	9.4	11.4	9.4	64
9960	20	18.4 17.4	15.0	14.6	10.0	7.6	14.4	13.2	70
9952	22	17.8 17.2	15.4	10.2	14.4	14.2	11.6	---	75
9959	26	15.2 13.8 16.8	11.2	9.8	7.8	6.8	5.4	8.4	54

Table E

Tensile Strength (pounds) of Dry, Wet and Artificially Shrunken Medium Chromic, Size 1 Implants Removed After Various Intervals of Digestion.

Rabbit	Implants Removed (Day)	Implant	Wet Control	Wet Implant	Dry Implant	Shrunken Implant(70°C.)	Shrunken Implant(100°C.)
292	1	A	14.7	14.9	19.5	11.9	
			14.3	14.5	19.0	10.7	
			12.5	14.7	17.3	10.5	
			12.0	12.9	16.5	10.4	
						9 .6	
						11.9	
		Mean	13.4	14.3	18.1	10.2	
		B	13.9	9.7	19.3		5.8
			13.3	9.9	18.3		6.6
			11.8	11.0	17.5		6.7
			11.4	12.3	14.5		7.2
							7.3
		Mean	12.6	10.7	17.4		6.7
285	2	A	15.6	13.5	18.0	10.2	
			15.0	14.5	17.5	10,1	
			12.9	14.7	16.8	9.2	
			12.5	16.8	14.3	8.7	
						8.6	
		Mean	14.0	14.9	16.7	9.4	

Table E (Continued)

Rabbit	Implants Removed (Day)	Implant	Wet Control	Wet Implant	Dry Implant	Shrunken Implant(70°C.)	Shrunken Implant(100°C.)
285	2	B	15.3	10.8	17.5		6.3
			15.1	12.6	17.5		6.5
			14.9	14.7	15.8		6.8
			12.7	14.7	14.5		8.0
		Mean	14.5	13.2	16.3		6.9
286	3	A	18.1	15.3	19.1		5.1
			17.5	15.1	19.1		5.3
			16.7	13.8	16.5		5.7
			15.8	12.7	16.4		6.8
							7.4
		Mean	17.0	14.2	17.8		6.1
		B	13.6	14.1	17.8	10.7	
			13.3	15.2	14.1	10.4	
			12.2	13.8	13.8	10.4	
			11.0	12.0	12.3	10.1	
						9.8	
		Mean	12.5	13.8	14.5	10.3	
284	5	A	15.3	8.8	15.8	9.2	
			14.4	12.2	15.4	8.4	
			13.2	12.2	14.0	8.3	
			11.0	13.2	11.6	8.1	
						7.7	
		Mean	13.5	11.6	14.2	8.3	

Table E (Continued)

Rabbit	Implants Removed (Day)	Implant	Wet Control	Wet Implant	Dry Implant	Shrunken Implant(70°C.)	Shrunken Implant(100°C.)
284	5	B	12.9	10.5	16.9		4.5
			11.2	8.4	16.8		4.2
			11.1	8.2	11.3		4.2
			11.0	7.7	11.3		3.6
							4.1
		Mean	11.6	8.7	14.1		4.1
288	7	A	16.4	11.8	18.3		5.9
			15.7	11.5	16.5		5.6
			14.6	10.8	16.3		5.6
			13.5	8.6	15.0		5.5
		Mean	15.1	10.7	16.5		5.7
		B	17.9	9.1	15.0	8.7	
			17.4	10.5	14.3	8.0	
			17.0	11.1	14.0	8.0	
			14.1	11.2	13.6	7.0	
						6.6	
		Mean	16.6	10.5	14.2	7.7	
276	9	A	12.8	9.8	17.0		4.4
			13.3	9.8	16.3		4.5
			13.7	9.7	14.5		5.3
			14.3	7.4	12.5		4.6
							5.6
		Mean	13.5	9.2	15.1		4.9

Table E (Continued)

Rabbit	Implants Removed (Day)	Implant	Wet Control	Wet Implant	Dry Implant	Shrunken Implant(70°C.)	Shrunken Implant(100°C.)
276	9	B	16.6	4.8	14.3	2.2	
			15.8	4.8	14.3	2.8	
			14.8	8.1	13.0	2.7	
			14.1	11.4	12.8	3.0	
						3.6	
		Mean	15.3	7.3	13.6	3.5	
278	10	A	18.0	14.6	15.5		7.4
			16.3	13.7	15.5		6.0
			16.2	13.6	15.0		5.9
			16.2	11.1	13.0		5.9
							5.7
		Mean	16.7	13.3	14.8		6.2
		B	16.6	12.3	14.8	7.5	
			15.9	11.6	13.8	7.5	
			15.2	8.8	13.5	6.3	
			13.9	8.3	8.8	4.8	
						3.8	
		Mean	15.4	10.3	12.7	6.0	
282	12	A	13.3	7.1	10.4		2.4
			12.7	5.2	10.5		1.9
			12.2	1.7	9.8		1.6
			11.8	1.6	6.5		1.5
		Mean	12.5	3.9	9.3		1.9

Table E (Continued)

Rabbit	Implants Removed (Day)	Implant	Wet Control	Wet Implant	Dry Implant	Shrunken Implant(70°C.)	Shrunken Implant(100°C.)
282	12	B	18.5	11.4	16.0	7.5	
			17.4	7.3	14.8	7.6	
			17.0	5.8	13.2	6.7	
			15.4	4.0	10.8	5.2	
						4.2	
		Mean	17.1	7.1	13.7	6.2	
279	14	A	18.0	5.7	13.8		3.0
			17.8	5.6	9.8		3.0
			17.3	3.6	9.3		2.5
			17.2	2.4	9.3		2.0
		Mean	17.6	4.3	10.6		2.6
		B	17.9	13.6	16.8	9.1	
			17.2	12.3	14.3	9.4	
			17.3	11.9	14.3	8.1	
			16.0	8.9	13.8	7.0	
						7.2	
		Mean	17.1	11.7	14.8	8.2	

Table E (Continued)

Rabbit	Implants Removed (Day)	Implant	Wet Control	Wet Implant	Dry Implant	Shrunken Implant(70°C.)	Shrunken Implant(100°C.)
281	15	A	16.4	7.7	14.5		3.8
			15.6	7.0	13.0		3.7
			15.6	5.4	12.0		3.1
			14.2	3.8	10.3		2.2
		Mean	15.5	6.0	12.5		3.2
		B	18.9	12.3	16.0	10.0	
			18.1	12.1	14.8	8.6	
			17.1	10.4	13.5	7.8	
				9.6	11.8	7.7	
						7.6	
		Mean	18.0	11.1	14.0	8.3	
283	16	A	18.5	8.3	15.0		7.3
			17.8	6.0	11.5		4.8
			17.7	5.8	10.3		4.0
			16.8	3.8	10.0		3.5
		Mean	17.7	6.0	11.7		4.9
		B	16.3	11.5	12.8	3.8	
			15.6	8.5	11.8	3.8	
			15.6	7.5	11.5	3.3	
			15.2	3.7	10.8	3.0	
		Mean	15.7	7.8	11.7	3.5	

Table E (Continued)

Rabbit	Implants Removed (Day)	Implant	Wet Control	Wet Implant	Dry Implant	Shrunken Implant(70°C.)	Shrunken Implant(100°C.)
280	17	A	13.5	4.4	8.0	2.2	
			13.5	3.2	7.6	1.7	
			13.3	3.0	6.5	1.6	
			13.1	2.3	6.4	0.5	
		Mean	13.4	3.2	7.1	1.5	
		B	15.1	7.0	12.4		4.1
			14.6	6.4	11.9		4.1
			14.2	5.2	10.9		3.8
			13.4	4.6	10.9		3.8
		Mean	14.3	5.8	11.5		4.0
287	17	A	16.7	6.6		3.5	3.8
			16.0	6.2		5.0	3.8
			15.8	4.6		5.3	3.3
			15.5	3.4		6.1	2.4
		Mean	16.0	5.2		5.0	3.3
		B	15.7	10.2		4.5	6.7
			15.6	10.1		5.1	5.6
			14.6	7.8		6.3	4.3
			12.0	6.5		9.3	4.6
		Mean	14.5	8.7		6.3	5.3

Table E (Continued)

Rabbit	Implants Removed (Day)	Implant	Wet Control	Wet Implant	Shrunken Implant(70°C.)	Shrunken Implant(100°C.)
291	17	A	13.9	4.4	5.0	4.2
			12.6	4.3	3.4	3.5
			12.6	4.2	2.9	2.2
			11.8	3.9	2.0	
		Mean	12.7	4.2	3.3	3.3
		B	16.6	6.7	5.2	2.7
			14.4	5.7	4.5	2.4
			14.3	5.2	4.4	2.5
			12.6	1.7	2.4	2.5
		Mean	14.5	4.8	4.1	2.5