The more for the less: fracture fixation tools for spine stabilization in difficult war times with analysis of modes of failure

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الخلاصة

شهد العراق احداث حروب كبيرة كان لها اثر كبير على العناية الصحية في البلد وعلى مستوى معايير العناية بامراض العمود الفقري. ان ظروف الحرب وعدم توفر اجهزة ومواد تثبيت العمود الفقري المعروفة عالمياءادى الى استخدام بدائل اجهزة وادوات تثبيت الكسور والعظام المستخدمة في الاصابات لكونها متوفرة ورخيصة الثمن ،حبث استخدمت هذه الادوات لتثبيت ازاحة الفقرات القطنية لاثنان وعشرون مريضا بواسطة البليت والبراغي مع ترقيم عظمي خلقي.

تمت متابعة المرضى لمدة (3,5 -10 سنوات) مع عرض تحليلي لاسباب فشل التثبيت لاربعة مرضى كما اجريت لاحدى عشر مريض عمليات تثبيت اربعة فقرات اثنان فوق مستوى الاصابة واثنان تحت الاصابة على مستوى الفقرات الصدرية القطنية لمرضى مصابين بحوادث مع كسور او اورام العمود الفقري, حدث فشل البراغي التحتية لثلاث مرضى مع عرض تحليلي لاسباب الفشل في التثبيت .

ان موجبات استخدام مثل هذه الادوات لمرضى مصابين بامراض العمود الفقري مع عدم استقرار الفقرات او المهددة بحصول تلف في الجهاز العصبي وفي مثل هذه الظروف قد يساعد المرضى حيث لوحظ تحسن احصائي نسبي من الناحية السريرية والشعاعية . ان الاستخدام الصحيح حسب قواعد الميكانيكا الحياتية للعمود الفقري هو اكثر اهمية من نوع ادوات التثبيت المستخدمة جراحيا.

Abstract

Iraq witnessed major war conflicts with devastating effects on the health care system .War and aftermath consequently affected standards of spine care. Patients with different spine melodies that jeopardize spine stability or neural integrity were stabilized using fracture fixation tools, that are inexpensive and were relatively available. This report describes the current application of short and long pedicle screw-plate constructs as spine stabilizers with analysis of modes of failure . Twenty two patients with grades two and three spondylolisthesis were stabilized with short single level constructs and followed for (5.3-10) years.Four patients had screw or plate failure.

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Long segment constructs with two segments fixed above and two segments below the index level were applied in eleven trauma and tumor cases with instability and incomplete or impending neurologic injury that jeopardize cord function .Three patients got caudal screws failure .Patients had statistically significant improvement in radiological and patient oriented outcome measures. Attaining the right biomechanical environment is more important than actual metal for fusion success and stability.

Introduction

Iraq recent history witnessed major war conflicts that had catastrophic effects on human health and well being .During whole 30 years , war impacts and the diversion of financial , human and natural resources for military purposes had their remarkable effects upon the general health care system.(1)

Health care resources during these tough times were severely limited and had adversely affected standards of spine care . Fracture fixation tools were used as an alternatives for spine stabilization as they were relatively available and inexpensive . Their application is based on the assumption that stiffness of the material used (typically Steel) is many order of magnitude higher than the bony and ligamentous spinal components responsible for the integrity in an intact motion segment. Constructs applying short segment and long segment pedicle screw-plate fixation ,whenever indicated, were evaluated regarding patients specific outcome measures as well as evaluating the longevity of the construct with an attempt to analyze biomechanical modes of failure .Ethically fracture fixation tools were used in trauma and tumor cases that threaten the neurologic state of the patient and when surgery is thought to further destabilize the spine segment operated on. A posterolateral fusion applying autogenouse iliac crest graft was used in all patients.

Biomechanical considerations

The primary objective in applying pedicle spine instrumentation is to facilitate a solid bony fusion and enhancing rapidity of fusion. Strain (deformation that occur at fusion site) determines the type of tissue at the fusion site. (2)

Biomechanically the pedicle screw -plate construct used in our series , applies a cantilever beam fixation force to the spine(A cantilever is a bracket or beam that projects from an immobile object, it is supported at one end only) .Screw-plate constructs allow toggling of the screw at screw-plate interface , thus applying a non fixed moment arm cantilever beam. In that manner they perform as semi rigid fixation constructs allowing some movement which may permit certain strain level and semi rigid stability. Screw-plate constructs used in our patients were placed in neutral mode; that is, they apply no forces of any type to the spinal column at the time of surgery. However ,in reality ,this is often not possible if we consider complex stresses opposed by the implant by movements of the body. The mechanism of the load bearing by the construct varies depending on the different loading conditions.(2)

The Toggling of the screw at the screw-plate interface , allowed by this technique, dictates that little if any , bending moment is applied to the spine or is resisted by the implant during axial loading. This highlights the importance of anterior column support in such constructs. A non fixed moment arm beam does not effectively bear an axial load , however it assists the already present load-supporting structures to do so.(3)

The ability of a non fixed moment arm cantilever beam to resist translation in the sagittal plane may be limited because of the parallelism like effect , particularly if one motion segment is encompassed by the construct (2, 4), however , non fixed moment arm cantilever beam constructs may achieve some of the rigidity characteristics of their fixed moment arm cantilever (Rigid pedicle fixation technique), by pulling the spine to the construct. The pulling of the spine elements to a plate may lend a considerable degree of stability to the construct by resisting bending and increasing axial load resisting abilities. Direct bony contact and friction between the plate and bone imply stability to the construct , screw purchase within the pedicle decreases toggling of the screw with the plate(cortical bone has relatively good screw pullout resistance). The extend of contribution of this factor varies and is not readily measurable. However, at best , pedicle screw-plate constructs stiffen the unstable segments and apply semi rigid fixation.

In general , spinal implants are not rigid. Dynamic bone deformation through remodeling decreases the rigidity and strain level even in more rigid constructs. However, the toggling of a non fixed moment arm cantilever beam permits deformation immediately , this dynamization by toggling may be beneficial in that it permits the construct to (see) adequate settling for fusion.(2, 5)

Materials and Methods

The study was conducted in patients operated on during the period from May 1997- July 2004.

Twenty three patients, with an age range from (29-56) and including (18) females and (5) males ,all presented with disabling back pain and claudicant neuralgic leg pain with and without neurological symptoms , refractory to at least 6 months of conservative treatment . Patients had radiologic evidence of single level lumbar spondylolisthesis with neural canal stenosis in the relevant level based on magnetic resonance imaging.

L4-5 level was involved in twenty patients and L5-S1 in three , all having isthmic type with pars defect . One patient had grade three L5-S1 olsithesis, twenty two patients had grade two.

In all patients a posterior decompression, including laminectomy , medial facetectomy , and foraminotomy were performed. A short single level instrumented fusion applying two hole, AO fracture fixation plates and 6.5mm diameter , 32mm partially threaded cancellous screws were used as an implant ,(Figures 1,2)

Decortication of transverse processes and autogenous graft harvested from the posterior iliac crest was applied for all patients.

Patients were evaluated using ,visual analogue scale ,Oswestry disability index , both preoperatively and on the first , second and third years postoperatively and at the final time of follow up.

Eleven patients were stabilized applying long three and four segments constructs. Two patients had tumors with disabling pain and impending pathological fracture , (One with L5 Giant cell tumor and one with L1 metastatic disease).

Six patients had neurologically unstable thoracolumbar burst fractures .Three patients had three column unstable rotational translational injury

(Figures 3-7) All nine had incomplete cord injury (Frankel grade C in six patients and grade D in Three). All patients had mechanical or neural instability according to well defined criteria in thoracolumbar trauma , that warrants stabilization or neural decompression whenever indicated.

Ten patients had two levels above the index unstable level and two levels below were instrumented using long oval hole , AO fracture fixation plates , with careful matching of the holes with pedicle entry points. One patient with L5 tumor had one level below and two levels above instrumented. 4.5 mm diameter cortical screws were used for dorsal spine pedicular fixation , while 6.5mm diameter ; 32mm partially threaded cancellous screws were used in the lumbar spine.

Radiologic evaluation including lumbar anteroposterior , lateral , flexion and extension views taken before surgery and at the mentioned intervals postoperatively. Outcome in terms of pedicle screw implant survival , fusion success , and functional status was evaluated in long segment instrumented group. The classification of Lenke (6) ,was used to determine fusion in patients with isthmic spondylolisthesis, which examines the size of the grafted bone created between the upper and lower transverse processes , and the discontinuity and resorption of the fusion mass. Results above B –level on the Lenke Classification were considered fusion. A more than 5 degrees movement on lateral flexion and extension views were considered fusion failure.

All data were entered into the SPSS statistical program (version 16.0; SPSS , inc., Chicago, IL).

A paired –sample t test was used to examine the statistical significance. All test results were considered significant if $P<0.05$.

Results

Length of follow up ranges from (5.3-10) years. The short segment fixation group with olisthesis showed statistically significant improvement in VAS score and Oswestry disability index (ODI)scores for both back and leg pain($P<0.01$). This improvement continued for the whole length of follow up. Four patients had implant failure, three with screw breakage at the screw plate junction or along the screw path (Figure 8), and one with plate failure at the upper screw hole on one side (Figure 9). All four patients had pseudoarthrosis in the form slip

progression or angular movement of more than 5 degrees on dynamic views. All other nineteen patients were above B-level Lenke classification score.

In patients with long segment instrumentation , three patients had implant failure in the form of screws breakage. Two trauma patients with flexion distraction thorascolumbar injury and three columns failure with painful focal kyphosis , sustained both caudal screws breakage at screw-plate junction. The third patient with L5 giant cell tumor had rostral screws failure at screw-plate junction four years postoperatively (Figure 10).Both patients had radiological evidence of kyphosis angle progression with follow up, although they continued to have pain VAS score improvement from their preoperative state. In all patients , a posterolateral only fusion was done.

Trauma patients with long segment construct fixation were immediately mobilized with external brace for comfort , discontinued within three weeks when pain lessened. Frankel scale improved in three patients from grade (C) to grade (D) with incomplete cord injury. Neurologic recovery plateaued and remained unchanged for the other six patients.

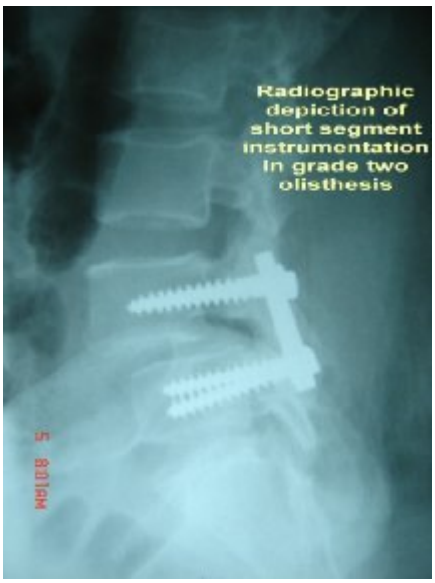

Figure 1

Figure2

Figure 3

Figure4

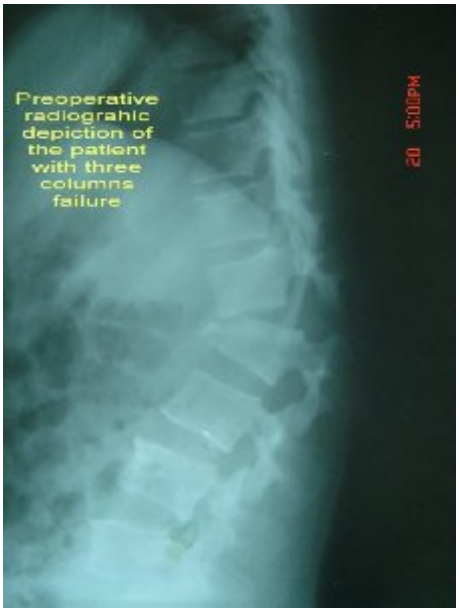

Figure 5

Figure 6

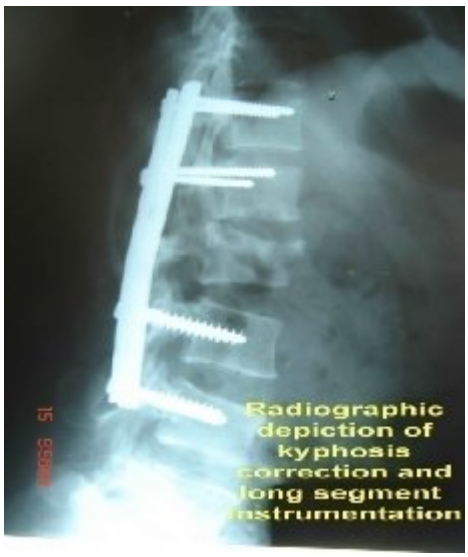

Figure 7

Figure8

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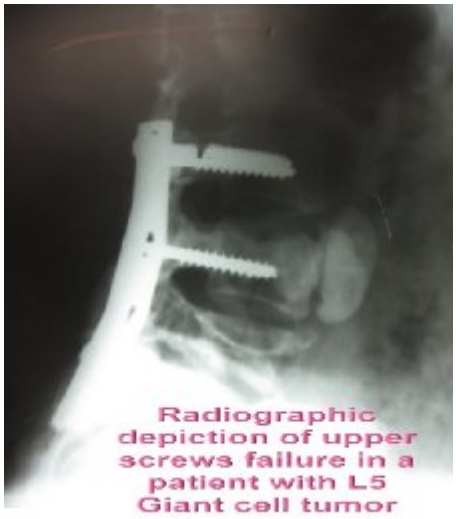

Figure10

Discussion

From 1980s , and for thirty years, Iraq witnessed difficult war times at which health care resources were severely limited . From 1991-2003, continued economic sanctions and internal political events added to the aftermaths of war in the form of extreme shortage of equipment and medical supplies. (1) Consequently the quality of spine care in Iraq was adversely affected. Patients presented with disabling spine conditions were managed with the currently available tools at that time. Spine stabilization ,utilizing fracture fixation tools ,were used alternatively to protect against impending neurologic injury, and in short segment stabilization when surgical removal of posterior elements (i.e., Laminae, articular factes, and pars interarticularis) was thought contribute to significant current or future instability.

The use of pedicle screws was first reported in the 1940s (4).The pedicle has been described as the (force nucleus) of the spine. The pedicle , as the strongest portion of the vertebral body , is ideal as a point of force application for segmental fixation. When pedicle screw is correctly placed ,it avoids spinal canal intrusion. Pedicle screw constructs are more rigid than other forms of internal fixation as measured by flexural , compression and torsional rigidity (2 , 4) .

However , the true value of pedicle screws can be determined only if these qualities translate to an improved fusion rate and enhanced patient outcome. Use of adjunct pedicle screw fixation improves the biomechanics of the maturing fusion.(5 , 7 , 8)

The indications for posterior instrumentation of lumbar and lumbosacral spine conditions are primarily related to deformity and instability resulting from trauma ,tumors, spondylolisthesis, segmental instability , scoliosis. The primary goals are to facilitate fusion , decrease pain , and increase patient mobility. Pedicle screws provide optimal fixation to the sacrum and the L4 and L5 vertebral bodies after a laminectomy (8). They are also useful in certain traumatic injuries with rotational translational instabilities.(3,9)

Posterolateral fusion applying short segment pedicle screw fixation was used in spondylolithesis patients .Screw-plate constructs used in our series , apply a non fixed moment arm cantilever beam fixation because of screw toggling at screw-plate junction. However , progressive screw

tightening and close approximation of the plate with the posterior elements , bringing the spine to the implant, adds greatly to stabilize spine motion segment and improving fusion mass stability. (2)

Screw-plate construct may function ,at least in part, as tension band fixation construct , they resist flexion , thus functioning as a tension band fixator in flexion via the application of bending moment (9). Excess shear and bending moment application may cause the plate to fail at point of maximum stress , this had occurred in one case with short segment fixation in grade two isthmic spondylolisthesis. Non fixed moment arm screw-plate construct may fail by screw pullout, however this has not occurred in our patients.

Successful fusion is the ultimate goal in olisthetic instabilities. Instrumented spine fusion , whether it increases fusion rate or improves ultimate patient outcome ,has been controversial in the literature (10 , 11). Kim et al (11) evaluated 89 consecutive adult patients with spondylolisthesis . They found no significant benefit in terms of fusion success between patients treated without instrumentation (75% had successful fusion) and those who underwent fusion plus spine fixation through the pedicles(65% had successful fusion).

Historically, progressive vertebral slippage and angulations' have been reported in up to 33% of radiographically solid in situ non instrumented posterior fusions in patients with spondylolisthesis (10).In short segment constructs , the fusion rate as determined by Lenke criteria was (81.1%) in our series. All patients with pseudoarthrosis had implant failure in the form of screw or plate failure. Radiologically they had progression of slip degree and angle . Implants used to stabilize the spine will eventually fail , no matter how strong they are ,if stable and solid fusion is not achieved in due time. It is a matter of (race) between the attainment of solid fusion and implant longevity.(2 , 9, 12, 13)

Implants fail at points of maximum stress application (2, 13). The point of failure of pedicle screws in a non fixed moment arm cantilever beam is usually at the screw plate junction (point of maximum stress)(2, 4). Fracture fixation screws used in the construct are of constant inner diameter ,hence the bending moment increases linearly along the screw (2)causing the screw to fail at screw-plate juncture or at some distance near the plate along the screw path.This mode of failure occurred in four

cases with short construct fixation and in two cases with long segments fixation . In addition ,when the whole construct is subjected to an axial load ,screws (see) different force vectors both in magnitude and direction at various points along the screw path .The load varies with varying consistencies and integrities of the materials through which the screw passes (plate, cortical to cancellous bone). These can cause a(shear)effect , and a three or four-point bending force application along the screw that may eventually fail(2).This mode of failure may predominate along with the long moment arm of mobile spine segments above the fused levels , stressing the screw to failure .This may explain the mode of failure occurred in the tumor patient with rostral screws breakage at some distance along the screw path.

Screw design offers varying degrees of fixation strength within the vertebral pedicle . In general , the larger the inner diameter , the greater the flexural rigidity , or bending strength. Screw breakage secondary to bending fatigue appears to be the primary mode of failure (14) . The pullout strength of a screw , which is of less importance as a cause of pedicle screw failure in non osteoporotic bone , is determined by the difference between the diameter of the outer –screw thread and the diameter of the inner core ;the larger this difference , the stronger the pull out strength (4 , 10). In general the use of fully threaded screws and insertion of the screws deeper within the vertebral body improve overall pull-out strength. Screw pullout was not a mode of failure in this series.

In long segment fixation constructs, a non fixed moment arm cantilever beam fixator can apply a three-point or four point bending moment that resists kyphotic deformation (2, 4, 9, 16) .This biomechanical principle was applied in unstable trauma cases with focal or regional kyphosis . An anterior column integrity and support is a perquisite for construct biomechanical success (2,17). A deficient anterior column , and the long moment arm , loads the caudal screws more than the rostral screws (2,4) .This can cause failure of the caudal screws which occurred in two trauma cases with long segment fixation in which posterolateral only fusion was used.

McLain et al (13)reported on 19 patients who underwent short and long segment screw fixation through the pedicle for unstable thoracolumbar and lumbar fractures. Only11 patients underwent two-

segment stabilization above and below the level of the injury. At an average follow-up of 15 months , 10 patients demonstrated some form of treatment failure, 7 patients had implant breakage with resultant kyphosis , and 3 patients had kyphosis due to osseous collapse or vertebral translation without hardware failure.

Ebelke et al (18)performed a survivorship analysis on 21 patients with lumbar-burst fractures who underwent two segment fusion with variable spine plate instrumentation . in the 8 patients who underwent an additional anterior or middle-column grafting procedure , there was no evidence of implant failure at an average follow-up of 27 months. The remaining 13 patients underwent posterior stabilization and fusion without anterior bone grafting . At the 18 month follow-up, only 49% of the implants had survived.

Many clinical investigators have noted a high incidence of hard ware failure with pedicle screw implant systems (9, 12, 13, 18, 19, 20,) . Screw breakage rates were approximately 30% in some studies (21). The use of fracture fixation tools for spine stabilization is atypical, and is dictated by difficult times. A historic cohort of patients studied with variable spine plate (VSP) and screws that perform essentially in a non fixed moment arm cantilever beam fixation mode was described in the literature in the 1990s.

In a survivorship analysis of pedicle spine instrumentation, McAfee et al reviewed the data on 120 patients who underwent fusion for disorders of the lumbar spine supplemented with either a (VSP) device n=78 or Cotrel-Dubousset instrumentation with bone screws placed in the predicle (N=42). At the 10 year follow up , 22 of the 526 pedicle screws placed were found to be either bent or broken. However the incidence of successful fusion was 90%, and the instrument survival rate was 80%.

Matsuzaki et al (12)reviewed the data on 57 patients with lumbar degenerative disease , of the297 screws placed, 17 broke (6% complication rate). Hsu et al reported on 76 patients who underwent fixation through the pedicle , primarily for lumbar degenerative disease , including spondylolisthesis. At follow up , 16 patients (21%) were found to have one or more broken screws.

Retaining the right biomechanical environment is more important in achieving successful fusion and improving patient outcome than the

actual metal used (2,4,21). Metal is stiffer than osteoligamentous components responsible for stabilizing spine motion segments (22, 23,24). Achieving fusion that permanently stabilize unstable spine segments is the ultimate goal. Screw-plate constructs used in our series were utilized mainly as internal splint to protect neural tissue from impending or continued injury , which is the primary justification for their use. Patients operated on , had statistically significant improvement in their pain and disability scores, however, this cannot be attributed solely to implant application .

Many other variables need to be evaluated in this heterogeneous group of patients(24,25). This report for utilizing inexpensive , relatively available tools for spine fixation may prove useful in conflicted countries with limited resources . Spine fixation technology is rather expensive and cannot be offered to many patients or even nations.

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