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Finite Element Study On Arthroscopic Anchor Design Aspects

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Abstract

AIM: This research aims to study arthroscopic anchors design parameters. Prototypes were manufactured by new parameters values. The the performance of the prototypes was also tested.

METHODS: Five 3D arthroscopic anchor models were created to evaluate the role of some design aspects. Thread type, pitch and tip angle were tested as variable parameters. These models were produced on engineering CAD software then imported into ANSYS for finite element analysis. A tensile load of 300 N was applied to each model while the simplified bone base was fixed-in-place as a boundary condition. The finite element results were compared with prototypes tensile testing.

RESULTS: The finite element analyses showed stresses within physiological limits on the bone with all tested models. Thread type and pitch affected stresses on bone and anchor body. From stress point of view, two critical zones appeared on anchor body, anchor cortical bone connection and eyelet zone, while thread geometry (depth) affect the cortical bone response only. Laboratory tests matched finite element results and literature.

CONCLUSION: Increasing thread pitch of arthroscopic anchors decreases stress on the bone, while increases stress on anchor body. Arthroscopic anchors thread type has a negligible effect on bone, while it reduces stresses on anchor body if it placed more material around eyelet in internal drive mechanism and suture eyelet type of anchors. Anchor tip angle has a negligible effect on bone and anchor body.

Introduction

Suture Anchors are very useful fixation devices for fixing tendons and ligaments to bone. They are made up of: (1) the Anchor-which is inserted into the bone. This may be a screw mechanism or interference fit (like a raw bolt used in DIY) [1]. They may be made of metal or biodegradable material (which dissolves in the body over time) [2], [3]. The Eyelet-is a hole or a loop in the anchor to through which the suture passes. This links the anchor to the suture. (2) The Suture-is attached to the anchor by through the eyelet of the anchor. It also may be a non-absorbable material or a biodegradable material.

Suture Anchor is mostly self-tapping titanium implant that comes pre-loaded with HiFi high-strength sutures. It allows for more fixation points providing the ability to better distribute the load more evenly across the tendon. Also, it allows for versatile suture placement [4], [5.]

Arthroscopic Anchors' designs have a punch of parameters starting from diameter, length, angles (taper, cutting, ...etc.), ...etc. [6] where rare literature are seeking for the optimal design(s) for specific cases. Most of these researches' results are protected by patents [7], [8], [9], [10].

The modern kits of arthroscopic implants are single use, that it contains (1) hollow plastic handle (polyethene) with one internally threaded end, (2) Titanium tube (threaded end at the handle, and outer hexagon end), (3) one or two HiFi fibres for knitting between anchors each of one-meter length, (4) Arthroscopic anchor. Assembling the plastic handle and Titanium tube by thread resulted in anchor driver [11].

Arthroscopic anchors can be made of varied materials, including stainless steel, pure titanium, titanium alloys and biocomposite materials. The three grades listed in standard specifications are austenitic types with specific compositions for these special applications. These materials are tested for biocompatibility and safety according to EN ISO 10993 and EN ISO 14971. The Chromium-Nickel-Molybdenum alloyed austenitic stainless steel used for BIOTEK implants complies with the international standards ISO 5832-1 and ASTM F138/ASTM F139. That production of such tools requires high-precision equipment including high-performance CNC machines, electropolishing facility, laser part identification, ultrasonic cleaning and passivation and state of the art inspection laboratories [12], [13], [14], [15], [16].

Recent studies reported PEEK (polyetheretherketone) as an alternative material to titanium implants. PEEK is biocompatible material with Young's modulus of 3.6 GPa. Additionally, the PEEK modulus of elasticity can be modified by reinforcing it with carbon fibres "CFR-PEEK (carbon fibre reinforced polyetheretherketone)" to reach 18 GPa, similar to that of cortical bone [2], [3], [11].

In this study, three major Suture Anchor parameter designs were investigated as; Thread type, pitch and tip angle via finite element analysis — laboratory testing for the prototypes to validate the theoretical study results against the in-vitro ones.

Material and Methods

Five 3D geometric models were prepared by "Autodesk Inventor" ver. 8.0 (Autodesk Inc. San Rafael, CA, USA) to investigate the three design parameters as:

a) Thread type (Models 1 and 3);

b) Pitch (Models 2 to 4);

c) Tip angle (Models 3 and 5).

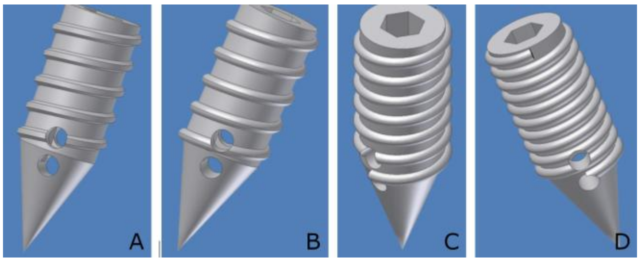

Figure 1: Sample of anchors with major modifications; a) Model 1, square thread type; b) Model 2, enlarged pitch; c) Model 3, regular thread pitch; d) Model 4, narrow pitch

The anchors 3D models were transferred to ANSYS Workbench Version 14 (ANSYS Inc., Canonsburg, PA, USA) as STEP files to be analysed. Where bone geometry was simplified and simulated as two co-axial cylinders. The inner one represents the spongy bone (diameter 14 mm & height 20 mm) which fills the internal space of the outer cylinder (shell of 2 mm thickness) that represents cortical bone (diameter 18 mm & height 24 mm). These models after assembly were subjected to 300 N [17], [18] tensile force located at eyelet (fibres resting). The base of the hollow cylinder representing the cortical bone was set to be fixed as a boundary condition. Linear static analysis was performed on a personal computer Intel Pentium Core 2 Duo, processor 3.0 GHz, 4.0 GB RAM. Figures 2, illustrate ANSYS screenshots show a sample of the analysis's models and meshed components before analysis.

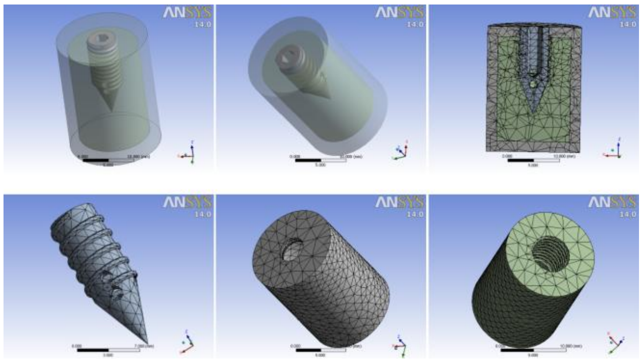

Figure 2: Sample of the analysed models and meshed parts from ANSYS workbench screen

Results

Comparing different thread types in models 1 and 3 showed the moderate effect on anchor body itself, which was not referring to the design rather than increasing material around the eyelet. Sharp-edged threads reduced stress on bone by more than 75% than blunt edged threads. Figures 3 and 4 illustrate Von Mises stress distributions in models 1 and 3 respectively.

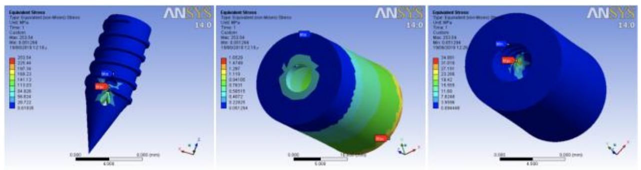

Figure 3: Model 1 (square thread design) Von Mises stress distributions

As presented in Figure 5, increasing pitch in model 4 showed negative effects on the anchor body itself by reducing material around the eyelet. On the other hand, increasing pitch reduces stresses dramatically on cortical bone by about 25%. Therefore, increased anchor pitch is very important for reducing bone stresses, which was verified by the results of model 2.

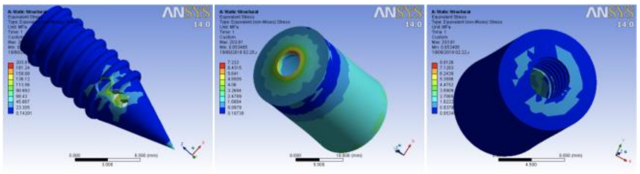

Figure 4: Model 3 (regular pitch design) Von Mises stress distributions

Changing the anchor tip angle as in model 5, and compare its results with model 3 results there will be no change in all values of stresses and deformation.

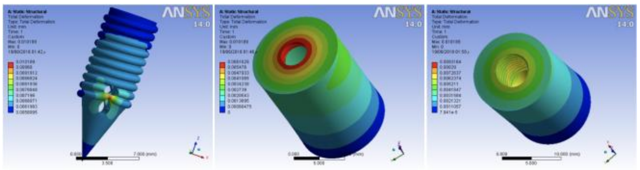

Figure 5: Results of model 4 (narrow pitch design) total deformation

Finally, set of 20 anchors (as model 3) were placed in transparent acrylic resin cube (dental laboratory prepared it) to make a trial for a tensile test of one Titanium anchor design as presented in Figure 6. Unfortunately, the HiFi and stainless-steel wires of 0.5 mm were cut inside the anchor at a tensile load lower than 280 N during a tensile test, and no failure was noticed on the anchor's body.

Figure 6: Test samples and one sample during testing on Universal Testing machine

Discussion

The internal drive mechanism and suture eyelet anchors performance are affected by; eyelet design, thread design, and material (metal, absorbable), the angle of suture pull, and insertion depth [5]. Failure can occur at the level of the suture, suture anchor, bone, and soft tissue. Anchors to be designed for suture pull along the axis of insertion, while the eyelet to be designed rounded or streamlined with channels that protect the suture [19], [20].

Reducing thread pitch decreases stresses dramatically on cortical bone. Therefore reducing implant pitch is very important for bone purchase. Reducing pitch also showed an improving effect on the implant itself by increasing material around the eyelet. On the other hand, a screw with a very small pitch may have a very high bearing area, but will not perform well because the threads are too close together to effectively engage the trabeculae [21]. Yakacki et al., [21]. The deeply inserted threads likely increased the pullout force past the predicted range based on smaller nominal insertion depth. The Bio-Corkscrew (Arthrex, Naples, Florida, USA) strength was consistently higher than the Opus Magnum, but this was simply due to the larger device size (5 vs 3 mm) and larger corresponding bearing area [21].

Thread type showed a moderate effect of implant body itself, which was not referring to the design rather than increasing material around the eyelet. Maximum Von Mises stress was recorded of order 250 MPa while the minimum was of order 190 MPa.

A screw of equal proportion but greater size will possess a higher strength than its smaller counterpart, comparing screws with different thread designs and sizes are difficult because of the different bearing area than the regular version [21]. The anchor has a short body with deep threads that secure it into the bone allowing decent holding strength. Finally, anchor tip angle has a negligible effect on anchor body, cortical and spongy bone.

According to in vitro tests, all sutures were failed at around 280N. That matches previous studies by Aktay et al., and Er et al., [5], [22], that find it of order 300 N. A common area of failure with metallic anchors is at the suture–anchor interface where the suture is serially abraded by the anchor’s eyelet [19]. The eyelet design along with surface roughness and the arc of contact between the eyelet and suture all contribute to the frictional resistance created. A greater amount of friction leads to a lower maximal breaking strength of the suture. The failures occurred in most instances by rupture of the suture material. For the metal anchors, the threads almost always ruptured at the eyelets of the anchors [23].

In conclusion, titanium arthroscopic anchors design parameters investigations resulted in: 1) Increasing pitch increase stresses on implant itself, while decrease stresses on bone; 2) Thread type has a negligible effect on bone, while it may reduce stresses on implant body if it placed more material around eyelet; 3) Implant tip angle has a negligible effect on bone and implant body.

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