BIOMECHANICS OF SUBAXIAL CERVICAL SPINE INSTRUMENTATION

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The rapid evolution of spinal instrumentation in the last two decades have been associated with a significant improvement in the patient care. Numerous techniques have been described to treat spinal instability. To determine the most appropriate technique is problematic in decision making process. Therefore, a surgeon must understand the biomechanics of the cervical spine and instrumentation to apply most appropriate technique to his/her patient.

Ventral Subaxial Cervical Spine Fixation

Ventral plates are commonly used implants all around the world. The first report was in 1964 by Bohler (1). By time specifically designed constructs were developed. From the point of biomechanics two concepts are important; 1) construct design and 2) the mode of placing the implant.

A) Construct Design

The first implants used in ventral cervical spine were not designed for this region (4,7). In 1971, the first specifically designed ventral implants were introduced (2, 9). The subsequent advance in construct design resulted in satisfactory outcome. However, there are many problems with anterior fixation of the cervical spine.

One of the important problems is screw loosening and resultant loss of fixation with possible esophageal damage. The rate of screw loosening and pullout with early plate designs, which allowed only one screw per vertebra, was higher than the more modern system plates which allows two screws per vertebra (18). The load distribution between the screws resulted a lesser force acting on a single screw, thus minimizing the pullout risk. Locking screws are used also to enhance the pullout resistance (Figure 1).

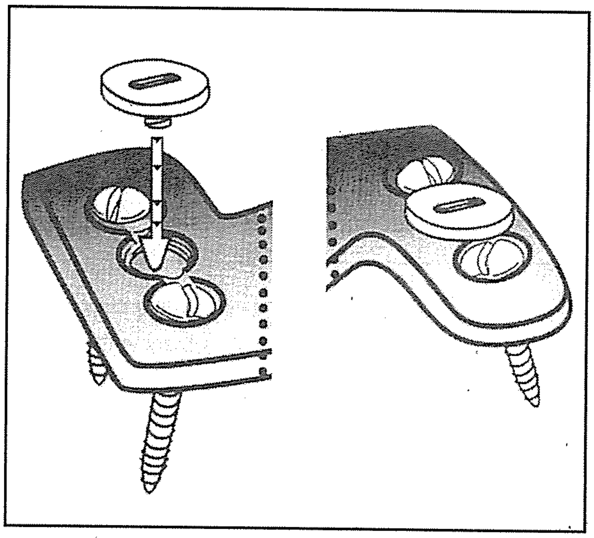

Figure 1. Locking screws are used to enhance the pullout resistance.

With this technique, one should keep in mind that the construct is now a rigid system due to locking screws and do not allow the screws to toggle in with respect to the plate. To achieve a greater pullout resistance, modified screws have been designed. Lesion (10) described an

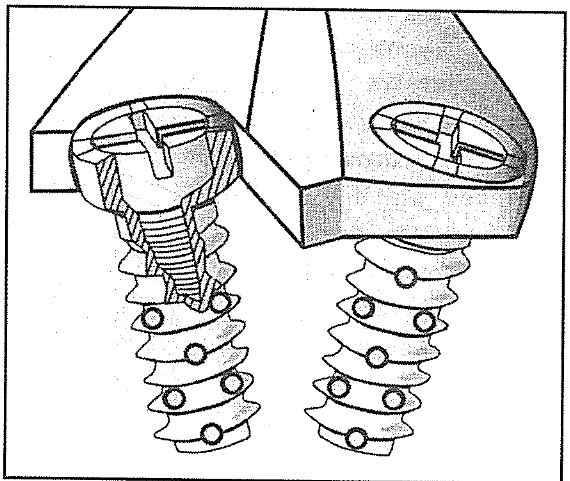

Figure 2. Expansion screws resist screw loosening and pullout forces.

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expansion screw. With this technique, the diameter of the tip of the screw can be increased by a set screw. Later, Morscher (12) applied similar technique with a modification. A set screw expands the head of the screw against the hole in the plate (Figure 2). The problem with these techniques is the fenestrations of the screws. The fenestrations in the screws allow bony ingrowth, on the other hand they are caused significant reduction in fatigue life (8). Another described technique to increase the pullout resistance is to place the screws in a toed-in' manner (Figure 3). The bony volume subtended by the screws is proportional to pullout resistance.

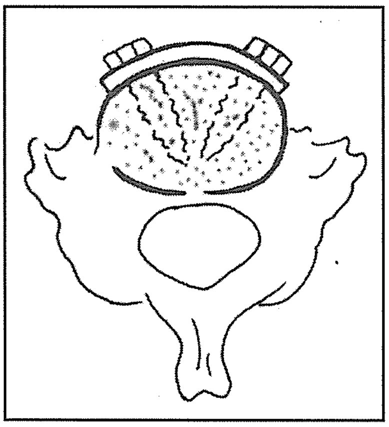
Figure 3. Toed-in' technique increases the pullout resistance. The bone volume, shaded area, is directly proportional to pullout resistance.

One of the major concerns in placing the screws is the penetration of the dorsal cortex. Biomechanical data with Caspar screws revealed that there is no additional significant pullout resistance to direct axial loads with bicortical purchase compared to unicortical placement (11). However, bicortical placement provided an enhanced stability under cyclical loading (16). Therefore it might be more appropriate to place the screws bicortically.

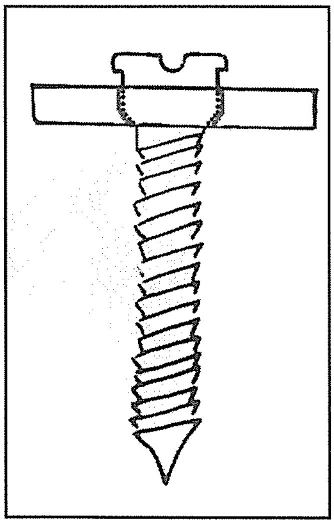
Figure 4. Rigid screw-plate interface does not allow screw movement in the plate

Finally, construct design in regard of subsidence is important. The commonly used ventral implants are rigid or semirigid. The rigid construct is, by definition, does not allow screw movement (toggle) in the plate (Figure 4).

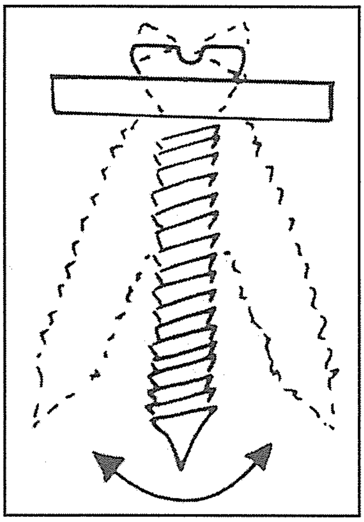
Figure 5. Semirigid screw-plate interface allows screw toggle in the plate

other hand the use of a rounded hub, allows some movement of the screw in the plate (Figure 5). The importance of this difference is manifested in load bearing concept. Both techniques have their own advantages and disadvantages. In the rigid system the greater stress is placed at the screw-plate interface. This might offer an advantage in osteoporotic spine. On the other hand, this technique effectively resists subsidence. Normal settling cannot theoretically occur. Since bone heals best under compression (Wolf`s law) (5) and since adequate compressive forces are not allowed to be transmitted to the fusion surface, healing may not occur. Non-union or pseudoarthosis may result with a semirigid system, the greatest stress is usually applied at the screw-bone interface. Therefore, screw pullout may result particularly in osteoporotic spine. On the other hand this technique allows, in part, subsidence of the bone. Compressive forces are applied to bone graft. Therefore, a higher fusion rate may be expected. A new ventral construct (named "DOC" Depuy Acromed, Raynham, Massachusetts) designed by senior author (ECB) address this dilemma. The "DOC" system may be placed in a rigid fixation made, however the technique itself permits spinal subsidence (Figure 6).

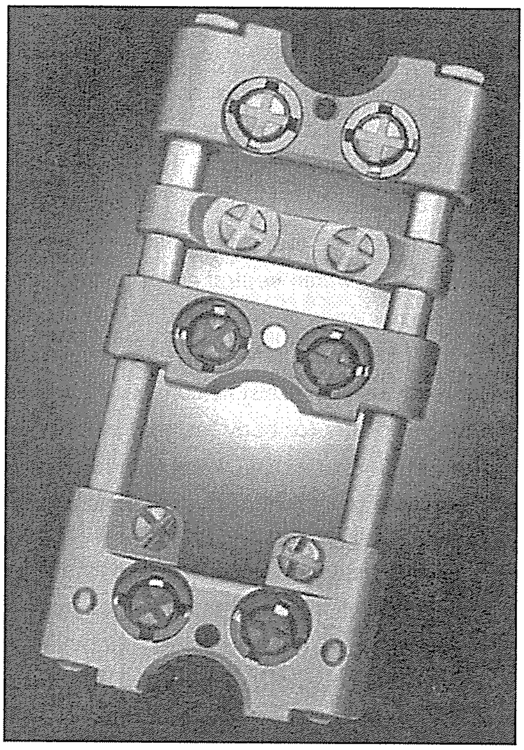

Figure 6. The screws of the DOC system are placed in a rigid manner, however sliding of the rods allows spine settlement.

B) The Mode of Implant Placement

Spinal implants may be placed in one or a combination of three different modes (along the long axis of the spine): 1) Neutral, 2) Distraction, or 3) Compression (Figure 7). Many spinal implants are placed in the neutral mode; i.e, they do not apply a force to the spinal column at the time of surgery. However, for the implant to never apply any force to the spinal column is impossible. After the surgery, any change in body posture (e.g., the assumption of the upright position) causes the implant to apply or to resist forces. Implants placed in a neutral mode usually resist compression forces when the patient assumes an upright position. Therefore, this implant is in fact in a distraction mode during this loading condition (Figure 8).

Load Sharing and Load Bearing

The mode of application of an implant significantly affects the forces acting up on the spinal column. A spinal implant placed in a distraction mode at the same time of surgery bears the major component of an axial load during the assumption of the upright position. However, if a spinal implant is placed in a compression mode at the time of surgery, it will share the axial load with intrinsic spinal structures, other spinal implants or an interbody bone graft. In such a circumstance, the implant may not bear any axial load during the assumption of the upright position if there is enough compression applied at the time of surgery (e.g., if the force of compression is equal to the weight of torso above implant). These concepts of load sharing and load bearing are closely related to the mode of application of the spinal implant. A spinal implant placed in a

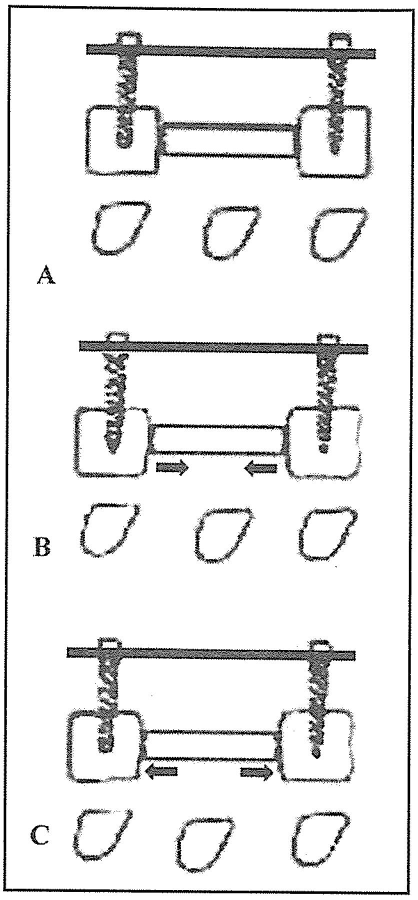

Figure 7.
a.Neutral mode,
b.Compression, mode, and
c.Distraction mode

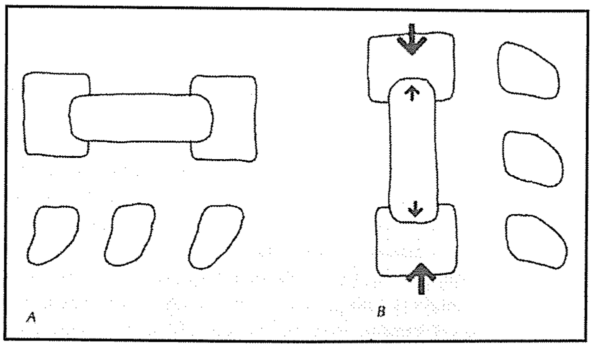

Figure 8. Neutrally placed construct in surgery acts in distraction mode when patient takes upright position.

compression mode thus allows the implant to share a portion of the load applied by the torso; whereas a spinal implant placed in neutral mode bears all the load applied by the torso, and a spinal implant placed in distraction mode bears all the load applied by the torso in addition to the load borne at the time of surgery (Figure 9).

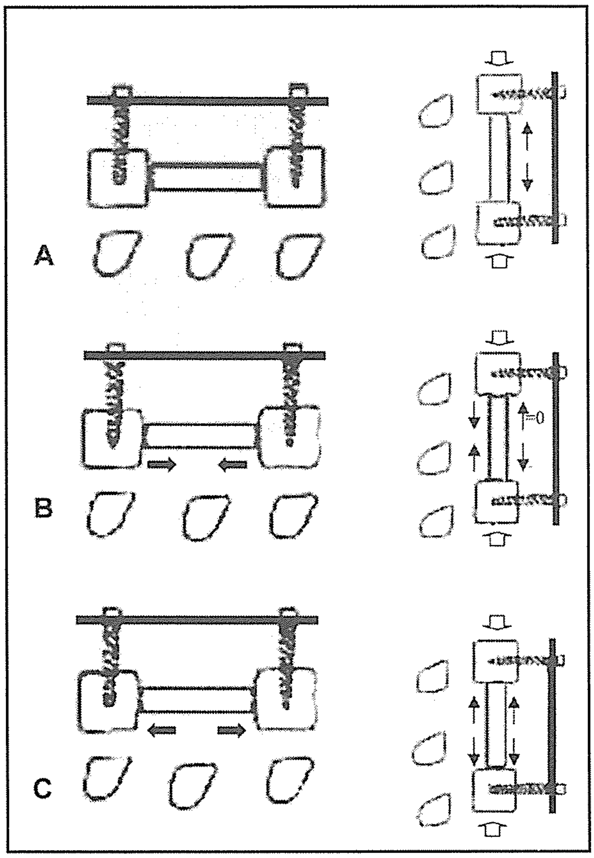

Figure 9. Changes in body position alter the load applied by an implant upon the spine. A) An implant is placed in a neutral mode (zero surgical load, left), resists to axial loads (hollow arrows) when an upright posture is assumed. This axial load, applied to the implant, is roughly equal to the weight of the torso above the implant (right, solid arrows). B) An implant is placed in a distraction mode (left, solid arrows), resists the axial load borne by an upright position (right, hallow arrows) plus surgical load. Thus the implant bears a greater load (right, paired arrows). C) If the implant is placed in a compression mode (left, solid arrows, negative surgical load) when an upright position is assumed, the implant bears an axial load that is less than the weight of the torso above itself. In such a case, if the negative surgical load is equal to the axial load borne by an upright position (weight of the torso above the implant) then the load borne by the implant during assumption of the upright position is zero; that is, the surgical load and weight of the torso above the implant are equal but in opposite direction (right, solid arrows).

Spinal implants (or bony fusions) placed "in-line" with the IAR will not cause a bending moment. On the other hand, spinal implants (or bony fusions) placed "away" from the IAR create a bending moment. The magnitude of bending moment is proportional to the moment arm (perpendicular distance from the IAR). The importance of this concept is related to the fact that implants (or bony fusions) placed within neutral axis ("in-line" with the IAR) resist axial loads better than ventrally placed implants (or bony fusions). Conversely, ventrally placed implants (or bony fusions) resist flexion loading forces better than the implants (or bony fusions) placed "in-line" with the IAR (Figure 10). One should always consider these biomechanical facts during the clinical decision-making process.

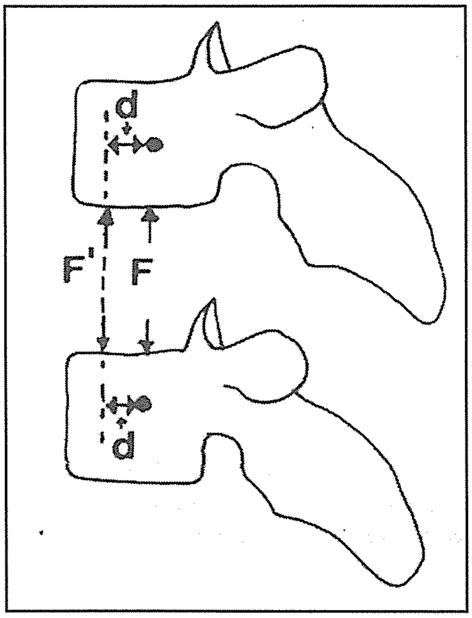

Figure 10. A distraction force (F) is applied "in line" with the IAR (in the neutral axis) does not cause a bending moment. However, a distraction force (F1) is applied at some distance from the IAR causes a bending moment. The magnitude of bending moment is related to the perpendicular distance (d) between force(F1) and the IAR (center of the neutral axis).

DORSAL CERVICAL SPINE FIXATION TECHNIQUES

Dorsal instrumentation of subaxial cervical spine is safe and effective. Therefore they are commonly used procedures. Numerous techniques have been described. The selection of the appropriate technique should be done with considering biomechanical principles in mind.

Wiring Techniques

In 1964 Rogers (13) described cervical interspinous wiring for post-traumatic instability. Numerous variations have been described. Sublaminar wiring technique carries additional neurologic risks due to wire passage around the lamina (3). This technique may be appropriate in case where spinous process fractures are present. Wires passed through the inferior articular process provide a useful vertebral attachment when the laminae are fractured or excised.

important with wiring techniques in regard of biomechanics.

First of all in spinous process wiring, if multiple motion segments are to be fused then multiple overlapping one-motion-segment cerclage wiring technique should be considered. The use of one long cerclage wire might cause of terminal bending moments (Figure 11).

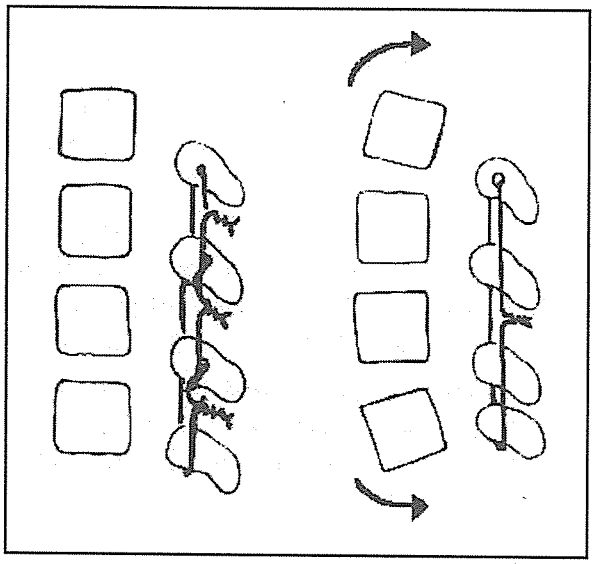

Figure 11. Multiple overlapping one-motion-segment cerclage wiring (A) minimizes with a Single-cerclage-wire technique (B)

Processus spinosus wiring technique provide greater biomechanical advantage compared to facet (or sublaminar) wiring technique. This is due to the fact that the fixation lever arm length is longer with processus spinosus wiring technique. Therefore, it provides a more stable construct (Figure 12).

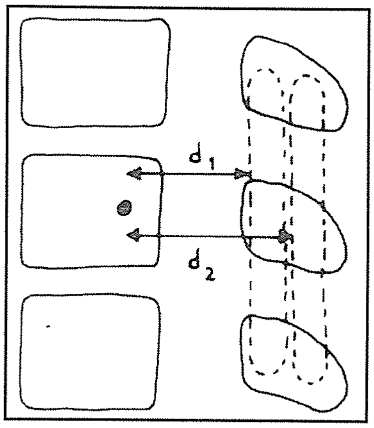

Figure 12. Spinous process wiring technique has a longer lever arm (d_2) compared to facet (or sublaminar) wiring technique (d_1).

With wiring techniques, one should keep in mind that in the presence of dorsal element fractures, additional motion segments must be incorporated into the construct.

Interlaminar Clamps

Tucker described the use of Halifax interlaminar clamps for dorsal cervical stabilization (17). The need for intact laminae and the bulkiness of the implant has diminished its popularity with a translational instability, a dorsally applied clamp may not prevent a translational deformity (Figure 13). Anatomic constraints on translation should exist before the use of such a clamp is considered.

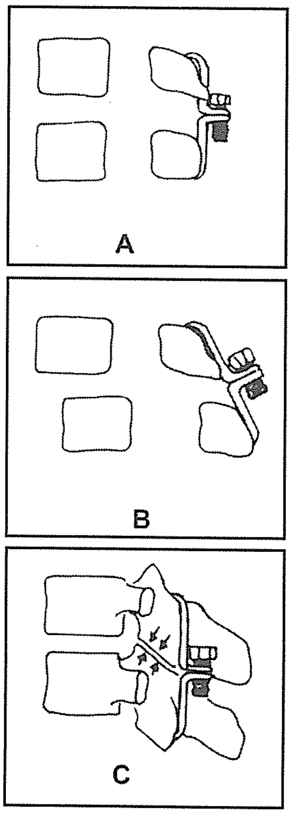

Figure 13. The application of clamp may not prevent a translational deformity (A,B). However, in case where an anatomic constraint (e.g., intact facet joint) exists, then a clamp can prevent translational deformity.

Lateral Mass Techniques

Roy-Camille developed the lateral mass plate technique in 1970s (14). The technique gained popularity due to it may be applied from C2 to upper thoracic spine, and that fixation is not dependent on intact laminae or spinous processes. These constructs provide significant flexural stability and resist extension and torsion better than wiring techniques (15). Additionally in experienced hands, fusion with lateral mass plates require less operative time compared to segmentally wiring bone grafts to the articular masses. The major disadvantage of this technique is the potential for the nerve root or vertebral artery injury. Two techniques have been described to insert the screws. The Roy-Camille technique is to place the screws 0° ventral and rostral and 10° ventral and laterally. The Magerl technique is placing the screws parallel to the articular facet and 30° ventral and laterally. Biomechanical analysis of these two techniques revealed a greater strength and stiffness of the Magerl technique (6).

One should keep in mind that dorsally applied constructs should not to be expected to bear axial loads. Therefore, an intact or sufficient load bearing capacity should exist ventrally, in order to achieve a satisfactory dorsal fixation. Additionally bone fusion usually applied with all types of instrumentation even ventral or dorsal. Clinical data expertise to date that fixation with implants provides early term stabilization while bone fusion provides long term stabilization.

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