HANDLING CHARACTERISTICS OF SURGICAL THREADS

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Abstract. The appearance of new suture materials has motivated a comprehensive study of their properties. The detailed mechanical information on suture materials must be at the disposal of practical surgeons to help them in choosing the appropriate material. They must know exactly to what extent a thread in the hands is soft and ductile, how many knots will be required to fix a suture, and what type of stitch is optimal for the chosen thread. This paper is devoted to evaluating the manipulation properties of surgical threads. Several foreign absorbable threads of a standard size 3-0, most frequently utilized in abdominal surgery, were examined. They were Vicryl, Sofsilk, Polysorb, Dexon (braided) and twisted Kapron (Russian production) in multifilament form, Catgut, Maxon and Biosyn (the last was obtained in 1996) in monofilament form. The tensile diagrams for these threads are given and Young's modulus is determined for each thread. The procedure is proposed here to determine the flexural stiffness of surgical threads. The interrelation of the stiffness of threads with Young's modulus and its dependence on the amount of fibres in the strand of twisted and braided threads are shown. In addition, the flexural stiffness of some Russian-made threads was measured: Lavsan, Florest, Polyamide, Polypropylene, Ftorlon, PKA, PA, PP.

Key words: suture material, surgical thread, Young's modulus, mechanical properties, handling characteristics, flexural stiffness

One of the requirements imposed on suture materials is their good handling characteristics. It means that a surgical thread must be flexible, ductile and easy to tie into a knot. Yet only few suture materials possess such properties. Structurally, suture materials can be differentiated into two groups: monofilament threads that represent a continuous fibre resembling a fishing line and multifilament threads that consist of many artificial or natural fibres, twisted in a strand or braided (cable braiding) (Fig. 1). The application of monofilament threads made it possible to substantially reduce the number of pyo-septic complications on the side of surgical sutures [1, 2]. Note, however, that these threads possess considerably higher stiffness in comparison with multifilament threads and much more knots are required for their retention, which increases the mass of the suture material implanted in tissues. Consequently, the duration of operation increases as well, and the surgeon must take particular care when stitching up a wound. Furthermore, being convenient in the work, the multifilament threads (twisted and braided) have some drawbacks that prohibit their wide use. These are capillarity existing to lesser or greater degree in such threads and traumatising properties caused by rough surfaces. However, in practice the preference is given to these suture materials. This can be explained, on the one hand, by the desire of surgeons to simplify the operational methods of sewing tissues and, on the other hand, by certain conservatism in selecting
threads. The point is that the production and, naturally, use of multifilament threads started much earlier than of monofilament threads. Therefore, in choosing suture material one should determine the expediency of using particular threads, including and taking into account their handling characteristics.

In order to estimate the flexibility of threads, some researchers determined Young's modulus for these materials [3–6] in uniaxial tensile tests and compared the obtained results, reasoning from the fact that the higher the modulus of elasticity, the stiffer the material.

We carried out a series of uniaxial tensile tests for seven foreign threads of a standard size 3-0 and a thread manufactured in Russia. These are commonly used Sofsilk («USSC»), Dexon («Devis+Geek»), Vicryl («Ethicon»), Polysorb («USSC») and Kapron in multifilament form, and Catgut («Ethicon»), Maxon («Devis+Geek») and Biosyn («USSC») in monofilament form.

So that the thread would not be damaged in grips, and the experimental results would not be distorted due to the local stress concentration, we designed the special-purpose grips, which are shown schematically in Fig. 2. The ends of the thread are fastened to the round rotating rods of diameter 5 mm, and at least two turns of winding are applied on the rods. The rods are fixed in this position, which means that the grips are ready to operate. This design excluded the breakage in the thread near the grips – all ruptures took place in the working (base) section.
Fig. 3. Tensile diagrams for surgical threads: b – Biosyn (mono); s – Sofsilk (braided); v – Vicryl (braided); m – Maxon (mono); p – Polysorb (braided); d – Dexon; k – Kapron (twisted); c – Catgut (mono).

Fig. 4. Initial section of tensile curves for surgical threads: b – Biosyn $E=9400$ MPa; p – Polysorb $E=6500$ MPa; s – Sofsilk $E=8200$ MPa; d – Dexon $E=5700$ MPa; v – Vicryl $E=7600$ MPa; k – Kapron $E=2100$ MPa; m – Maxon $E=7400$ MPa; c – Catgut $E=2000$ MPa; $E$ – initial modulus of elongation (Young’s modulus).
The tensile properties of all suture materials were determined on the tensile testing machine 2156 P-50. The threads with a length of 200 mm were extended with a constant velocity of 200 mm/min. Deformation was measured with respect to the base marks with accuracy 0.5 %.

In the test procedure widely used by foreign investigators [4], the measurements have been made in terms of «tenacity» that is an equivalent to «stress». Tenacity is measured in grams per denier (GPD) and can be characterised by the amount of weight required to break up a fibre or a thread of size of one denier (a denier is defined as the weight in grams of a fibre or a thread of 9,000 meters long). The weight characteristic of a thread was used to avoid difficulties encountered in defining the cross-section area of multifilament threads – the method employed in the textile industry. Accordingly, the modulus of elasticity was also determined in GPD. The nominal diameter of a surgical thread was defined with the aid of an indicator with a plane measuring surface solely to obtain the standard size of a thread. A drawback of this method is that it does not allow the establishment of the interrelation between the mechanical characteristics of threads determined in different tests.

In the present work, we used the traditional method, accepted in mechanics for determining the stress–strain relationship. The cross-section of threads was determined by the use of a toolmaker's microscope БМИ–1Ц. Diameters of threads, preliminarily stretched under the load of 3 N, were measured with an accuracy of 0.001 mm. For twisted Kapron that consisted of fibres large enough to be measured, we determined the cross-section of one fibre and then multiplied the obtained value by a number of fibres in the thread. The result was the «effective» cross-section of the thread. Thus, we reduced to a minimum the error introduced by the presence of spaces between fibres. The stress caused by tension was defined as the ratio of force in the newtons to the effective cross-section in square meters (Pa). Then, by performing simple calculations, the effective diameter of a twisted thread was determined. This approach makes it possible to obtain the mechanical characteristics of suture materials with highly inhomogeneous structure that reflect the real properties of materials from which the thread is made and relates such parameters as Young’s modulus, stiffness, strength, etc. Thus, our experience has verified some important advantages of the proposed method over the existing procedures.

The results of tensile tests are presented in Fig. 3. It is evident from the graph that it is not possible to simply calculate the secant modulus as the ratio of maximum strength to maximum strain, because almost all threads have an elongation plateau that strongly distorts data, not allowing the comparative estimation. Then it was suggested to use a tangent modulus after the elongation plateau. Yet this did not give good results as well, since for modern monofilaments, made from polymeric materials, this plateau is very great and the tangent modulus is less than, for example, that of silk. At the same time, it is well known that their stiffness is considerably higher. It was proposed to measure the initial modulus of elasticity. Some researchers [3, 7] determined it at 2 % strain. Others [8], having revealed that the zone of elasticity of synthetic monofilaments was very small, started to determine Young's modulus at 1 % strain. It should be noted that the absence of the zone of elasticity is characteristic of polymeric materials; therefore, the measurement of the initial modulus is associated with great difficulties and is sometimes impossible.

Figure 4 shows the initial sections of tension diagrams of threads. For the latest available Biosyn thread, Young's modulus was determined even at 0.2 % strain. However, these results can be considered positive, since, in the case of Biosyn, Young's modulus (at 0.2 % strain) exceeds the Sofsilk and Vicryl moduli only slightly, and in the case of Maxon it is even lower than that of the last two threads. Each surgeon, from his practical experience, knows that the stiffness of monofilament threads, such as Biosyn, Maxon, Polypropylene, Catgut, etc. is several times higher than that of twisted or braided threads, and Sofsilk, until now, is considered one of the most flexible fibres. From the viewpoint of manipulation
properties, it is even called a «golden standard» in surgery [2]. Therefore, a simple comparison of Young's moduli challenges the usefulness of this method for evaluating stiffness. Young's modulus characterises the properties of the material, of which the thread is made. A comparison of the initial moduli of elasticity does not take into account the number of fibres, of which threads consist of, and the sizes of these fibres, i.e. just the factors that substantially influence the flexibility of threads.

In [8], the stiffness of a suture was determined by using a ИЖ-3 stiffness tester. Here the tests were run on a strand of threads to allow application of greater loads. The threads of a prescribed length were fixed in grips with their ends attached to a force gauge. Then the grips were turned around their axes to 30°, and the load was recorded. Only the first load was taken into consideration. The stiffness of the strand of threads was determined by multiplying the test load by the numerical coefficient, typical for this device. The handling properties of the threads were estimated from comparison of the stiffness of threads. The obtained results were compared with the data of the organoleptic method and found to be in good agreement with the latter.

In [9], the stiffness of a thread was determined by using a Taber V-5 testing machine (model 150B, Teledyne Taber) in arbitrary units of the gage scale during the rotation of a head with grips by an angle of 7.5°.

Both methods are equivalent, but due to the fact that they are adapted to particular test machines, they are not easily comparable with the results, obtained by other methods, and with each other.

We used the same procedure for determining the flexural stiffness of the rod (supported as a cantilever) under load applied to its free end [10]. Materials were tested on a highly sensitive testing machine [11]. Figure 5 depicts a measuring circuit. It is seen that a thread was held in the mobile grip. The distance from the free end to the place of fastening was 10 mm. The free end of the thread moved towards the rod of a force sensor until it touched it, which is the benchmark of the movement of the mobile grip, and then the free end
was quickly bent to a prescribed value. The obtained deflection was 2 mm (deviation from the prescribed value was not more than 5 %). The value of the actual deflection was recorded by a cathetometer (with an accuracy of 0.01 mm) and was used in further calculations. The bending force was recorded with an accuracy of 0.5·10⁻⁶ N.

According to formula [12, 13], stiffness was determined on the basis of the exact solution to the problem of bending of the transversally isotropic rod by the force, applied to the free end of a cantilever fixed beam:

\[ EI = \frac{Fl^3}{3h} \]

where \( EI \) is the flexural stiffness, \( F \) is the test load, \( l \) is the cantilever length, \( h \) is the displacement of the free end, and \( E \) is Young's modulus in the plane \( yz \), perpendicular to isotropy plane (it is assumed that Young's modulus in transverse directions may not coincide with the modulus \( E \) along the thread), and \( I \) is the moment of the inertia of the cross-section relative to the axis of symmetry.

Using the proposed procedure, we have determined the stiffness of eight threads enumerated above, and some others: Sofsilk-0, Polysorb-0, Kapron-2/0, Ftorrest, Lavsan, Polyamide, Florlon, PKA – threads consisting of several fibres, and Polypropylene, Ftorrest-2, PA, PP – monofilament threads of Russian production.

In our experiments, the increased stiffness of all threads was detected at the first moment after bending. Then the stiffness index fell and after a certain time was stabilized. For some threads, the difference between the initial and basic stiffness reaches 36 %. In [9], the basic stiffness was determined 1 minute after loading. We established that this time was clearly insufficient. Only 5 minutes after loading the loss of stiffness (in comparison with the 4 minutes measurement) was less than 1 %; therefore, in this work the 5 minutes lag prior loading was used. The loss of stiffness under loading is explained as a “creep” phenomenon [9].

The obtained results are given in Table 1. They coincide with the subjective judgement of the stiffness of these threads [8].

As can be seen from Table 1, the flexural stiffness of monofilament threads is far in excess of the stiffness of multifilament threads. This can be explained only by the fact that the total stiffness of all fibres is not equal and is substantially less than the stiffness of one fibre, having an equivalent cross-section. Indeed, as it is evident from the axial moment of inertia for the round cross-section of diameter \( d \) in the stiffness formula,

\[ I = \frac{\pi d^4}{64}, \]

the dependence of stiffness is proportional to a change of the diameter to the fourth degree, and the stiffness of a multifilament thread must be equal to the sum of stiffness values of each fibre. In order to verify this statement, we measured the stiffness of a Lavsan surgical thread (see Table 1). This thread consists of 144 separate fibres of approximately equal diameter of \( d =0.0298 \text{ mm} \) (to improve the accuracy of determination of diameter up to \( 10^{-4} \text{ mm} \), the fibres were photographed under the microscope, and then their dimensions were measured on the photograph). The fibres of this thread are connected by twisting only (no surface treatment or impregnation). Following the procedure described above, we measured the stiffness of one fibre \( (EI =0.0293 \text{ cN-mm}^2) \). The total stiffness of all fibres \( (EI =4.22 \text{ cN-mm}^2) \) was only slightly lower than the stiffness of the thread \( (EI =4.52 \text{ cN-mm}^2) \). This difference is explained by the interaction of fibres in the thread – by their friction.
Table 1. Stiffness of some surgical threads

<table>
<thead>
<tr>
<th>Suture type</th>
<th>Diameter, mm</th>
<th>Basic stiffness, cN-mm²</th>
</tr>
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<tbody>
<tr>
<td>Vicryl 3-0 braided</td>
<td>0.280</td>
<td>1.97±0.06</td>
</tr>
<tr>
<td>Sofsilk 3-0 twisted</td>
<td>0.277</td>
<td>2.29±0.07</td>
</tr>
<tr>
<td>Polysorb 3-0 braided</td>
<td>0.314</td>
<td>2.51±0.08</td>
</tr>
<tr>
<td>Kapron 3-0 twisted</td>
<td>0.333</td>
<td>4.56±0.21</td>
</tr>
<tr>
<td>Dexon 3-0 braided</td>
<td>0.266</td>
<td>8.60±0.25</td>
</tr>
<tr>
<td>Catgut 3-0 (wet) mono</td>
<td>0.364</td>
<td>15.4±0.45</td>
</tr>
<tr>
<td>Catgut 3-0 (dry) mono</td>
<td>0.278</td>
<td>86.7±2.7</td>
</tr>
<tr>
<td>Biosyn 3-0 mono</td>
<td>0.288</td>
<td>42.5±1.7</td>
</tr>
<tr>
<td>Maxon 3-0 mono</td>
<td>0.282</td>
<td>67.3±2.8</td>
</tr>
<tr>
<td>Kapron 2-0 twisted</td>
<td>0.391</td>
<td>9.40±0.06</td>
</tr>
<tr>
<td>Sofsilk-0 twisted</td>
<td>0.429</td>
<td>13.5±0.54</td>
</tr>
<tr>
<td>Polysorb-0 twisted</td>
<td>0.472</td>
<td>27.5±0.82</td>
</tr>
<tr>
<td>Lavsan twisted</td>
<td>0.381</td>
<td>2.05±0.07</td>
</tr>
<tr>
<td>Lavsan twisted</td>
<td>0.359</td>
<td>4.52±0.13</td>
</tr>
<tr>
<td>Lavsan braided</td>
<td>0.413</td>
<td>3.59±0.25</td>
</tr>
<tr>
<td>Fforest twisted</td>
<td>0.329</td>
<td>4.83±0.58</td>
</tr>
<tr>
<td>Fforest-2 mono</td>
<td>0.430</td>
<td>141.4±2.98</td>
</tr>
<tr>
<td>Polyamide braided</td>
<td>0.368</td>
<td>2.90±0.17</td>
</tr>
<tr>
<td>Polypropylene mono</td>
<td>0.386</td>
<td>335.9±32.0</td>
</tr>
<tr>
<td>Ftorlon twisted</td>
<td>0.355</td>
<td>13.1±0.50</td>
</tr>
<tr>
<td>PKA twisted</td>
<td>0.282</td>
<td>1.00±0.03</td>
</tr>
<tr>
<td>PA mono</td>
<td>0.309</td>
<td>153.5±1.90</td>
</tr>
<tr>
<td>PP mono</td>
<td>0.335</td>
<td>229.7±16.1</td>
</tr>
</tbody>
</table>

Fig. 6. Types of intestinal sutures: a – continuous suture; b – knotted Kratzer’s suture.
Thus, two factors effect the stiffness of surgical threads. First, it depends on the cross-section (and the form of cross-section!) of individual fibres of which the thread consists and the number of fibres in the thread (the more the number of fibres, and therefore they are thinner at equal effective cross-section, the less the stiffness, the more flexible the thread is). Secondly, it depends on the mechanical properties of the material, from which the thread is made, i.e. on Young's modulus (the higher the modulus, the stiffer the thread).

Such factors as the braiding density, the interaction between the fibres (friction value), impregnation or coating, etc. also increase the thread stiffness.

It should be noted that the stiffness of braided and twisted threads is of approximately similar order of magnitude and differs by several units. For surgeons, the difference in stiffness exceeding two or more times is of practical importance.

In the literature [9], there are test data for the Gore-tex («Gore») surgical thread. The flexural stiffness of these monofilament threads in arbitrary units was the lowest of all that investigated, including braided. The detailed examination of the structure showed that in contrast to all other monofilament threads, which are continuous, the «Gore-tex» surgical thread has porous microstructure, where the value of porosity is about 50 %. Inside this porous structure there are knots of continuity, connected by the tiny, but highly oriented fibres of length up to 17 mm. It is this structure that provides the thread with unique flexibility. This example again shows that, by separating the solid section into many small parts, it is possible to decrease the axial moment of the inertia of each separate element, i.e. its flexural stiffness and, consequently, the stiffness of the whole thread. This understanding is a key to the control of stiffness in manufacturing new suture materials.

Very high stiffness is characteristic of continuous monofilaments. For example, the stiffness of Polypropylene 150 times exceeds that of silk (Sofsilk). The wide scattering in stiffness is typical for these threads and must be related to the pronounced memory effect during their storage. This strongly complicates the task of surgeon. The most successful to date Biosyn («USSC») monofilament has stiffness two times less than the Maxon («Devis+Geek») thread, and 8 times less than the Russian-made Polypropylene monofilament. Nevertheless, Biosyn is almost 20 times stiffer than twisted and braided threads, for example, Sofsilk. With the breakage of Biosyn, it is seen that this thread consists of several (3–4) tightly packed fibres (no empty spaces are observed with a microscope at Biosin cross-section) encased in smooth coating made of the same material. Strictly speaking, Biosyn is not a monofilament thread. Evidently this method made it possible to decrease the total stiffness in comparison with other monofilaments of the same size.

While on the subject of handling properties, one should turn attention to the strength and deformation of suture materials (Fig. 3). Such widely used threads as Sofsilk (breaking stress 329 MPa), Catgut (416 MPa), Kapron (318 MPa) possess comparatively low tensile strength. This can lead to the break of thread in putting some types of stitches and in tightening the knots. The Biosyn monofilament (781 MPa) turned to be the strongest. Of slightly lower strength was the braided Vicryl (708 MPa). The Maxon (605 MPa) and Polysorb (553 MPa) threads also have good strength.

Deformation of suture materials must be taken into account when treating surgical wounds with severe edema to ensure that no cutting of tissues occurs after the wound closure (in any event it must not exceed 30 %) [5]. However, the threads with a pronounced yield plateau (Biosyn, Vicryl, Maxon) may «stretch» in the hands of surgeon, causing additional inconvenience in the work.

The experimental results obtained in the tensile test and our experience of their application in clinical conditions led us to some conclusions. Proceeding from the fact that nowadays various types of continuous sutures have acquired popularity (Fig. 6), it is reasonable to use for them monofilament threads, which are characterised by greater strength
and pronounced stiffness. In this case, the thread does not strongly press the sewed tissues, knots are required only in the front and at the end of the suture, suture channels tightly press the thread, preventing the penetration of microbes, and the thread, because of its smooth surface and the non-traumatic needle, creates a minimum «sawing» effect in tissues [14]. Thus, owing to monofilament threads, the sewing of tissues with continuous sutures, apart from convenience and quick action, possesses good impermeability and minimally disrupts blood circulation along the line of a suture [15, 16]. The application of multifilament threads makes continuous sutures less impermeable, especially if this concerns tender tissues such as, for instance, guts. As to coarse tissues or parenchymatous organs, there is no need to distinguish between threads.

Some knotted sutures can be done with multifilament threads only. It is known that this suturing has some drawbacks: it takes much more time than that with continuous threads, the obtained physical impermeability is lower, and the degree of disorders of blood circulation near the suture is higher. Nonetheless, these sutures are most popular. With the purpose to prevent further damage of tissues, undoing of knots or leaving any alien material in tissues, one ought not even to attempt to close a wound with monofilament materials, as long as their stiffness remains many times higher than that of multifilament materials.

With the proposed procedure for measuring the stiffness, it is possible to test quantitatively any surgical threads for evaluating their handling properties. It can be helpful for surgeons in choosing optimal suture materials or sutures and for engineers in designing new suture materials.

References

МАНИПУЛЯЦИОННЫЕ СВОЙСТВА ХИРУРГИЧЕСКИХ НИТЕЙ

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С появлением современных шовных материалов возникает потребность всесторонне изучить их свойства, в том числе и механические. Для практического хирурга при выборе важно знать, насколько податлива и послушна нить в руках, сколько узлов потребуется для закрепления шва и, в конечном счёте, какой тип шва оптималь для данной нити. Работа посвящена методике определения манипуляционных свойств хирургических нитей. Рассматриваются наиболее часто используемые в абдоминальной хирургии зарубежные рассасывающие нити типоразмера 3-0: Vicryl, Sofsilk, Polysorb, Dexon – плетёные, состоящие из нескольких волокон и кручёный Капрон (российского производства), Catgut, Maxon и, сравнительно недавно появившаяся (1996 г.) нить Biosyn – монофиламентные. Представлены диаграммы одноосного растяжения этих нитей и определён их модуль Юнга. Предложена методика определения изгибной жёсткости хирургических нитей. Показана взаимосвязь жёсткости нитей с модулем Юнга и зависимость её от количества волокон в пучке у кручёных и плетёных нитей. Дополнительно измерена изгибная жёсткость нескольких российских нитей: Лавсан, Фторест, Полиамид, Полипропилен, Фторлон, ПКА, ПА, ПП. Библ. 16.

Ключевые слова: шовный материал, хирургическая нить, модуль Юнга, механические свойства, манипуляционные характеристики, изгибная жесткость

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