Reprint of: The Deadman Theory of Suture Anchors: Observations Along a South Texas Fence Line

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Abstract: Suture anchors are being increasingly reported as a means of fixation of torn rotator cuff tendons to bone. The author has developed a mechanical model for the suture anchor–rotator cuff construct based on an analogy to the deadman system used to stabilize a corner fence post. Using this model, one can demonstrate a mechanically favorable angle of insertion of the suture anchor ($\theta_1$) such that the anchor’s pullout strength is increased at low angles of $\theta_1$. In addition, the angle that the suture makes with the direction of pull of the rotator cuff ($\theta_2$) has a direct effect on tension in the suture. A low angle of $\theta_2$ minimizes the total tension in the suture, thereby minimizing the chance of suture breakage.

Form follows function. As physicians and scientists, we accept this immutable tenet of nature. However, some of nature’s important functions can be difficult to recognize if the form is well disguised. Allow me to explain the lessons I have learned about suture anchors by studying a South Texas fence line.

The Deadman Analogy

Suture anchors have been reported as a means of fixation of torn rotator cuff tendons to bone.1-3 Tensile loading of a buried suture anchor by the rotator cuff through an intercalated suture creates a complex system of forces that can be configured in a variety of ways, each with different mechanical consequences. To my knowledge, the mechanical consequences of these configurations have not been rigorously investigated.

I recognized the analogy of a suture anchor to a deadman as I was watching a new barbed wire fence being constructed on a South Texas ranch. At the corner fence post, the fence crew placed a deadman, which is a large buried rock attached by means of a twisted wire to the top of the corner fence post (Fig 1). The function of the deadman is to counteract the pull of the fence wire and thus prevent the corner post from leaning.

The analogy of the deadman system to the suture anchor system then becomes obvious. The deadman is analogous to the suture anchor, the deadman wire is analogous to the suture, and the pull of the fence wire on the corner post is analogous to the pull of the rotator cuff. The fence post is represented by the compressed rotator cuff tissue between the suture and the bone (Fig 2).

Fig 1. Representation of the anchoring effect of a corner fence post by a deadman. The deadman is a large rock buried under the ground and attached to the fence post by means of a wire at an angle $\theta$ to the ground. ($T$, tension in deadman wire; $W$, pull of fence wire; $A_x$ and $A_y$, ground reaction forces; $M_0$, ground reaction moment; $T_x$, component of tension in $x$ direction; $T_y$, component of tension in $y$ direction; $W_x$, pull of fence wire in $x$ direction). (Courtesy of the University of Texas Health Science Center at San Antonio.)
South Texas ranchers have an “ideal angle” (θ) for the deadman. They try to place the deadman so that θ (the angle that the deadman wire makes with the ground) is less than or equal to 45° (Fig 3A). They have found that if they place the deadman too close to the post so that θ is greater than 45°, the post tends to gradually lean away from the deadman until θ is reduced to 45° and equilibrium is reached (Fig 3B).

If we look at the free body diagram (Fig 4), we can understand why the fence post leans. The only force resisting the pull of the wire (W_x) is the X component of tension in the deadman wire (T_x). The post will lean until it reaches equilibrium so that T_x = W_x. One can intuitively see that T_x increases as θ decreases.

The relationship between T_x and θ can more rigorously be shown by formulating the three equilibrium equations for this system (Figs 1 and 4):

Fig 2. Analogy of the deadman system to the suture anchor—rotator cuff system. The deadman is analogous to the suture anchor; the deadman wire is analogous to the suture; the pull of the fence wire on the corner post is analogous to the pull of the rotator cuff; and the fence post is analogous to the compressed rotator cuff tissue between the suture and the bone. (Courtesy of the University of Texas Health Science Center at San Antonio.)

Fig 3. (A) The deadman wire makes an angle θ with the ground. The ranchers’ ideal angle is less than or equal to 45°. This corner post has two deadman systems at right angles to each other. (B) The deadman for this corner post was placed too close to the post, so that θ was greater than 45°. The post leaned away from the deadman until θ was reduced to approximately 45°. At that point, the system had reached equilibrium, with T_x equal to W_x.

Fig 4. Free body diagram of the deadman system. The only force resisting the pull of the wire (W_x) is the X component of tension in the deadman wire (T_x). (Courtesy of the University of Texas Health Science Center at San Antonio.)
\[ \Sigma F_x = W_x + A_x - T_x = 0 \]
\[ \Sigma F_y = A_y - W_y - T_y = 0 \]
\[ \Sigma M = W_x \times a - T_x \times a + M_0 = 0 \]

By substituting the additional relationships
\[ a = c \times \sin \theta \]
\[ b = c \times \cos \theta \]
\[ T_x = T \times \cos \theta \]
\[ T_y = T \times \sin \theta \]

one establishes the important relationship \( T \cos \theta = \) constant.

Because \( \theta \) is inversely proportional to \( \cos \theta \), \( T \) decreases as \( \theta \) decreases, and \( T_x \) increases as \( \theta \) decreases.

**The Suture Anchor Construct**

This model shows two important mechanical relationships in the suture anchor construct. First of all, because \( T \cos \theta = \) constant, tension in the suture is less at lower angles of \( \theta \). Ideally, to minimize tension in the suture, thereby minimizing the chance of suture breakage, we should not place the anchor directly

![Fig 5](image1)

(A) If the suture anchor is placed directly under the cuff with a vertical suture, there is no \( x \) component of tension (\( T_x \)) in the suture to balance the pull of the rotator cuff (\( W_x \)). The system will attempt to reach equilibrium by having the rotator cuff pull away from the anchor to develop a \( T_x \) to balance \( W_x \). This can cause failure of the repair as well as very high tension in the suture at high angles of \( \theta \). (B) Optimal suture orientation at 45° or less. This configuration “builds in” a \( T_x \) to balance \( W_x \). (Courtesy of the University of Texas Health Science Center at San Antonio.)

![Fig 6](image2)

Pullout strength of a suture anchor increases as \( \theta \) decreases. That is, a suture anchor is more difficult to pull out at a low angle of \( \theta \) (6A) than at a high angle of \( \theta \) (6B). (Courtesy of the University of Texas Health Science Center at San Antonio.)

![Fig 7](image3)

Representation of \( \theta_1 \) and \( \theta_2 \), the pullout angle for the anchor (angle the suture makes with the perpendicular to the anchor); \( \theta_2 \), the tension-reduction angle (angle the suture makes with the direction of pull of the rotator cuff). Ideally, \( \theta_1 \) and \( \theta_2 \) should both be less than or equal to 45°. (Courtesy of the University of Texas Health Science Center at San Antonio.)
under the cuff but at the lateral edge of it, and we should place the suture obliquely into the rotator cuff tendon to minimize $\theta$ (Fig 5).

Secondly, pullout strength of a suture anchor increases as $\theta$ decreases (Fig 6). One can calculate that there is 41% more resistance to pullout at $\theta = 45^\circ$ than at $\theta = 90^\circ$. This is one other reason to try to minimize $\theta$.

**The Obliquely Placed Suture Anchor**

One can infer from the above discussion that it is mechanically advantageous to place the suture anchor oblique into bone. However, if this is done, then there are two ideal angles of interest (Fig 7):

- $\theta_1$ = the pull-out angle for the anchor, which is the angle the suture makes with the perpendicular to the anchor; and
- $\theta_2$ = the tension-reduction angle, which is the angle that the suture makes with the direction of pull of the rotator cuff.

Ideally, both $\theta_1$ and $\theta_2$ should be less than or equal to 45°, the ideal angle that the ranchers strive for on their deadman wires.

**Avoiding Predestined Failure**

An ideally placed suture anchor will have an obliquely-placed suture that develops a tension ($T_x$) to balance the pull of the rotator cuff ($W_x$) (Fig 5B). However, rotator cuff tears are frequently repaired directly over the top of a bone trough with a vertical suture (Fig 8A). This is a dysequilibrium situation because there is no $T_x$ to balance $W_x$ (Fig 8B). The only way that this system can reach equilibrium is for the cuff to pull away from its bed, thereby decreasing $\theta$ until there is a $T_x$ adequate to counteract $W_x$. This is exactly analogous to the fence post leaning until it reaches its “ideal angle”.

It is interesting and instructive to look at the balance of forces in a standard rotator cuff repair through bone tunnels. Because the tunnels are always positioned obliquely across the greater tuberosity, there is always a significant $T_x$ in this configuration to balance $W_x$, thus...
making it less likely that the repair will pull away from
the bone (Fig 9).

For a given value of pull by the rotator cuff, there is a
specific value of $T_x$ required to counteract it. Because
$T_x = T \cos \theta$, the total tension $T$ in the suture increases
as $\theta$ increases. As $\theta$ approaches $90^\circ$ (the verti-
cally-placed suture), one must bear in mind that $\cos 90^\circ = 0$,
so that $T$ in this case would be infinite. It is important to
appreciate that as $\theta$ approaches $90^\circ$, the tension in the
suture rises dramatically, and the chance of suture
breakage is much greater than at low angles of $\theta$.

**Conclusions**

Attention to minimizing the angle of insertion of the
suture anchor ($\theta_1$), as well as the angle that the suture
makes with the rotator cuff ($\theta_2$) can increase the pull-
out strength of the anchor and reduce the tension in the
suture, thereby minimizing the chance of suture
breakage. The deadman theory of suture anchors ex-
plains how to maximize the mechanical stability of the
suture anchor–rotator cuff construct by minimizing $\theta_1$
and $\theta_2$.

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