STRING THEORY: AN EXAMINATION OF THE PROPERTIES OF "HIGH STRENGTH" SUTURE MATERIALS

A. Jhamb, J. Goldberg, W. Harper, A. Butler, P.J. Smitham, W.R. Walsh

Surgical & Orthopaedic Research Laboratories

University of New South Wales, Prince of Wales Hospital

Sydney, Australia

Abstract

The evolution of arthroscopic shoulder surgery has lead to advanced developments in instrumentation and equipment. Pivotal to successful surgery are the high strength sutures. With all claiming high strength, we aimed to assess biophysical properties of each material via light microscopy, scanning electron microscope and mechanical testing. Peak load and stiffness were assessed using a knot free length secured with friction loops distracted at 10 mm/min using a Bionix MTS 1000kN load/test cell. Results were analysed by SPSS for windows

New packets of #2 sutures were provided by Arthrex (Fibrewire), Depuy/Mitek (Orthocord), Linvatec (HiFi), and Smith & Nephew (Ultrabraid) for examination Fibrewire contains a UHMWPE central core within a braided polyester sleeve while Orthocord, does not have a structurally significant central core, and Hifi and Ultrabraid contain no central core. Fibrewire has a mean twist angle (MTA) of 20 degrees while the other three have a MTA of 35 degrees. HiFi, Orthocord and Ultrabraid have a large initial toe region as the braiding aligns itself with the applied load and achieved maximum strength and stiffness after significant deformation. In contrast, the central core and tighter braiding pattern in Fibrewire resulted in a stiffer suture early in loading ($P<0.05$).

Ultrabraid had the highest ultimate strength in tensile testing at 264N followed by Fibrewire 238N, then HiFi at 215N and Orthocord at 212N. Fibrewire was significantly stiffer than HiFi, Orthocord, and Ultrabraid in the first 50N of testing

All sutures provide strength well above those required for tissue repair on immediate testing. Our review of suture materials may provide more insight into the available sutures on the market. Further testing is required to interpret clinical implications including preloading and creep during knot tying.

Introduction

Suture materials form an integral part of arthroscopic shoulder surgery. With many suture materials available on the market, all claiming high strength, it may be confusing and difficult to distinguish one from another, and certainly to decide on which is superior. These materials are non-absorbable making it critical we understand what we are implanting into a patient and the properties of these implants.

Many studies exist on knot performance using different knots and traditional suture materials. Monofilament sutures can lead to dehiscence and clinical failure due to knot slippage and/or loop elongation at low applied loads (1). This study examined the tensile and morphologic properties of the new so-called “high strength” sutures.

Shoulder surgery has evolved from open to minimally invasive arthroscopic surgery. Most forms of surgery rely on suture materials. First generation braided multifilament non-absorbable sutures (ethibond / ticron) provided a suitable implant for open surgery. These sutures are based predominantly on polyester. Newer arthroscopic equipment (both implantable anchors and knot pushers) places higher loads on the suture. The first generation sutures were a common point of failure. The newer second generation high strength sutures are based on ultrahigh molecular weight polyethylene. The commercial form of this product is known as Dyneema. Dyneema has been used in many forms outside of the medical industry. Its biomechanical properties have lead to the rapidly expanding use throughout the world. It is manufactured through a gel-spinning process. It is capable of absorbing large amounts of energy and thus used in ballistics protection, from bullet-proof jackets to armored vehicles. Its strength is fifteen times stronger than steel yet is so light it floats on water, allowing its use in marine vessels. It has a high modulus of elasticity and is flexible. Its properties also include having superior wear and abrasion resistance. Second generation suture materials are composed of this Dyneema.

Materials and Methods

New samples of number 2 suture materials were opened and each examined straight from the packet. Materials were provided by Arthrex (Fibrewire), Depuy/Mitek (Orthocord), Linvatec (HiFi), and Smith & Nephew (Ultrabraid). Materials were characterized based on the macroscopic, microscopic , and electron microscopic appearances to define flaws and differences between materials. Each material was then loaded to failure (knot –free) in tension. Load deformation curves were analysed for ultimate strength and stiffness.

Macroscopic/Microscopic Appearance - Each material was examined under an Olympus stereozoom microscope both in transverse and longitudinal sections. Each was then photographed under x 4 and x 10 magnification. The photographs were then viewed in Windows picture viewer and the mean twist or mean braid angle measured (Fig 1) using an electronic goniometer. Cross-sections of each suture were also examined and photographed and the presence or lack of a central cord noted.(Figure 2)

Electron Microscopic Appearance – Each material was sectioned and set in a liquid metal mould and photographed under an electron microscope under magnification of x 100, x 500 and x70 (transverse section only) (figure 3)

Tensile Load Testing – Single strands of each material, knot-free, were loaded in tension to failure. A Bionix 858 MTS testing device with a 2 kN load cell was used to record load displacement curves. The material was secured using friction loops (3 wraps at each end) and then clamped past the friction loops so that no weakness could be created in the material with knots (Figure 4). The testing protocol used a constant 5cm length of material and was distracted to failure at a rate of 10mm/min.

Results

Macroscopic/Microscopic Appearance- Visually few differences could be detected except from each distinguishing colour. Fibrewire has a light blue appearance. Hi-Fi is predominantly white with a blue polydioxanone strand. Orthocord is purple and Ultrabraid is white. The color may affect its material properties as a higher percentage of polyethylene Dyneema may contribute to its overall strength.

The main differences in longitudinal section lay in the mean twist angle. (see figure 2). The fibrewire had the lowest twist braiding angle of 20 degrees while the other 3 all showed similar angles of 35 degrees.

Both Fibrewire and Orthrocord contain a central core in cross section. The Fibrewire has a true central polyethylene core. The Orthocord can be seen to contain bundles of polydioxanone filaments which are far weaker than polyethylene.

Hifi and Ultrabraid have no central core in transverse sectioning.

Electron Microscopic Appearance – All materials were quite similar under electron microscopy with minimal surface flaws in the filaments/materials themselves. Overall all 4 materials were clean of debris however orthocord showed most debris compared with the other 3.

Tensile Load Testing – Ultrabraid (UB) had the highest ultimate strength in tensile testing at 264N followed by Fibrewire (FW) 238N, then HiFi (HF) at 215N and Orthocord (OC) at 212N (Figure 5). FW was significantly stronger than OC but not UB or HF. UB was significantly stronger than both OC and HF. The overall stiffness showed Ultrabraid to have the maximum stiffness (Figure 6). However, examining individual load displacement curves for each substance (Figure 7) shows that fibrewire was initially stiffer over the first 20mm.If we therefore, exam only the first 50 N FW was significantly stiffer than the other substances (Figure 8).

Discussion

Significant differences in material composition and construction can explain the differences in the biomechanical properties of each material.

It would seem that the two main differences are:- 1.) The central core and 2.) The mean twist angle. The central core (predominantly a UHMWPE core) as opposed to no core or a PDS core separate the materials. Fibrewire is the only material with a PE core. Orthocord contains a central core of PDS while HiFi and Ultrabraid have no central core.

The PDS does not add to the strength of the material and infact will reduce the strength as to create the same thickness of suture the PDS must take up the space the stronger dyneema would hold.

The dyneema explains the ultimate strength of all four materials being so much stronger than the first generation sutures which were based on polyester. All four provide strength above 200N. Ultrabraid had the highest ultimate strength of 264N followed by Fibrewire (238.5N), HiFi (214.3N) and Orthocord (211.7N). From our assessment of loads applied during knot tying, it would appear that all have enough strength to tolerate these loads. Even though significant differences were present, clinically all would be suitable.

Differing stiffness may have clinical implication brewire certainly provides a far stiffer material during loads <50N. And once loads are applied >50N the stiffness rises for all 4 with some differences. Clinically in low applied loads including pulling through tissue, different materials may be more suitable. For example, a stiffer material may actually cut through tissue rather while gathering slack as opposed to the less stiff tissue. This may have clinical implications in that perhaps younger tissue may be more suitable to a stiffer material and perhaps more frail tissue would be more suited to a less stiff material to “take up the slack” rather than cut through the tissue.

The mean twist angle was lowest in the fibrewire (20degrees) while the other three had a similar angle of 35 degrees. This twist angle with the central core was responsible for the significantly stiffer properties of fibrewire.

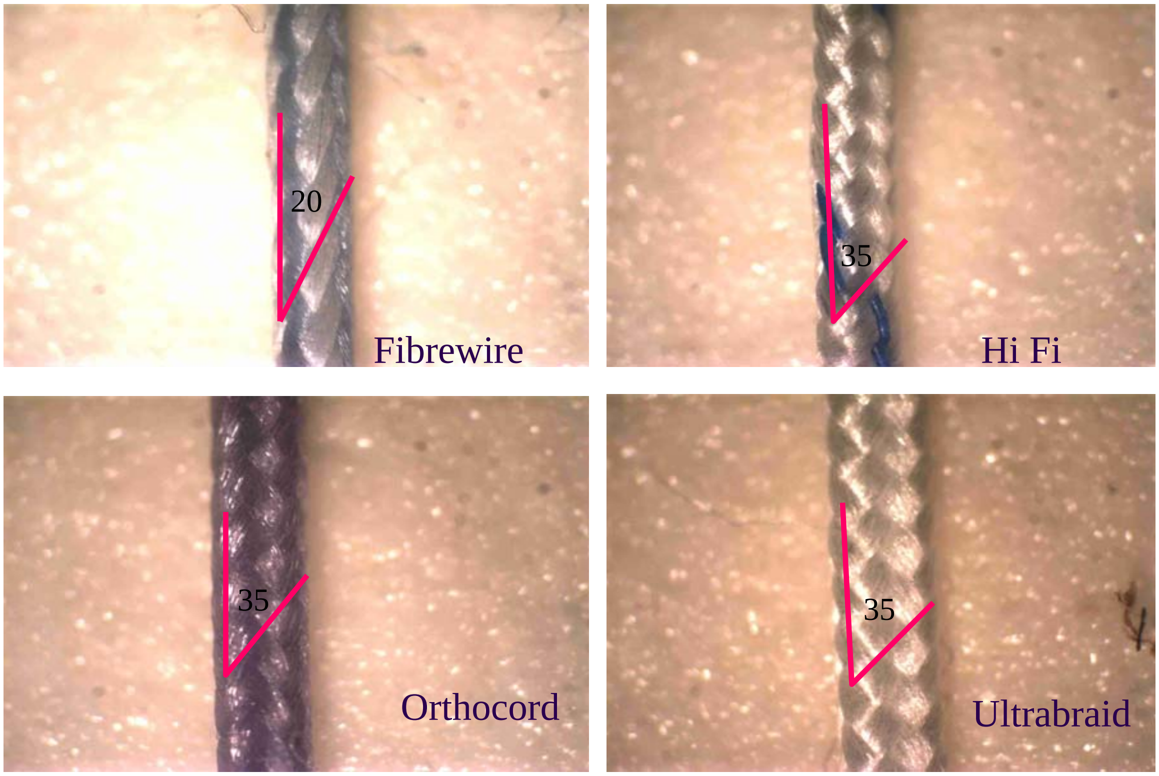
The difference in color between materials may also affect the properties of the individual sutures, as a higher percentage of polyethylene Dyneema may contribute to its overall strength and this may explain any other differences between suture types.

Overall the main differences in biomechanical properties can be explained by the microscopic analysis of structure. The lower twist angle and central dyneema core lead to a significantly stiffer material (FW) compared to the other three materials. All three have a strength well above those required during knot testing (peak loads in vitro approximated 115N). The pressure remaining in a closed knotted suture drops off by 90% from loads applied.

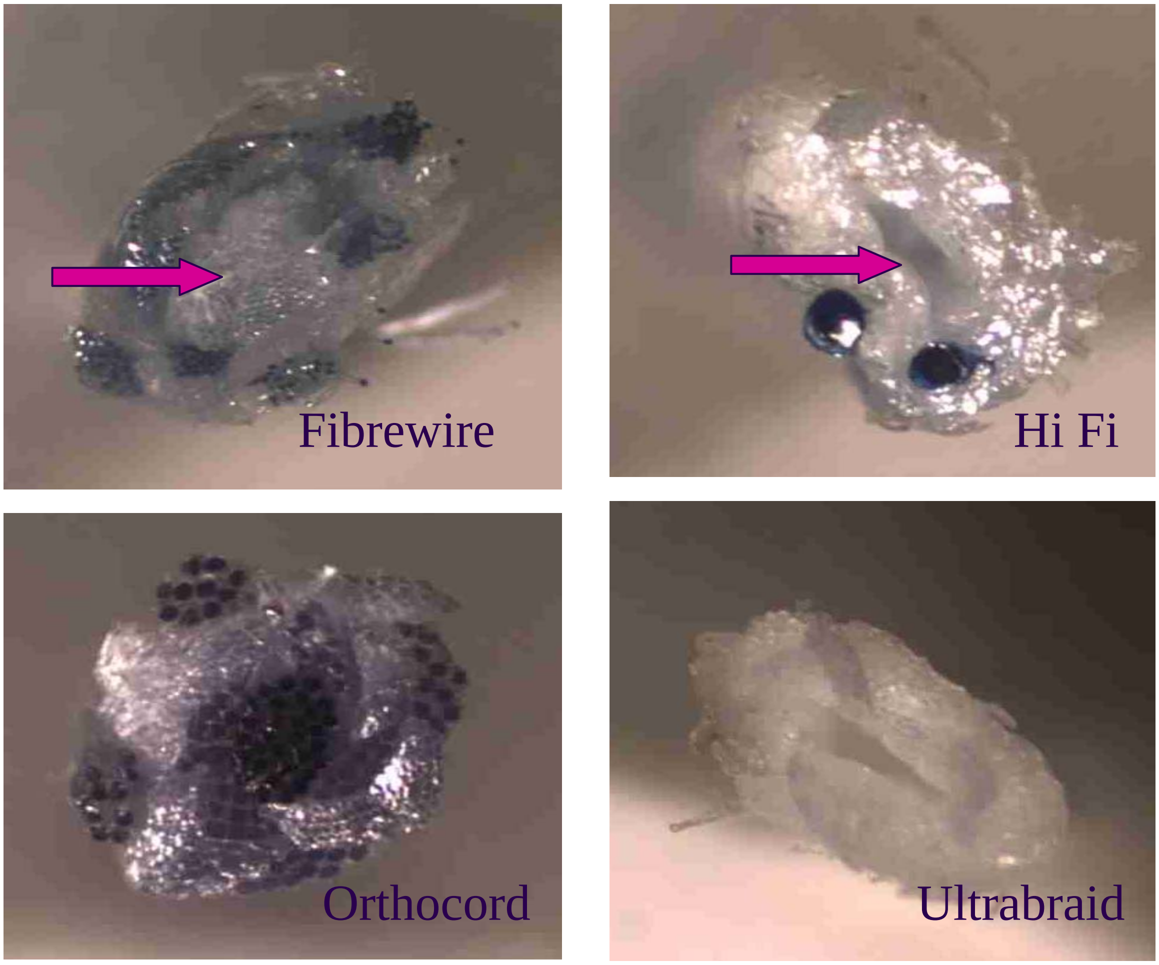
These newer generation suture materials all provide a material suitable for arthroscopic surgery. Certain individual characteristics based on the surgeon's preference for "feel" may ultimately dictate preference, however this study shows all have adequate strength and the suture is no longer the weakest link in our interlinked system of surgical failure involving surgical factors, patient biology, and implants and materials.

References

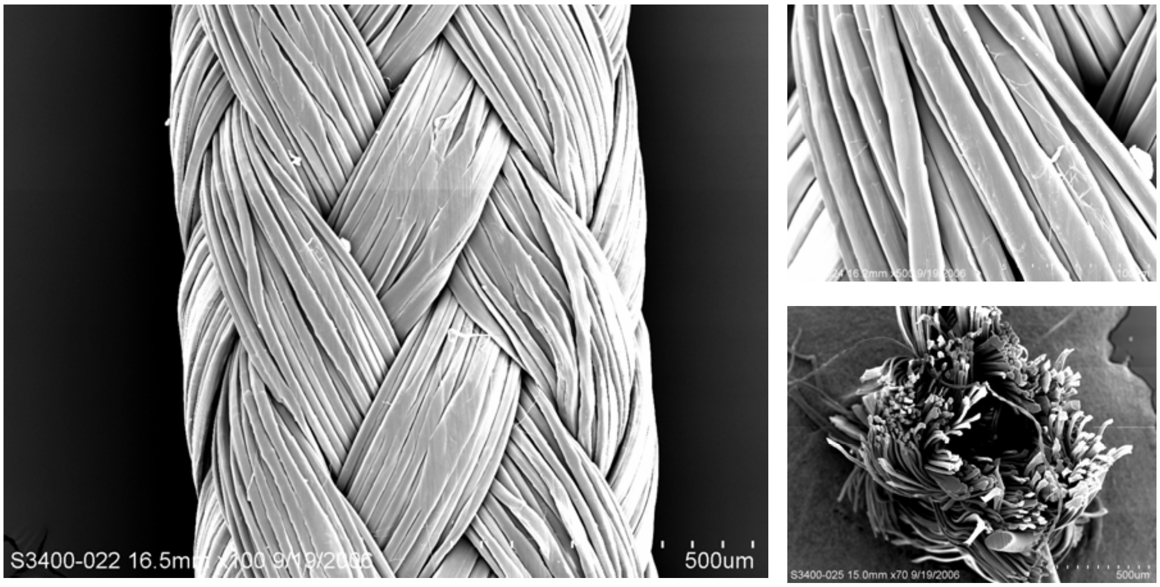
1. Li X, King M, MacDonald P Comparative study of knot performance and ease of manipulation of monofilament and braided sutures for arthroscopic applications.
Knee Surg Sports Traumatol Arthrosc. 2004 Sep;12(5):448-52. Epub 2004 Apr 30.



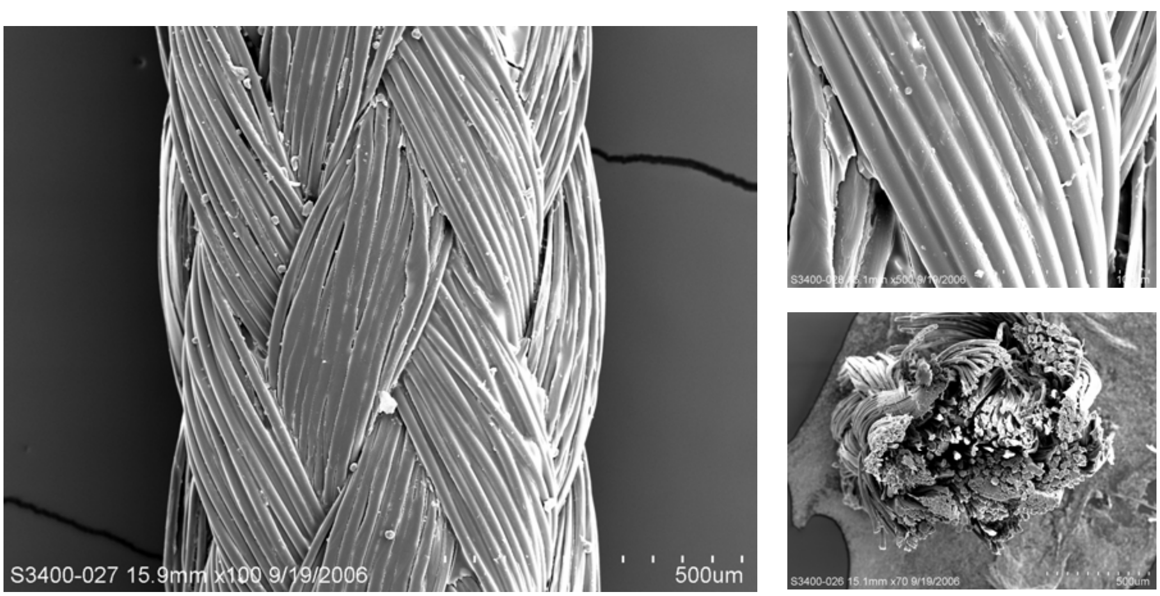
20
Fibrewire
35
Hi Fi
35
Orthocord
35
Ultrabraid


Fibrewire
Hi Fi
Orthocord
Ultrabraid

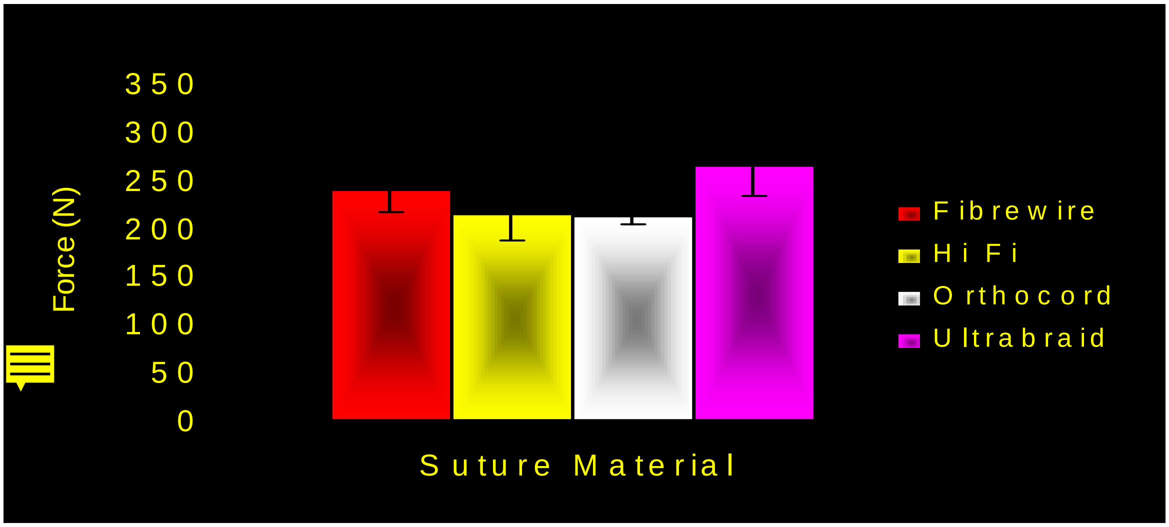
SEM –HF – x 100, x 500, x 70

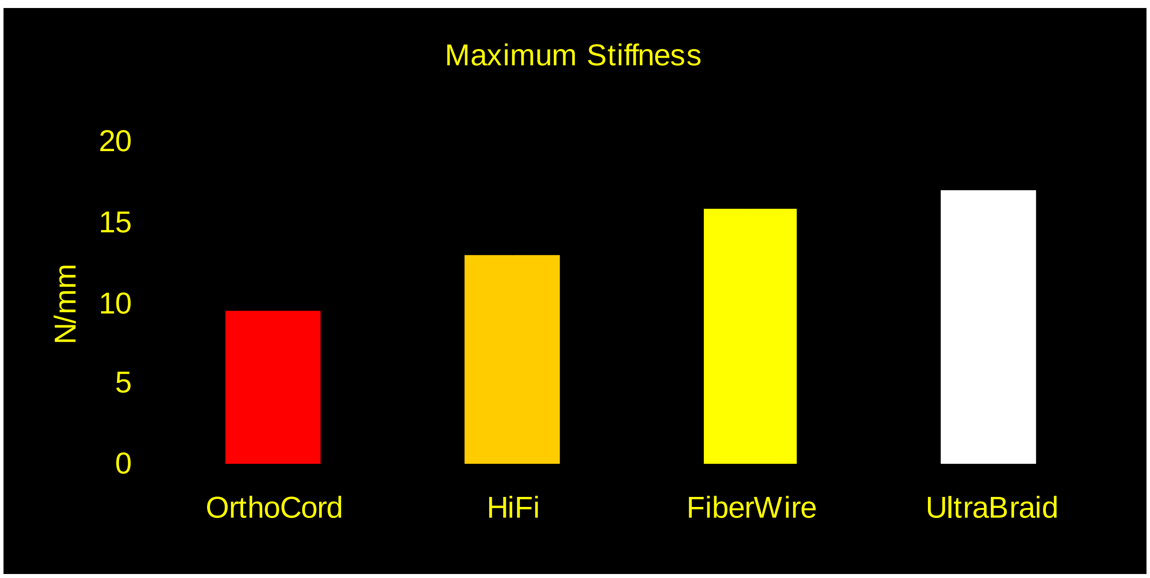


SEM – FW x 100, x 500, x 70



Peak Force:Single Strand

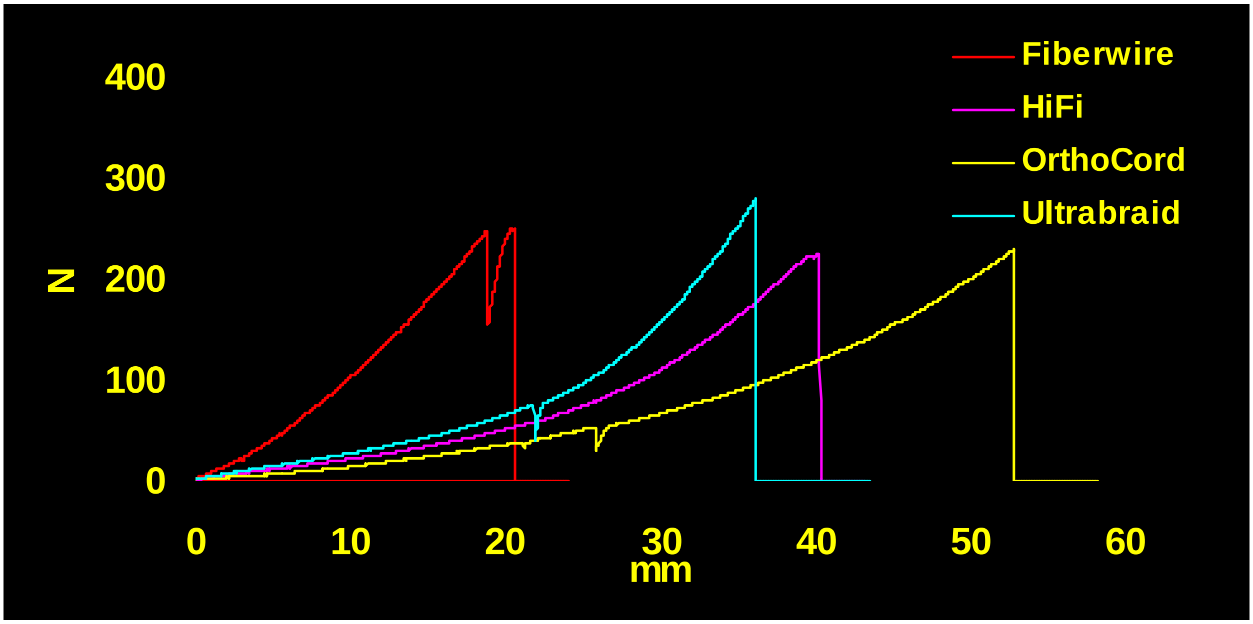




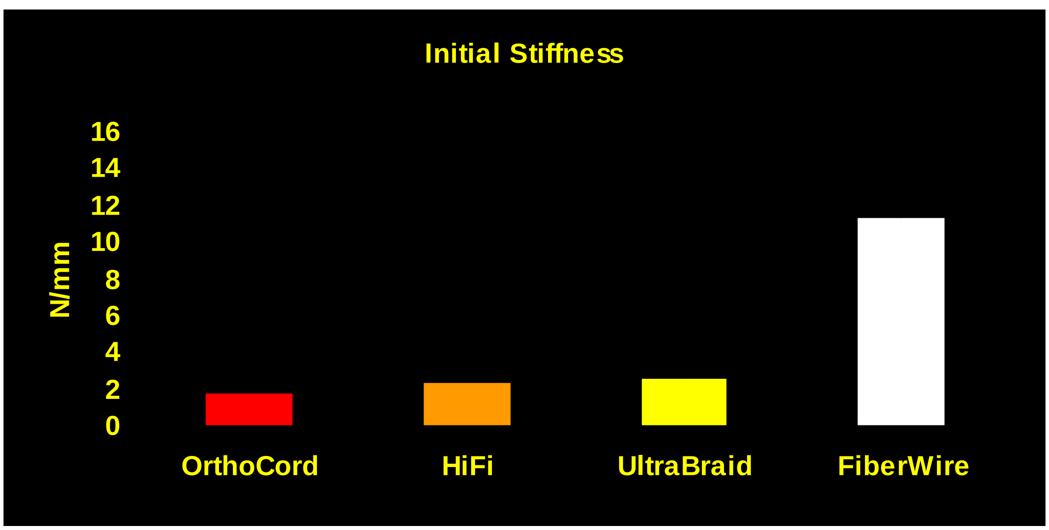
OrthoCord < HiFi < Fiberwire = Ultrabraid

P<0.05, P=0.383

Load Displacement Curve

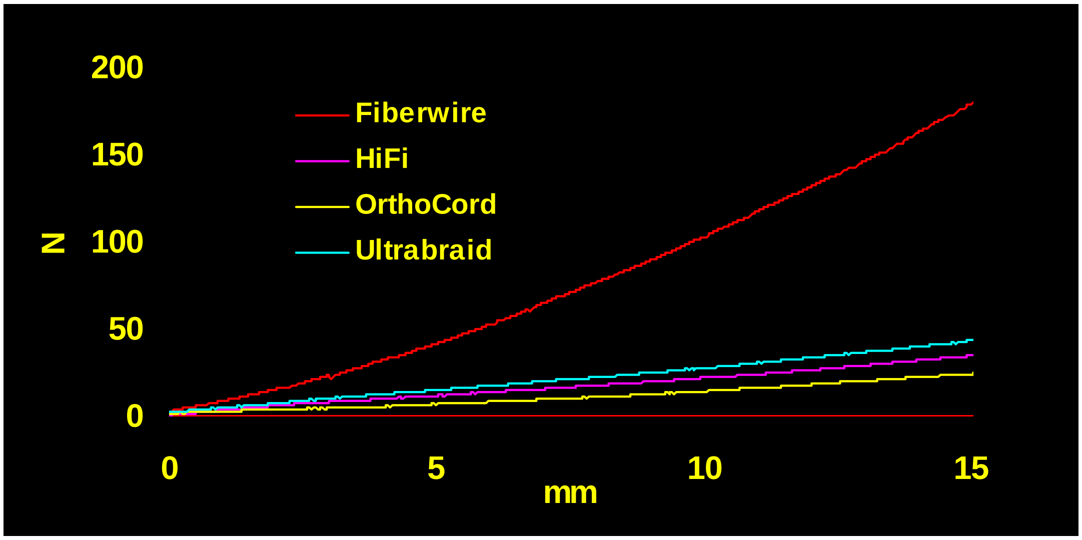


Initial Stiffness



Fiberwire > all others (P<0.05)

Stiffness (N/mm) – first 15mm of displacement


200
150
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Fiberwire
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mm