All-Suture Anchors: Biomechanical Analysis of Pullout Strength, Displacement, and Failure Mode

F. Alan Barber, M.D., and Morley A. Herbert, Ph.D.

Purpose: To evaluate the biomechanical and design characteristics of all-suture anchors. **Methods:** All-suture anchors were tested in fresh porcine cortical bone and biphasic polyurethane foam blocks by cyclic loading (10-100 N for 200 cycles), followed by destructive testing parallel to the insertion axis at 12.5 mm/s. Endpoints included ultimate failure load, displacement at 100 and 200 cycles, stiffness, and failure mode. Anchors tested included JuggerKnot (1.4, 1.5, and 2.8), Iconix (1, 2, and 3), Y-knot (1.3, 1.8, and 2.8), Q-Fix (1.8 and 2.8), and Draw Tight (1.8 and 3.2). **Results:** The mean ultimate failure strength of the triple-loaded anchors (564 ± 42 N) was significantly greater than the mean ultimate failure strength of the double-loaded anchors (465 ± 33 N) ($P = .017$), and the double-loaded anchors were stronger than the single-loaded anchors (256 ± 35 N) ($P < .0001$). No difference was found between the results in porcine bone and biphasic polyurethane foam. None of these anchors demonstrated 5 mm or 10 mm of displacement during cyclic loading. The Y-Knot demonstrated greater displacement than the JuggerKnot and Q-Fix ($P = .025$) but not the Iconix and Draw Tight ($P > .05$). The most common failure mode varied and was suture breaking for the Q-Fix (97%), JuggerKnot (81%), and Iconix anchors (58%), anchor pullout with the Draw Tight (76%), whereas the Y-Knot was 50% suture breaking and 50% anchor pullout. **Conclusions:** The ultimate failure load of an all-suture anchor is correlated directly with its number of sutures. With cyclic loading, the Y-Knot demonstrated greater displacement than the JuggerKnot and Q-Fix but not the Iconix and Draw Tight. JuggerKnot (81%) and Q-Fix (97%) anchors failed by suture breaking, whereas the Draw Tight anchor failed by anchor pullout (76%). **Clinical Relevance:** All-suture anchors vary in strength and performance, and these factors may influence clinical success. Biphasic polyurethane foam is a validated model for suture anchor testing.

The importance of suture anchors to assist in the attachment of tendons, ligaments, and other soft tissue to bone is readily apparent, and these devices are used widely for most minimally invasive techniques, especially in the upper extremity. Over time, suture anchors have been improved with fully threaded designs, distally placed eyelets, the ability to accommodate multiple sutures, the use of first biodegradable and later biocomposite materials, and knotless designs. Suture anchors made completely of suture material are a recent development.[1,2] These all-suture anchors are based on one of more ultra-high-molecular-weight polyethylene (UHMWPE)-containing sutures. The anchor portion of the device typically consists of a sleeve or tape also made from suture material through which the UHMWPE containing suture is woven. When the all-suture anchor is inserted into bone and the main suture pulled, the sleeve or tape is cinched up to compress against the overlying cortical bone creating a "ball," which serves as the anchor.

As with conventional anchors, these all-suture anchors are configured for glenoid-labral and tuberosity-tendon applications. The glenoid anchors are smaller and usually have 1 or at most 2 sutures.[1,3] The rotator cuff anchors are larger and are either double or triple loaded. All-suture anchors are radiolucent, nondegradable, and concern has been raised about the development of cyst formation at the anchor site.[4] An understanding of the failure mode and strength characteristics of these all-suture anchors is necessary for the surgeon considering their use. The purpose of this

From Plano Orthopedic Sports Medicine and Spine Center (F.A.B.), Plano; and Advanced Surgical Institutes, Medical City Dallas Hospital (M.A.H.), Dallas, Texas, U.S.A.

The authors report the following potential conflicts of interest or sources of funding: F.A.B. and M.A.H. receive support from Stryker Endoscopy, Smith & Nephew Endoscopy, ConMed-Linvatec, Biomet Sports Medicine, and Cayenne Medical (funding for Instron costs from the anchor makers). This study was funded by support from the F. Alan Barber, M.D., F.A.C.S., Research Foundation, and the donation of anchors by Biomet Sports Medicine, Stryker Endoscopy, ConMed Linvatec, Smith & Nephew, and Parcus Medical.

Received June 6, 2016; accepted September 26, 2016.

Address correspondence to F. Alan Barber, M.D., Plano Orthopedic Sports Medicine and Spine Center, 5228 West Plano Parkway, Plano, TX 75093, U.S.A.

0749-8063/16518/$36.00

http://dx.doi.org/10.1016/j.arthro.2016.09.031

study was to evaluate the biomechanical and design characteristics of all-suture anchors. Our hypothesis was that these anchors do not have time zero failure profiles or biomechanical properties that are materially different from conventional suture anchors. A secondary hypothesis was that the all-suture anchor performance could be reliably assessed in either porcine bone or in biphasic polyurethane foam blocks.

Methods

All-suture anchors of each type to be evaluated were obtained from their respective manufacturer for testing and implanted into 2 different substrates. The goal was to have 10 samples of each anchor type and size for placement in the diaphyseal cortex of fresh adult porcine femurs obtained from a local abattoir.[1,3] Each anchor tested was rotated among at least 5 different femurs, and the insertion sites also were rotated among different positions on the diaphysis to minimize the potential effect of variations in bone thickness. No more than 2 anchors of each type were placed in any one femur. Later, as the literature began to demonstrate the validity of testing implants in polyurethane foam, whenever possible, an additional 10 samples of each anchor type and size were placed in biphasic polyurethane foam blocks (Pacific Research Laboratories, Vashon, WA). The biphasic polyurethane foam material was selected to replicate the environment of the cortical bone in the shoulder. The greater tuberosity and glenoid may offer different cortical thickness, especially if abrasion of the anchor insertion site is done in the greater tuberosity. For an all-suture anchor to deploy, however, it does require some cortex against which to be pulled and compressed. A robust biphasic "cortex" was selected to eliminate this feature as a point of failure in this test system. This biphasic material consisted of a solid rigid polyurethane foam block with a density of 12 pcf with a fiber filled epoxy coating similar in density, hardness and strength to cortical bone laminated on top. Appropriately sized drill holes were placed through the dense simulated cortex to allow access by the anchor into the polyurethane foam beneath.

Every all-suture anchor tested was based on UHMWPE-containing suture. The all-suture anchors were separated in either the porcine bone or biphasic polyurethane foam block by at least 1 cm from any adjacent anchor to prevent crack propagation between drill holes during testing. All anchors were inserted according to the manufacturer's instructions with the appropriate instruments by the senior author (F.A.B.) or by a company product manager or engineer if available to assure adequate familiarity with the anchor and instrumentation. Both anchor insertion and pull-out testing were conducted with the bones or biphasic polyurethane foam blocks at room temperature in a non-aqueous environment.

The biomechanical testing was performed (M.A.H.) by securing the femurs or foam blocks holding the anchors to a platform directly under the actuator arm of a mechanical materials testing machine (model 3345; Instron, Canton, MA). The femurs were placed in a specially prepared aluminum box that supported the bone and automatically aligned the anchors' sutures directly under the actuator arm of the mechanical materials testing machine. The blocks were secured on the sides by clamps secured to the base plate. Thus, the load applied was always in line with the axis of anchor insertion. The sutures were secured in the upper hydraulic fixture with a constant gauge length. The upper arm of the Instron machine was positioned so that there was no load on the device and then under program control, a preload of 10 N was applied. After the preload, a cyclic load alternating between 10 N and 100 N was applied at 0.5 Hz for 200 cycles or until failure occurred. A gauge length of 30 mm was used for all tests to start and the gauge length after the initial cycle considered the baseline. After completion of 200 cycles, destructive testing was performed at a displacement rate of 12.5 mm/s. Data sampling of load and displacement was obtained at 100 samples per second. The number of cycles needed to reach both 5 mm and 10 mm of displacement was recorded if it occurred.[1,3,5,6]

Endpoints of this study included anchor dimensions and characteristics, the ultimate load at failure, displacement at 100 and 200 cycles (initial displacement was calculated at 10 cycles), stiffness, and mode of failure (M.A.H.) (anchor pull out, eyelet/suture cut out, or suture breakage).

The anchors tested varied in size, suture material and number, and characteristics, which are listed in Table 1. All companies producing anchors were invited to provide their anchors for this test. Those who were willing donated an appropriate number of anchors along with the associated insertion equipment and personnel to assist in the anchor insertion. Some anchors were limited in their supply and not available for testing in the polyurethane foam blocks. The anchors tested are listed in the paragraphs to follow.

JuggerKnot 1.4 mm, 1.5 mm, and 2.8 mm all-suture anchors (Biomet Sports Medicine, Warsaw, IN) (Fig 1) are composed of 1 or 2 (blue/white) size No. 1 or 2 braided UHMWPE sutures that pass through a flexible tube of No. 6 braided polyester material measuring 2 mm wide and between 20 and 24 mm in length. The size of the polyester tube varies depending on the anchor. This sleeve bunches up under a cortical surface, creating a ball that provides the anchoring effect. The JuggerKnot 1.4 has a single No. 1 braided UHMWPE suture, whereas the JuggerKnot 1.5 has a single No. 2