Mechanical Study of the Properties of Sutures used in Orthopedics Surgeries*

Estudo mecânico das propriedades dos fios de sutura usados em cirurgias ortopédicas

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Abstract

Objective To evaluate the mechanical properties of sutures commonly used in orthopedic surgeries, characterizing their behavior through tensile tests and determining which one has greater mechanical strength.

Method Tensile tests of different sutures were performed in a mechanical testing machine BME 10 kN, using a 50 kgf maximum capacity loading cell. Seven samples from each suture material were tested. Both ends of the sample material were fixed in the proper metal claw, maintaining an initial length of 5 cm. Tests were performed at a speed of 20 mm/minute and at room temperature, recording data for maximum displacement and maximum force at the rupture point.

Results FiberWire® #2 (Artrhex, Naples, FL, USA) presented the highest mean strength of rupture (240.17 N), followed by HiFi® #2 (Conmed, Utica, NY, USA) (213.39N) and Ethibond® #5 (Ethicon Inc., Somerville, NJ, USA) (207.38 N). Ethibond® #2 (Ethicon Inc., Somerville, NJ, USA) had the lowest mean strength of rupture (97.8 N).

Conclusion Non-absorbable braided polyblend sutures, more recently introduced, are superior to conventional, braided polyester sutures, and FiberWire® #2 is the most resistant suture evaluated in the present study.

Keywords
- shoulder
- acromioclavicular joint/injuries
- acromioclavicular joint/surgery
- biomechanical phenomena
- sutures

Resumo

Objetivo Avaliar as propriedades mecânicas dos fios de sutura normalmente usados nas cirurgias ortopédicas, caracterizar seu comportamento por meio de ensaios de tração para verificar qual deles apresenta maior resistência mecânica.

Método Os ensaios de tração dos diferentes tipos de fios de sutura foram feitos na máquina de ensaios mecânicos BME 10 kN, com célula de carga de capacidade máxima

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palavras-chave
- ombro
- articulação acromioclavicular/ lesões
- articulação acromioclavicular/ cirurgia
- fenômenos biomecânicos
- suturas

de 50 kgf. Foram ensaiadas sete amostras de cada tipo de fio de sutura, foi fixada cada uma das extremidades da amostra na garra metálica própria para o ensaio de fios e manteve-se o comprimento inicial de 5 cm. Os ensaios foram feitos com uma velocidade de 20 mm/min e à temperatura ambiente, registraram-se os dados de força máxima e o deslocamento máximo na ruptura dos fios.

Resultados A força média de ruptura mais elevada foi observada na sutura FiberWire® 2 (240,17 N), seguida pela HiFi® 2 (213,39 N) e Ethibond® 5 (207,38 N). A menor força média de ruptura foi obtida para o fio Ethibond® 2 (97,8 N).

Conclusão Os fios de sutura não absorvíveis de polimistura trançada, de surgimento mais recente, são superiores ao fio de sutura convencional de poliéster trançado, o FiberWire® 2 é o mais resistente dos fios avaliados no estudo.

Introduction

The main objectives of orthopedic surgeries are total biomechanical[1] and anatomical[2] restoration. As such, there is a great variety of materials and methods for the treatment of dislocations and fractures, such as plates, screws, intramedullary nails, and pins, among others. Similarly, there are also several types and models of surgical materials for suturing and ligament repair. The literature recommends a variety of procedures to treat acromioclavicular joint injuries, including pin attachment through the acromioclavicular joint, coracoacromial ligament transfer using the Weaver-Dunn technique, fixation between the clavicle and the coracoid process, plaques, muscle transfer, and coracoclavicular binding with large-diameter nonabsorbable suture.[3]

The suture materials that maintain the surgical reduction of the acromioclavicular joint, for instance, in the coracoclavicular binding technique, need to withstand the tensile forces to which these ligaments are normally subjected to keep joint stability; this is especially true for the coracoclavicular ligaments, which are responsible for the vertical stability of the joint. In addition, the ideal suture material must be easy to handle, allowing effortless knots with minimal discomfort to the fingers of the surgeon, and presenting good fastening capacity.[4] The tensile strength aspect led us to study the properties of the various suture materials to define those most suited for orthopedic surgeries.

The present study aims to evaluate the properties of the suture materials normally used in orthopedic surgeries and to characterize their behavior through tensile tests to determine those with the greatest mechanical resistance.

Material and Methods

The present study evaluated the mechanical behavior of four types of suture materials commonly used in the surgical treatment of acromioclavicular dislocation: Ethibond® #2 (Ethicon Inc., Somerville, NJ, USA), Ethibond® #5 (Ethicon Inc., Somerville, NJ, USA), HiFi® #2(Conmed, Utica, NY, EUA), and FiberWire® #2 (Artrhex, Naples, FL, EUA) (►**Fig. 1**). Ethibond® #2 (Ethicon Inc., Somerville, NJ, USA) and Ethibond® #5 are sterile, nonabsorbable polyester sutures with a multi-laminated construction covered with polybutylate. FiberWire® #2 is a sterile, non-absorbable suture consisting of a long multistranded chain of ultra-high molecular weight polyethylene (UHMWPE) core coated with braided polyester. Hi-Fi® #2 suture is a nonabsorbable, braided structure also based on UHMWPE.

Tensile tests of the different suture types were performed on a BME 10 kN mechanical test machine with a 50 kgf maximum capacity loading cell (►**Fig. 2**). Seven samples of each suture were tested; without knots, each end of the sample was fixed in the metal claw for test at an initial length of 5 cm (►**Fig. 3**). Tests were performed at 20 mm/minute and at room temperature to record the maximum force and the maximum displacement data at the rupture of the suture.

Results

The tests recorded the maximum and mean rupture forces (N). The maximum and mean displacement values at each rupture of the suture (mm) were also calculated. Ethibond® #2 exhibited a mean rupture strength of 97.98 N and a mean displacement of 35.24 mm (►**Fig. 4**). Ethibond® #5 presented a mean rupture strength of 207.38 N and a mean displacement of 37.98 mm (►**Fig. 5**). HiFi® #2 presented a mean rupture strength of 213.39 N and a mean displacement of 72.90 mm (►**Fig. 6**). FiberWire® #2 presented the highest rupture strength force (240.17 N), with a mean displacement of 34.19 mm (►**Fig. 7**). Mean rupture forces were compared in the graph shown in ►**Fig. 8**.

Discussion

Suture materials are used in orthopedic surgeries to close wounds, repair fasciae, muscles, tendons, ligaments and joint capsules, and to cerclage or perform tension bands in certain fractures. The quality of the tissue repair depends on multiple variables, including characteristics of the tissue, properties of the suture material, and the surgical technique used. The choice of the suture material has important implications in tissue repair, so adverse surgical outcomes can be avoided



Fig. 1 Samples from HiFi® #2, FiberWire®#2, Ethibond® #2 and Ethibond®#5 sutures.

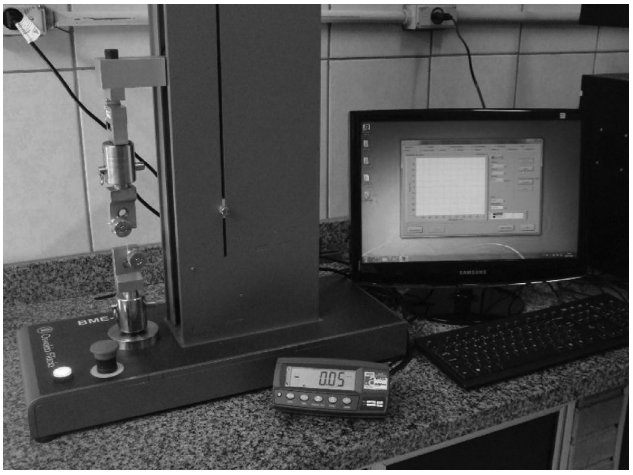

Fig. 2 Experimental equipment for tensile assays: BME 10 kN test machine, 50 kgf loading cells and fixation claws.



Fig. 3 Metallic claw for assays with sutures at an initial length of 5 cm.

by selecting the suture material according to the diagnostic indication.[5]

Traditionally, braided and nonabsorbable polyester sutures were used in surgery because they were more resistant and less likely to slip than absorbable polydioxanone (PDS) monofilament sutures. However, factors such as frequent suture rupture and reduced resistance led to the development of braided and nonabsorbable mixed sutures, consisting of polyethylene, polyester and PDS. Thus, several suture materials with these characteristics have emerged, such as FiberWire® and HiFi®,8 and their use became common in orthopedics.

To maintain the surgical reduction of the acromioclavicular joint, for instance, as in the coracoclavicular binding technique, the sutures must withstand the tensile forces to which joint stability-involved ligaments are subjected; this is especially true for the coracoclavicular ligaments, responsible for vertical stability.[6]

The literature shows that the intact coracoclavicular ligament supports a maximum traction force of 500 $\pm$ 134 N, a stiffness of 103 $\pm$ 30 N/mm, and an elongation at rupture of 7.7 $\pm$ 1.9 mm, with no significant difference between the contribution of the trapezoid and conoid ligaments in this configuration. The isolated conoid ligament presented a

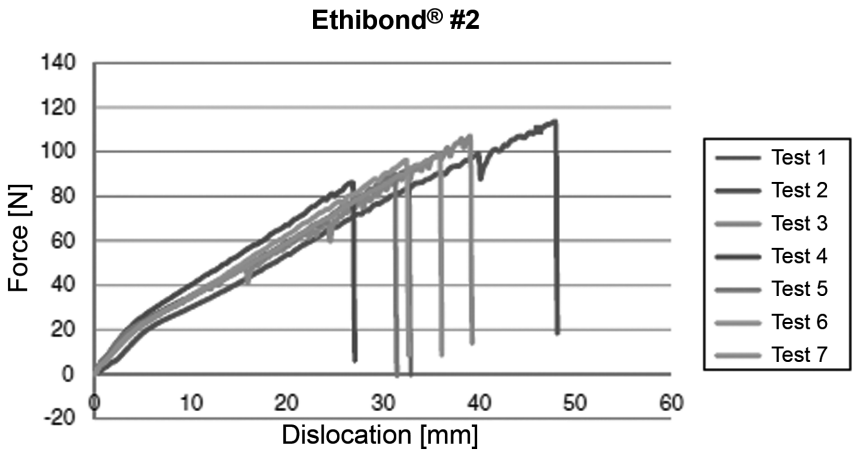

Fig. 4 Deformation force graph for Ethibond® #2.

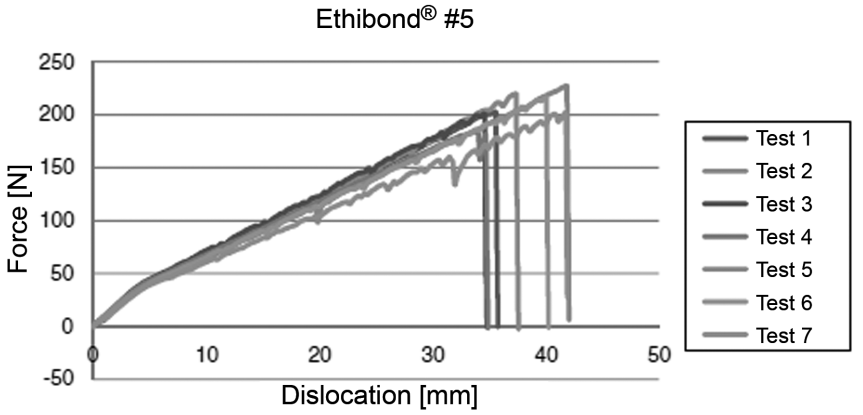

Fig. 5 Deformation force graph for Ethibond® #5.

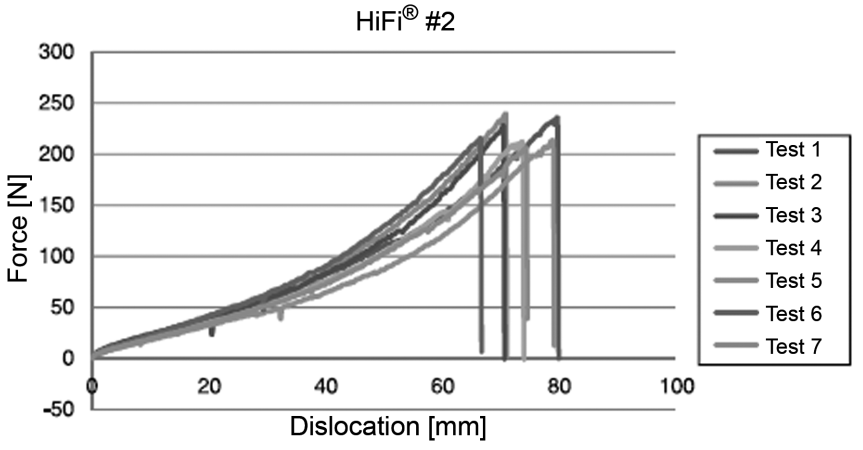

Fig. 6 Deformation force graph for HiFi® #2.

maximum strength of 394 ± 170 N, a stiffness of 105 ± 45 N/mm, and an elongation of 7.1 ± 2.1 mm, whereas the isolated trapezoid ligament presented a maximum strength of 440 ± 118 N, a stiffness of 84 ± 18 N/mm, and an elongation of 9.2 ± 2.6 mm.[7]

A study by Wüst et al[8] aimed to compare the mechanical properties of the mixed braided nonabsorbable sutures FiberWire®, Hi-Fi®, Orthocord (DePuy Synthes, Rayham, MA, USA),® and Ultrabraid (Smith & Nephew, London, UK) ® with conventional braided polyester suture, Ethibond®, and the PDS absorbable monofilament sutures, PDS II and Ethicon®; all of the sutures were #2. The initial hypothesis was that the polyester sutures are superior to the conventional braided polyester and degradable monofilament sutures regarding tensile strength and maximum elongation, but require more configurations of stable knots. The tests were performed at 60 mm/minute and at room temperature. Compared with the results obtained by Wüst et al,[8] our work confirmed that mixed sutures had advantageous mechanical properties. However, mixed sutures have significant

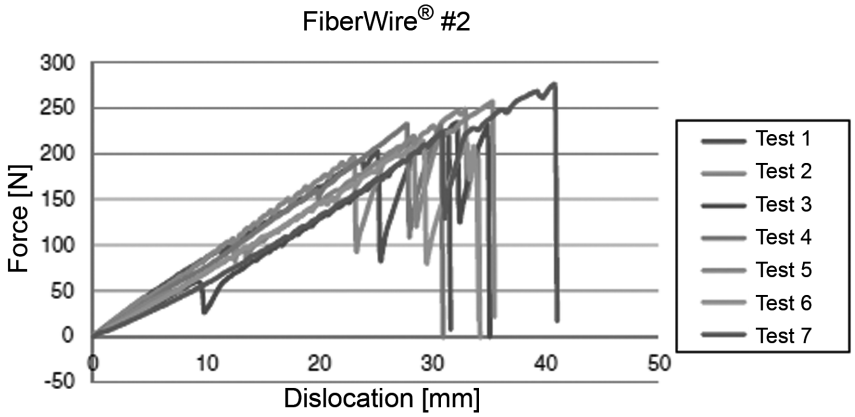

Fig. 7 Deformation force graph for FiberWire® #2.

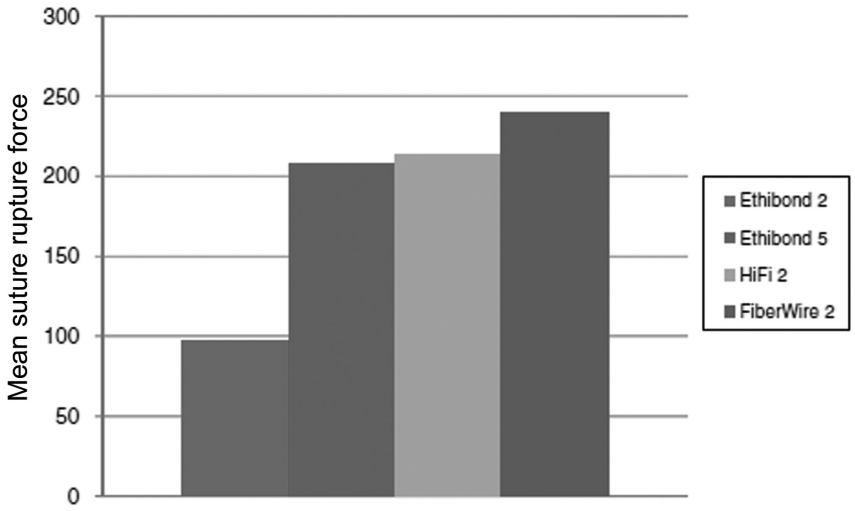

Fig. 8 Mean suture rupture forces.

differences in their properties. All of the mixed sutures tested without knots were 2 to 2.5 times more resistant than the polyester and PDS sutures. The tensile strength tests of nonknotted sutures showed that FiberWire® had the highest maximum rupture load value, 263 N, whereas Ethibond® had a maximum force of 110 N. These values are in line with those obtained in the present study: 240.17 N and 97.98 N for FiberWire® #2 and Ethibond® #2, respectively.[8]

Wright et al[9] studied the behavior of nondamaged and damaged sutures in tensile tests, as well as the wear of sutures passed through anchors. The tensile force was applied at 90° and at 180° while the suture was drawn through the anchor hole. A total of 20 samples, 10 damaged and 10 intact, of each #2 suture from different materials were tested: PDS, Ethibond®, Tevdek (Teleflex Medical OEM, Gurnee, IL, USA)®, Orthocord® and FiberWire®, always in a dry environment at room temperature. From the tensile tests for the rupture of the suture, the modulus of elasticity and tensile strength were determined. The tensile test until rupture was performed in a Bionix MTS 858 test machine at a speed of 60 mm/minute. Among the non-damaged sutures, FiberWire® had the highest values of maximum rupture load (255.3 $\pm$ 10.37 N), followed by Orthocord® (214.22 $\pm$ 11.63 N), PDS (141.22 $\pm$ 7.62 N), Tevdek® (116.61 $\pm$ 1.13 N) and Ethibond® (114.58 $\pm$ 1.58 N). These values are in line with those obtained in the present study, which were 240.17 N and 97.98 N, for FiberWire® #2 and Ethibond® #2, respectively.[9]

Jhamb et al studied the biophysical properties of the high-strength suture materials FiberWire® #2, Orthocord® #2, HiFi® #2, and Ultrabraid® #2, using light microscopy, scanning electron microscopy, and mechanical testing.[10] Different types of sutures without knots were loaded until rupture in a Bionix 858 MTS test device with a 2 kN loading cell to register load $\times$ displacement curves. The samples tested were 5 cm in length and the speed used in the test was 10 mm/minute. The Ultrabraid® suture presented the maximum strength of 264 N in traction tests, followed by FiberWire® with 238 N, HiFi® with 215 N, and Orthocord® with 212 N. The rupture force for FiberWire® was 240.17 N, and 221.96 N for HiFi®; these values are in line with those obtained by Jhamb et al.[10]

The review of these literature reports showed different speeds adopted for suture tensile tests, ranging from 10 mm/minute to 60 mm/minute. The speed of 20 mm/minute is at a level between these values and so it was adopted by us. We believe that this small speed difference had no relevance in the results.

Our study demonstrated the superiority of polyethylene, polyester and PDS mixed sutures (FiberWire® #2 and HiFi®

#2) over braided, multifilament polyester sutures covered with polybutylate (Ethibond® #5 and #2). FiberWire® #2 and HiFi® #2 presented, respectively, a mean rupture strength of 240.17 N and 213.38 N; while Ethibond® #5 resisted until 207.38 N and Ethibond® #2, until 97.98 N.

No suture material presented a tensile strength higher than that described in the literature for the coracoclavicular ligaments. However, the present study did not use sutures similar to in vivo coracoclavicular binding techniques, but assays with isolated suture samples fixed in metal claws. Therefore, new tensile studies must be performed with biomechanical models representing the anatomy of the shoulder and of the coracoclavicular ligaments in a simplified way, allowing a better comparison between the resistance of the ligaments and bindings with suture materials.

Conclusion

The more recent braided nonabsorbable polyester sutures are superior to the braided conventional polyester sutures. Among the sutures tested, the most resistant to tensile forces is FiberWire® #2, followed by HiFi® #2. Ethibond® #5 and Ethibond® #2 were shown to be less resistant, the latter being the least resistant.

Conflicts of Interests
The authors have no conflicts of interests to declare.

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