IMPROVEMENT OF MECHANICAL PERFORMANCES OF BRAIDED POLYESTER SUTURES

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Abstract

Non-absorbable sutures are monofilaments or braided structures generally made of polyamide, polyester or polypropylene. The success of a suture is widely linked to its mechanical performance features, such as tensile strength and dimensional stability. We introduced an additional treatment in the manufacture of non-absorbable braided sutures made of polyester. This treatment is based on heat setting of the textile structure by using textile-industry stabilisstabilisation techniques. Boiling water, saturated vapour and dry heat have been tested to stabilise a braided polyester suture. The three techniques involved longitudinal and transversal shrinkages. Heat setting with saturated vapour, and especially with dry heat, increased the breaking strength of the textile structure.

Key words:

braided suture, PET polyester, heat setting, dimensional stability, shrinkage, breaking strength

Introduction

The desirable fibre properties that a good suture material should possess include inertness, adequate tensile strength & strength retention in the body's environment, and good healing characteristics [6]. Furthermore, the fibres must be biologically compatible with the surrounding body tissue. There is no one universal suture material, but a number of natural and synthetic fibres. Silk fibres have been used as sutures for many years, but they suffer from drawbacks such as insufficient tensile strength and undesirable tissue reaction. Polyester-, polyamide- and polypropylene-fibre have high strength and excellent strength retention properties, and are mostly used as non-absorbable suture. The biocompatibility and the high tensile strength of polyester poly(ethylene terephtalate) (PET), which has long been used for vascular prostheses or artificial ligaments, has been well documented [1, 5, 6]. Sutures made from natural absorbable fibres such as catgut and collagen have some disadvantages, such as poor strength retention. Synthetic absorbable sutures obtained from glycolide homopolymer, glycolide/lactide blended copolymer, and polidioxanone have higher strength retention than that of catgut sutures, but sterilisation with gamma-irradiation accelerates their degradation.

Sutures are made from both monofilament and multifilament yarns. Braided sutures are generally obtained by using a circular braiding machine. The number of yarns composing the braid depends on the required diameter of the suture. Monofilament yarns have a smooth surface, from which knots can be easily undone. They suffer from relatively high stiffness, which creates problems for surgeons during knotting. Similarly, braided multifilaments with a rough surface have a greater tendency to break [6], in spite of being more flexible. The tensile strength of suture materials have been identified as critical to secure suturing.

We propose introducing a new treatment to non-absorbable suture manufacturing process based on heat setting. This treatment, inspired by the textile finishing of fabrics made of synthetic fibres, aims to improve the tensile strength and dimensional stability of the braided suture and reduce its tendency to present irreversible elongations after suturing. Three heat-setting techniques, using boiling water, saturated vapour and dry heat, were tried. The influence of the heat setting process on the suture shrinkage, load-extension curves and breaking strength has been studied.

Material and methods

We fabricated a circular braided suture composed of 12 multifilament yarns using a LAMEL GM circular braiding machine (HERZOG, Germany), such as is normally used to produce simple and core-braided structures. We used a non-texturised PET polyester yarns with a count of 110 dtex. Preliminary experiences with texturised polyester yarns showed that the braided structures obtained were extremely elastic and could not be used for suturing. The multifilament yarns were placed in a circular braiding machine with a 12-carrier arrangement. The circular braiding machine uses the sequential motion of the carriers to interlace the 12 yarns, and a simple circular braid is then obtained (Figure 1).

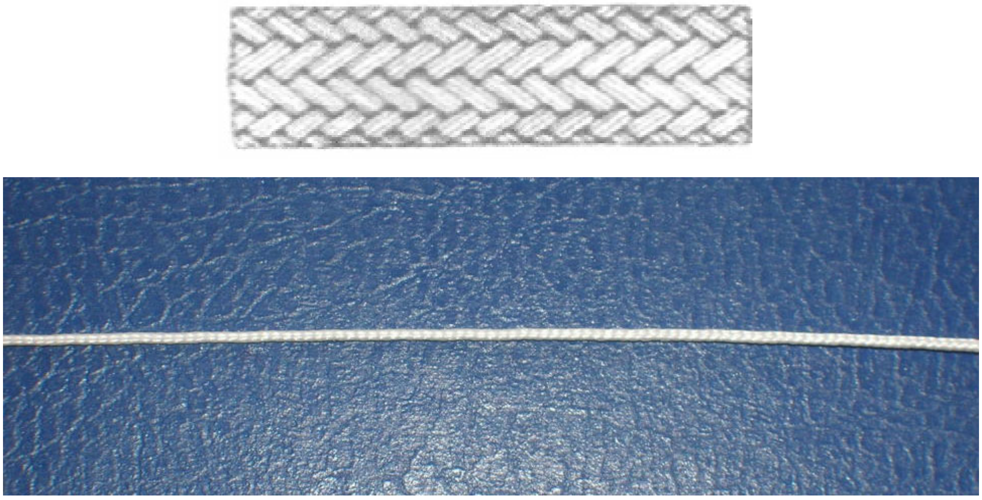

Figure 1. The polyester circular braided suture

Before heat setting, the braided suture dimensions (length and diameter) were determined, in order to compare them with those obtained after the heat-setting treatment. In the absence of an international standard method [3], load-extension curves and breaking strengths were obtained using an LRX 2.5 K constant speed gradient dynamometer (Lloyd, England) at a speed of (200 $mm.min^{-1}$) (Figure 2) normally used for textile yarns.

Figure 2. Dynamometer for breaking strength measurements

For heat-setting the braided suture, we tested 3 different techniques using a bain-marie, an autoclave and a fixing tenter. A Texinox autoclave (Collebaut de Bliquy, France) and a KTF continuous fixing tenter (Mathis, Germany) were used for saturated vapour and dry heat treatments. The treatment conditions presented in Table 1 are those normally recommended by synthetic fibre manufacturers for finishing textile fabrics made of polyester [7]. Suture dimensions, breaking strength and load-extension curves were determined before and after the heat setting. Longitudinal S_L and transversal S_T shrinkages were then calculated:

$$S_L(\%) = \frac{L_0 - L}{L_0}.100 \;;\; S_T(\%) = \frac{D_0 - D}{D_0}.100$$

where:

L_0 : suture length before heat setting,
L : suture length after heat setting,
D_0 : suture diameter before heat setting,
D : suture diameter after heat setting.

Table 1. Heat setting conditions

Heat setting technique	Temperature, °C	Time, minute	Pressure, bar
Bain-marie Boiling water	100	120	-
Autoclave Saturated vapour	140	30	1
Fixing tenter Dry heat	220	0.33	-

Results

The dimensions and the shrinkages of the braided suture stabilised according to the three different heat setting processes are summarised in table 2. We may note that heat setting involved longitudinal and transversal shrinkages in all cases. The highest longitudinal shrinkage (9%) was obtained with saturated vapour. Transversal shrinkages are less important, and never exceed 3%.

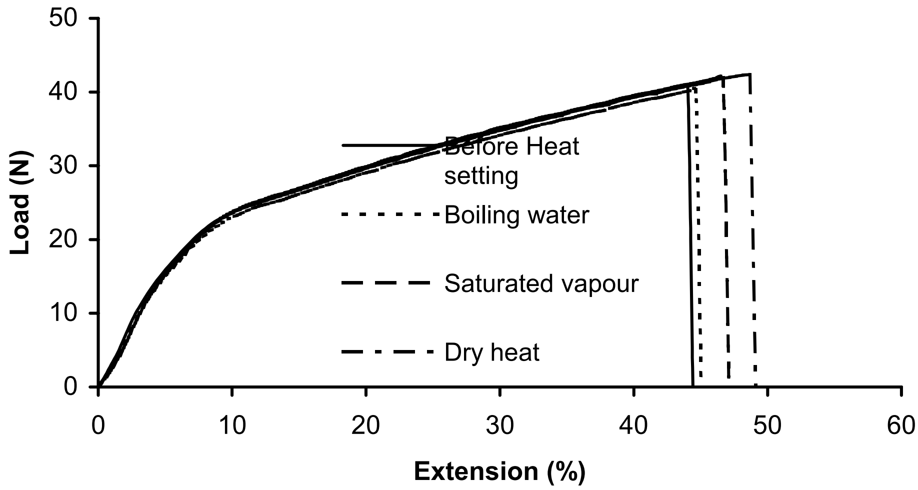

Figure 3. Load-extension curves of braided suture

Figure 3 shows the load-extension curves before and after heat setting. From this figure, we can see that polyester braid exhibits an almost elastic region until 10% extension, after which it behaves in a plastic manner.

Table 2. Braided suture dimensions and shrinkages

Heat setting technique	L_0, mm	L, mm	D_0, mm	D, mm	S_L, %	S_T, %
Bain-marie Boiling water	100	93	0.37	0.361	7	2.4
Autoclave Saturated vapour	100	91	0.37	0.360	9	2.7
Fixing tenter Dry heat	100	95	0.37	0.362	5	2.2

Breaking strengths are represented in Figure 4. Heat-setting with saturated vapour and dry heat involved an increase in breaking strengths, while boiling water slightly reduced the suture resistance. The highest breaking strength (42.36 N) was obtained upon treatment with dry heat.

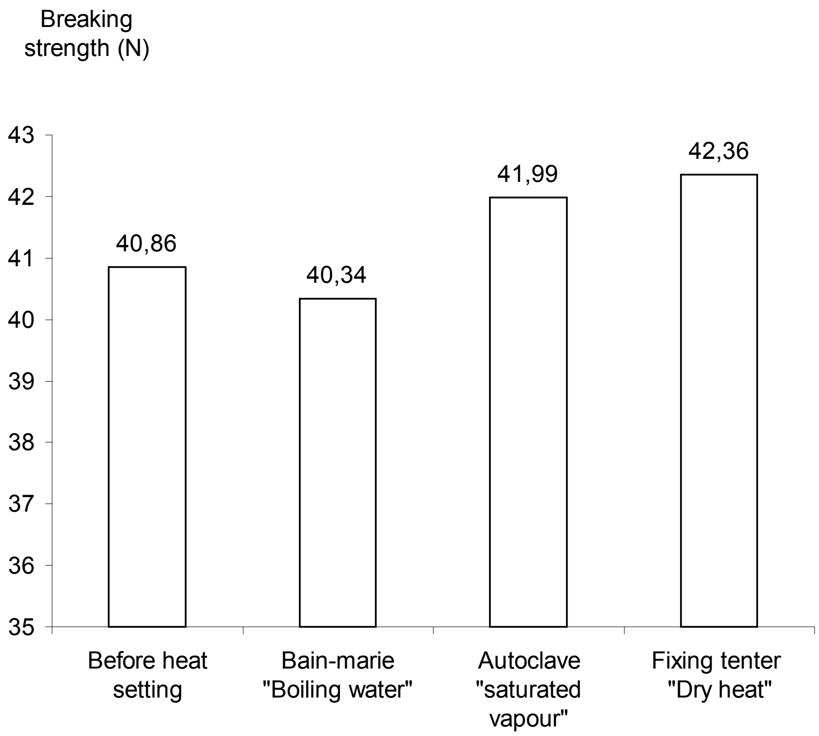

Figure 4. Suture breaking strengths

Discussion

The primary purpose of this study was to develop a novel treatment in manufacturing braided suture made of polyester multifilament focusing on the nature, temperature and duration of the process. This novel treatment was inspired by textile heat setting techniques, which permit both controlled shrinkage and the dimensional stability of textile fabrics made from polyester fibres. Heat setting with saturated vapour involved the highest shrinkages. This is due to the combination of high temperature and long duration of the treatment. The two other treatments showed lower shrinkages, because the boiling water treatment was carried out at a relatively low temperature (100°C), and the dry heat treatment duration was quite short (20 seconds). The interest of this shrinkage is to stabilise the suture structure and avoid dimensional changes, such as lengthening after knotting, that could compromise the mechanical functionalities of the suture.

The type of heat setting had no effect on the shape of the load-extension curves. The succession of almost elastic and plastic regions was maintained after the different heat setting treatments. The elastic region was not perfect. These results correspond with results reported by Hristov *et al* [4], who tested the mechanical behaviour of circular hybrid braids made of polypropylene and PET. A braid is a textile structure formed by interlacing yarns such that their paths are not parallel to the axis of the fabric. The imperfect linearity of the load-extension curves is obtained at low load levels because braids go through a geometric transition, and there is virtually no elastic deformation in the yarn. At higher tensile loads, the rearranged yarns reduce the braid diameter. When the load increases further, the braid starts to reach a jammed state and the yarns elongate. The structure is fully jammed when the decrease in the diameter of the braid is almost negligible and the yarn properties govern the mechanical response.

Saturated vapour and dry heat provided a gain in breaking strength. The suture is then mechanically more resistant to traction, and consequently more resistant to knotting operation and biodegradability during use. The duration of the boiling water treatment was probably too long, and the breaking strength was slightly reduced. The results of the mechanical tests carried out by Yahia [8] on artificial knee ligaments made of polyester showed that a correlation exists between resistance to the biodegradability of the graft and its tensile strength. Dry heat treatment seems to be the most suitable heat-setting process since it provided the highest gain of breaking strength.

The increase in breaking strength obtained after heat setting is due to the fact that the treatments were carried out at temperatures higher than the glass transition temperature of the PET polymer. The glass transition temperature (Tg) marks the onset of the polymer’s segmental mobility; it is the temperature below which the polymer segments do not have sufficient energy to move past one another. If the temperature is above the Tg, the segments rearrange to relieve the externally applied stress. This rearrangement due to the mobility of polymer macromolecular chains permits the increase of crystalline zones, and then the improvement of tensile strength. The results presented in Figure 5 confirm that heat setting with saturated vapour and dry heat increases the polymer crystallinity, and therefore the mechanical resistance of the fibre.

Dieval *et al* [2] used a viscoelasticimeter and an X-ray diffraction device to measure the dynamic modulus and crystallinity of PET fibres at different temperatures. They noticed that a loss of the dynamic modulus was obtained for temperatures close to 100°C, and concluded that the Tg of PET is reached at this temperature. This could explain the results we obtained concerning the influence of heat setting on the mechanical properties of the fibres. The treatments with saturated vapour and dry heat involved a gain in breaking strength because the processes were carried out at temperatures somewhat higher than the polymer Tg. At 140°C and 220°C, the mobility of polymer chains is sufficient to enable an increase of the crystallinity and the tensile strength of the fibres. Heat setting with boiling water induced poor mechanical results because the temperature of treatment was not close to the Tg of PET fibres.

Conclusion

We proposed a new additional step in the manufacturing process of artificial braided sutures made of polyester fibres, with the aimi of reducing the lengthening and rupture of the sutures during and after knotting. Three techniques based on the treatment with boiling water, saturated vapour and dry heat have been tested on a PET braided suture. Saturated vapour and dry heat treatments induced a shrinkage of the suture, especially in the longitudinal direction, as well as an increase of its breaking strength. The treatment using dry heat shown the best efficiency concerning the gain of breaking strength.

Further work will focus on heat setting by using dry heat at different temperatures and treatment durations in order to optimise the mechanical performance of braided sutures.

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