Review Article

Spinopelvic fixation

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Historical Review

Fusion to the sacrum presents as a complex and difficult technical procedure with outcomes which have been up until recently, relatively poor, with high pseudoarthrosis rates and associated with the development of so called flat back deformity or loss of lumbar lordosis. Previous reports from the morbidity committee of The Scoliosis Research Society in the late 1970's indicated that this did not appear to be a problem in adolescence

Kostuik et al[11] published, the first results of fusion to the sacrum in adults with idiopathic scoliosis, in 48 cases, using Harrington rods. The pseudoarthrosis rate was 40 percent, there was a flatback deformity rate of 50 percent. Balderston,[3] reported similarly poor results with loss of lordosis in 39 percent, poor results in up to 72 percent, loss of lordosis in 37 percent and 56 percent required additional surgery. The subsequent development of the Luque-Galveston Segmental Instrumentation showed enhanced results. Kostuik in 1988[14] demonstrated a pseudoarthrosis rate of 15 percent and a flatback deformity rateof 20 percent. Blumenthal,[4] reported further use of Luque-Galveston Segmental Instrumentation as did Boachie, who in,[5] reported a pseudoarthrosis rate of 41 percent, complications of 82 percent and a pain improvement of 63 percent. This is associated with the anterior fusion at the lumbo sacral junction. Saer et al[25] again using the Luque-Galveston techniques, reported a pseudoarthrosis rate of 12 percent which was associated with an anterior column support of the lumbo sacral junction. They reported no flatback deformity. Devlin et al[6] reported in adults requiring fusion to the sacrum, a pseudoarthrosis rate of 26 percent, flatback deformity in 19 percent and instrumentation difficulties of 17 percent in 27 adults. There was no additional anterior column support.

Bradford et al[7] at the annual meeting of The Scoliosis Research Society in 2000, reported a 36 percent pseudoarthrosis rate using Luque-Galveston Techniques, seven point five percent with iliac screws and an eight point five percent rate with sacral screws. Kostuik[12] subsequently reported on the use of Cotrel-Dubousset instrumentation, a seven percent pseudoarthrosis rate, a flatback incidence of five percent, also using adjunctive anterior column support. More current results by Kostuik et al,[18] indicate a pseudoarthrosis rate of three percent and a flatback deformity of five percent using more current forms of sacral fixation.

Indications

The indications for fusion and fixation to the sacrum are many and varied. The most common cause is for degenerative low back disability and problems associated with neurological difficulties secondary to degenerative problems, such as is associated with degenerative spondylolisthesis or spinal stenosis. This article however is confined to long fusions to the sacrum that is four or more levels, more commonly encountered in such conditions as scoliosis, kyphosis, post lacemenctomy kyphosis and imbalance such as flatback deformity. In the adult patient with scoliosis, whether it be of a degenerative nature or idiopathic with subsequent degenerative changes, fusion to the sacrum is indicated if the L5-S1 level is part of the pain complex or severely degenerative. This should always be accompanied with anterior column support using structural materials such as structural allograft, autograft or other more modern types of cage fixation. Ideally pain at the L5-S1 level should be identified pre-operatively with the use of disgography.

Biomechanics

The sacrum is formed mainly from cancellous bone and in older adults is often associated with osteoporosis. The cortical shell of the sacrum is generally thin except for the anterior superior part of the S1 body. The ilium provides a platform for excellent fixation but it is superficial and may present with problems with prominent hardware post-operatively. Moreover surgery in this area may put at risk neurovascular structures particularly as one goes more lateral on the sacrum where anteriorly the common iliac vessels may be found as well as the nerve roots. The mid point of the sacrum over the sacral prominatory is void of many major neurovascular structures and can be safely used. The S1 pedicles in the sacrum are large but do not afford good engagement on the lateral cortical walls (Figure 1). Screws placed at S2, S3 are by necessity short and do not provide good fixation. The posterior

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sacrum does not readily accept hooks. There may be crowding of instrumentation in the posterior sacrum. The anatomy of the lumbo sacral base may be divided into three zones (Figure 2). The first is the lower lumbar spine where the pedicles provide fixation. The second is the sacrum and the third is the ilium. McCord et al.[22] showed that large cantilever loads exist at the lumbo sacral junction primarily on the middle column at the osteo-ligimentous annulus which acts as a pivot point. (Figure 3)

At that time, McCord[22] showed that iliac screws and Galveston Rods were best at resisting flexion moments. McCord[22] indicated that the maximum moment of failure was greater if fixation to the pelvis was anterior to the middle osteocartilagenous moment or pivot point. Fixation to resist failure in flexion was less with ilio sacral screws, Chopin block, single screws at the S1 pedicle, S1 sublaminar wires or hooks. These findings were similar for the maximum stiffness at failure, again iliac screws and S1 screws and the Galveston Technique being the most preferred techniques at that time. Alegre et al in[1] compared various techniques doing bio-mechanical testing for lumbo-sacral fusion and demonstrated that the more rigid constructs occured when the long posterior instrumentation was extended to either the ilium or to S2 screws, in addition to the S1 pedicle screws. Kornblatt et al[10] demonstrated that fixation devices at the lumbo-sacral junction see up to 100 percent newton forces during 90 percent of forward bending thus pointing out the large cantilever forces present at this junction. This is compounded, as Zindrick et al[32] showed that bone mineral density may be the most important factor in screw fixation strength. The anterior sacral cortex can be less than one millimetre thick in osteoporotic bone.[26] The superior sacral end plate has the highest bone density with in the S1 body as pointed out by Zheng, et al in 2000.[30] Leong et al[17] showed that divergent S1 screws, for example for with use of the Chopin block increased pullout 20 percent to 26 percent. S1 screw pull out is clearly better with biocortical purchase of the sacral prominatory than with the unicortical purchase. Medial purchase is greater than lateral purchase which is found in the sacral ala which may be extremely osteoporotic. More recent studies by Polly et al have shown that tricortical fixation with the screws in the S1 pedicle passes, not only through the promonatory but through the end plate of the S1 provides greater pull out strength and resistance to cantilever loads than bicortical purchase. Unpublished data to date, recently submitted by Eiji, Kostuik et al has showed that purchase through the S1 pedicle which goes through the end plate of S1 and transgresses through the L5 S1 disc and proceeds into the vertebral body of the L5, provides the most rigid construct and resistance to cantilever loads. Polly et al[24] (Figure 4) demonstrated clearly that there is increased stiffness with anterior column support, particularly the more anterior the support. Structural materials are placed anterior in the interspace, increases stiffness by 18 percent versus midbody placement of 12 percent and posterior interbody placement of six percent.

As well numerous options exist for fixation to the sacrum. These include; hooks, wires, cables, screws, screw blocks and various plates. Considerations also need to be given as to whether the fixation should be isolated to the sacrum only or to the sacrum and ilium. Single S1 pedicle screws are adequate for short fusions, for example two level fusions, although there has been an increased tendency to provide interbody support in recent years resulting in the so called 360^{o} fusion. These screws at S1 should be directed medialy in the sacrum, preferably in the prominatory and be bi-cortical at least. Sacral screws at S1 may be augmented with S2 screws, however these may be ineffective due to the short pedicle length of the S2. Directing the S2 screws laterally into the ala may

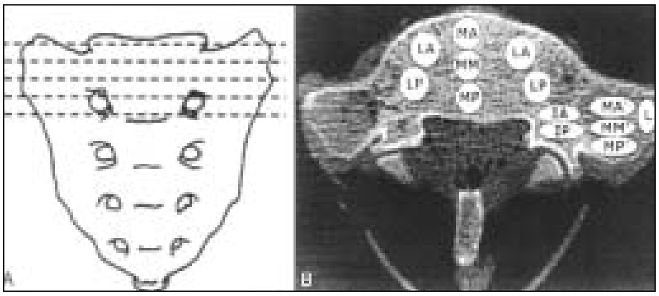

Figure 1: The safe zones for placement of sacral pedicle screws

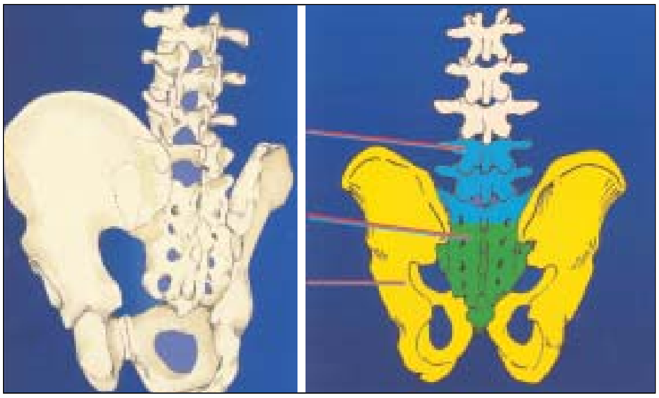

Figure 2: The three zones of firm fixation at the lumbosacral base

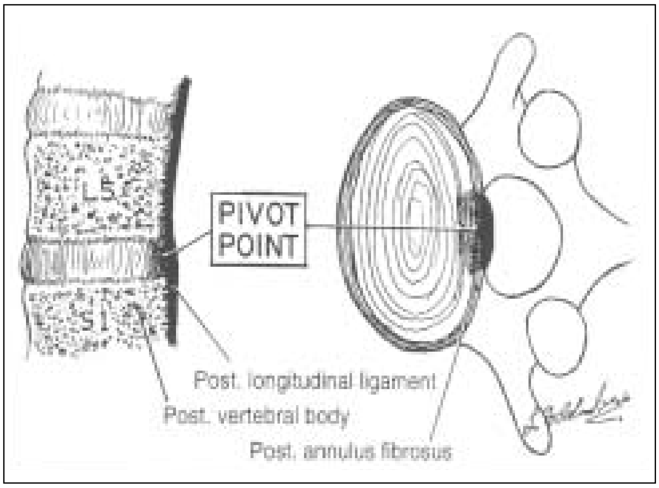

Figure 3: Large cantilever loads exist at the lumbo sacral junction primarily on the middle column at the osteo-ligamentous annulus which acts as a pivot point.

provide improved pullout strength, but can result in alignment difficulties and rod insertion may result in loosening. As well S2 screws may be prominent under the skin. On occasion, the author, where S2 screws have been necessary, has transgressed in a lateral direction, the sacro iliac joint, in order to obtain better fixation. This has not resulted in any significant long term sequellae. Numerous screw plates have been developed. These include the Roy-Camille plate, the Butterfly Plate by Louis,[20] the Steffe plate and the Chopin block and Tacoma Blocks. Louis[20] pointed out that by using these plates, a high fusion rates of 97 percent was obtained. Mechanical performance of these plates varies and they have been essentially abandoned. The screw plate devices do provide for controlled insertion of the screws, but may be difficult to orient and may result in some degree of stress shielding.

Intra- sacral rods

Jackson (1993)[10] introduced the concept of intra sacral rods using the so called iliac buttress. The advantage of these rods theoretically result in improved resistance to flexion bending moment. The disadvantages are that these may prove to be technically demanding in osteoporotic bone and prone to failure. (Figure 5)

Sacral hooks

Hooks in the sacrum are often prominent. The posterior cortex may be thin and fracture may occur. They may be used as an adjunct and are bio-mechanically similar in strength to intra-sacral rods distal to S1. If there has been a previous fusion to the sacum and the bone is dense, then hooks may be of advantage.

Luque galveston techniques

Although Luque[21] had previously introduced the concept of the Luque Rods, the Galveston pelvic extension was introduced in 1982 by Allen and Ferguson.[2] As noted, these are bio-mechanically superior in flexion and in stiffness. The advantage of the Galveston rods is that they provide an anchor in the ilium that is low profile and provides excellent resistance to flexion and helps to correct pelvic obliquity and are excellent for low demand patients. The disadvantages of the Luque Galveston Rods are that they offer little resistance to axial pullout [Figure 5]. Micro motion occurs resulting in the windshield wiper effect. Delamination of the ilium may occur with subsequent fracture propagation. They can be technically demanding in obtaining accurate rod bending. The development of the unit rod by has roven to beneficial in long fusions to the sacum required for people with paralytic deformities or deformities secondary to muscular dystrophy.

Ilio-sacral screws

Ilio-sacral screws where first introduced in 1973 by Vidal.[28] These were subsequently modified by Dubousset and Farcy.[8] McCord et al[22] showed that iliac screws were bio-mechanically equivalent to Galveston Rods for maximum moment in stiffness

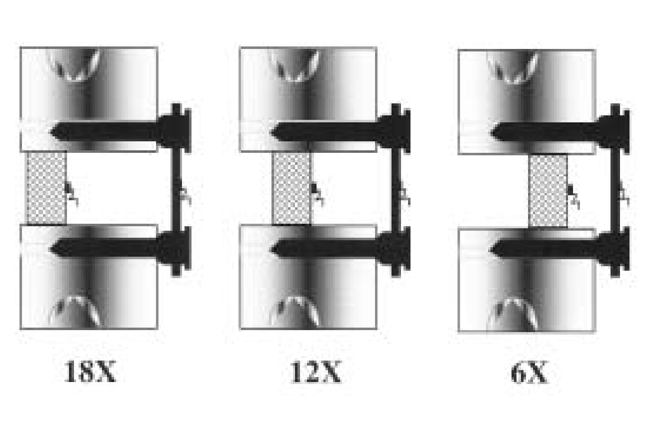

Figure 4: Increasing stiffness with anterior column support, particularly the more anterior the support

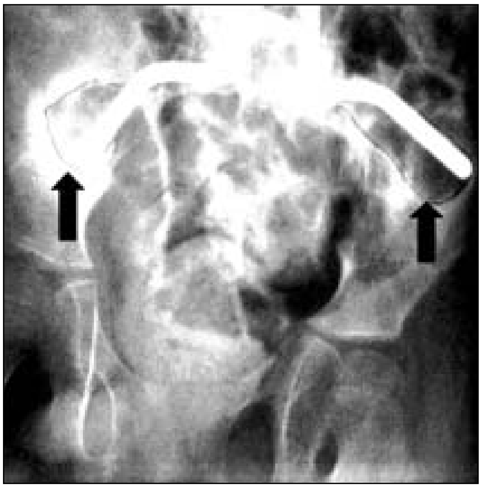

Figure 5: Failure of Galveston technique due to loosening

at failure and had an improved pullout over the Galveston Technique. They can be utilized with various systems [Figure 6]. Iliac screws offer advantages of improved bio-mechanics. They permit iliac crest bone harvesting and have shown to have high fusion rates, in long fusions and are valuable for the use in high grade spondylolisthesis. There may however be hardware prominence and exposure may be somewhat difficult. As well, they offer advantages for correction of pelvic obliquity and for revision surgery and do not violate the sacro-iliac joint. Disadvantages may occur as a result of difficulties in insertion. There has been a reported associated 10 percent neurological injury rate by Farcy et al[8] and is recommended that they be used in revision surgery. Iliac screws do require well developed iliac wings and are a value also in muscular deformity patients. For optimal fixation, iliac screws should be placed within 1.5 centimetres of the greater sciatic notch and extend anterior to the axis of rotation in flexion / extension. Fluoroscopic evaluation is an effective method to determine iliac screw placement in order to avoid sciatic notch violation, hip joint violation and medial wall

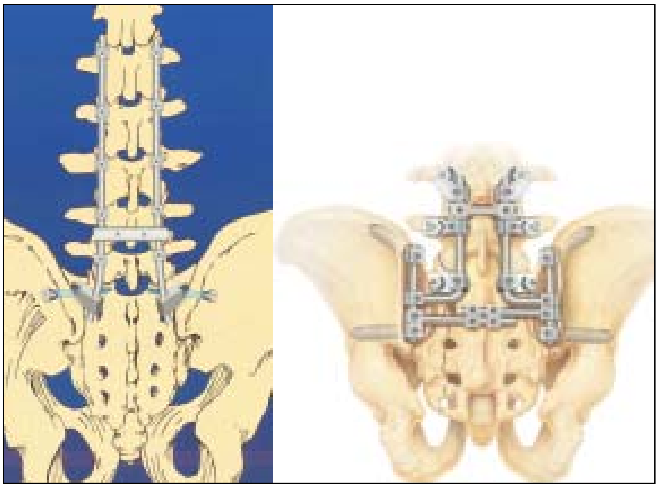

Figure 6: Iliosacral fixation

violation. Fluoroscopy, however can not determine screw placement when a lateral wall violation occurs. [Figure 7] illustrates dorsal lumbar sacral instrumentation using iliac-sacral screws through the S1 Pedicles, which offers a very firm form of fixation, but may be somewhat prominent and the instrumentation may be difficult to contour. Subsequent bio-mechanical studies by Kostuik et al, reported the most rigid construct across the lumbo-sacral junction to be a combination of four sacral screws, two L5 pedicle screws, together with anterior L5-S1 structural grafting. The L5 pedicle screws were found to significantly decrease rotational stresses at L5-S1. Subsequent studies by Kostuik, et al[15] have shown that the use of a sacral bar to be equivalent to iliac screws. The Jackson intra sacral technique does offer the stiffest construct. Whether one uses two or four sacral screws has shown to be of no statistical difference when anterior column support is provided a L5-S1.

Lebwohl et al in[16] tested S1 screws alone, S2 proximal screws, S2 distal screws, intra-sacral rods and iliac screws. As might be expected there was less sacral strain and axial compression and screw micro strain on the S1 iliac screws. This was similarly true for screw strain in flexion and extension and was highest for S1 screws alone. In axial compression the lumbo sacral range of motion was not significantly different in the various groups although slightly less for the intra-sacral rods and iliac screws associated with S1 fixation. In axial rotation, S1 plus iliac screws was significantly better than other techniques. Transacral bars were not tested in his bio-mechanical assessment in lateral bending, again S1 plus iliac screws proved to be the best construct, although S1 and S2 screws, the latter inserted distally, were equivalent. S1 plus iliac screws clearly provided the greatest resistance to flexion load to failure [Figure 9 and 10]. Fluoroscopy is recommended for placement of iliac screws. Iliac screws have often been utilized, placing them with blind techniques. Incorrect placement may damage vital neurovascular structures. Medial placement may injure the lumbo-sacral plexus and nearby vessels. Screws that compromise the sciatic notch may injure neurovascular structures, long screws may violate the hip joint. Orchowski et al,[23] evaluated the optimal anatomical placements. They utilized posterior / anterior inlet, outlet views with fluoroscopy. Judet views were also used to evaluate screw placement including iliac oblique and obturator oblique views. The obturator oblique views is best to demonstrate cortical breach at the sciatic notch. Inlet and outlet views were able to determine hip joint violation. Iliac oblique views were best to demonstrate medial wall violation, however no specific radiological view was able to adequately determine lateral wall violation which can only be confirmed by a surgical exposure such as is used in iliac bone graft harvesting. [Figure 6] illustrates iliac sacral fixation. These exclude the use of the sacral bar to be demonstrated later.

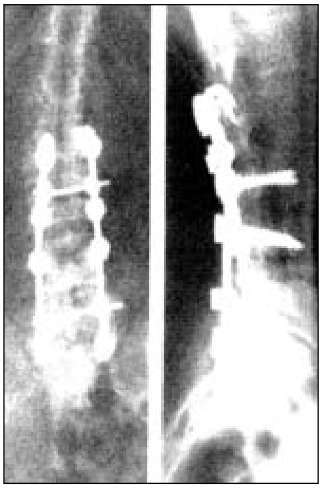

Figure 7: Dorso-lumbar-sacral fixation

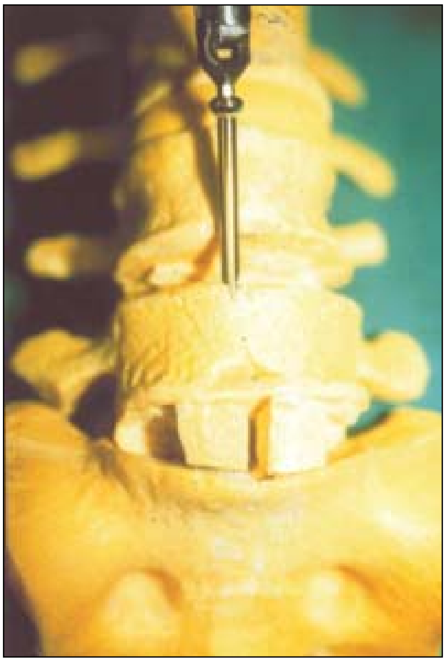

Figure 8: Anterior lumbo sacral fixation using L5-S1 trans discal screw fixation or the use of retention screws at L5-S1

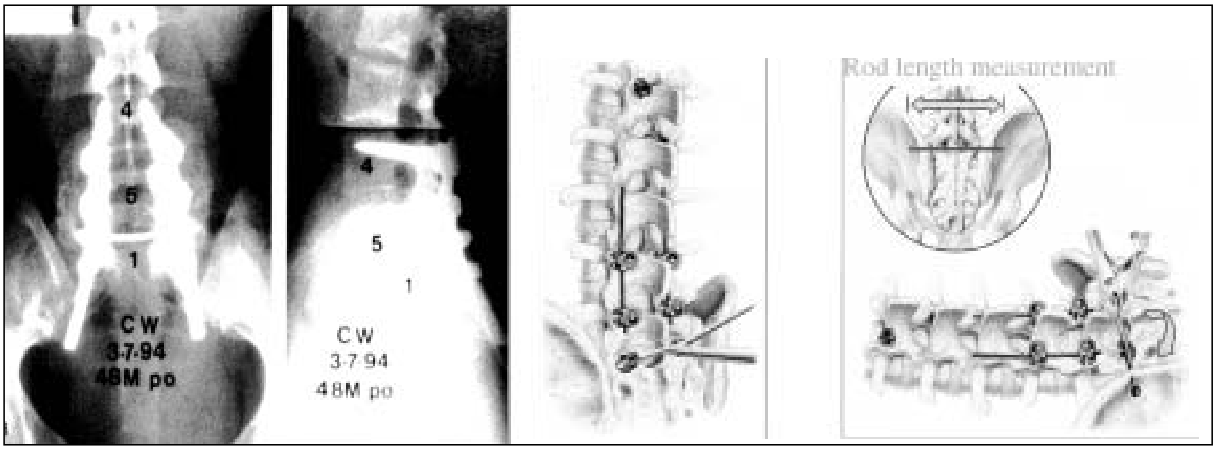

Figure 9A: The trans ileal rod, using an inside-out technique a)

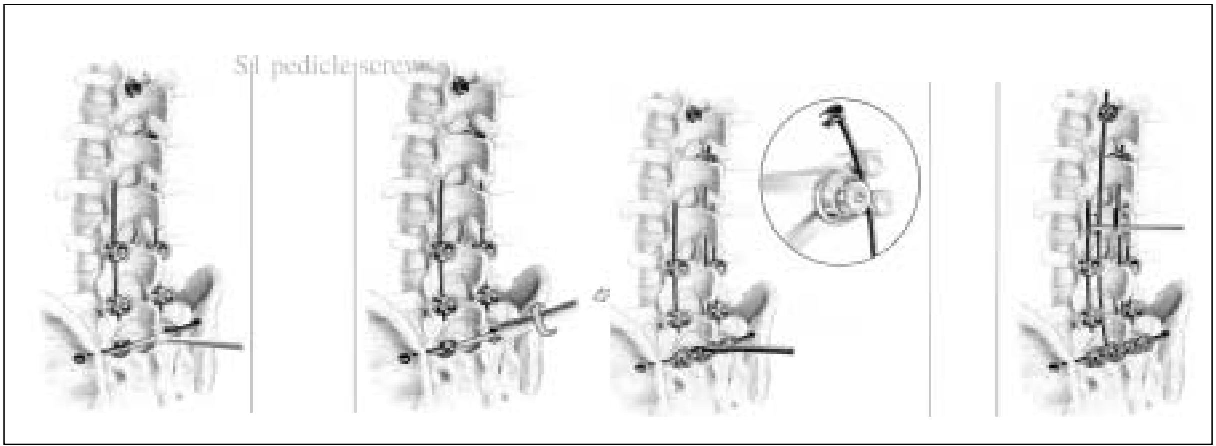

Figure 9B: The trans ileal rod, using an inside-out technique

Anterior Lumbo-Sacral Fixation

[Bio-mechanical rationale] Although improved posterior sacral fixation techniques have decreased, potentially pseudoarthrosis rates, without the use of anterior column support they remain unacceptably high. The addition, as shown previously L5 pedicle screws decreases instability in torsion at the lumbo-sacral junction. Bio-mechanical studies by Kostuik et al[15] have shown that the use of anterior structural grafting at the L5-S1 level, in conjunction with adequate posterior fixation, decreases stability immediately post operative. As a result Kostuik has recommended the use of anterior lumbo sacral fixation using L5-S1 trans discal screw fixation or the use of retention screws at L5-S1 [Figure 8]. As well as the use of fixation more proximal to L5 either through the use of rod or plate screw systems is recommended. Kostuik et al[15] found that an anterior fixation provides increased stiffness in extension and that screws and graft were superior to graft alone. The increase in stiffness in flexion was not significant with the addition of anterior fixation.

Sacral bar fixation

The ability to align long rods into S1 and S2 pedicle screws and the use of intra sacral rods or the use of ilio sacral screws can be technically demanding. Harrington in the 1960's (9) devised a sacral bar. At that time fixation to the bar was by hooks only, which did not control rotational stresses or flexion extensions moments well. Kostuik[18] subsequently modified the Harrington sacral bar by using a trans iliac bar fixed to S1 pedicle screws to which proximal longitudinal members could be dominoed. This posterior fixation system is not recommended without the use of anterior column support as is true for all forms of posterior sacral fixation for long fusions. Bio-mechanical studies have shown that the modified Harrington Kostuik sacral bar is equivalent to the iliac screws or trans iliac screws or trans sacral fixation. A clinical study, independently reviewed, of the author's cases, using the trans ileal rod, using an inside-out technique [Figure 9a and 9b] has shown superior results. The study population consisted of 93 patients with a mean age of 57 years, the older being 82 years of age. 95 percent of patients have had previous surgery. The overall fusion rate at two years was 96.8 percent [90 of 93 patients]. The pseudoarthrosis rate in patients who had anterior column support was only 2.7 percent. Patients who did not under go anterior column support for a variety of reasons, mainly health, had a pseudoarthrosis rate of 3.6 percent. There were no cases of failure of trans ileal fixation, twenty-three patients required additional surgery. Eight cases were unrelated to the lumbro sacral junction and 15 had surgery at the lumbo-sacral junction, 11 for the removal of painful hardware and three patients for the repair of pseudoarthrosis and one patient required a sacro iliac fusion. The advantages of the trans iliac technique is its rapid ease of use and has the lowest reported pseudoarthrosis rate for the lumbo sacral junction with comparable complication rates to other techniques and provides superior rigidity. We continue to recommend the adjunct of anterior column support with anterior fixation.

Conclusion

In conclusion lumbo sacral fixation for long fusions to the sacum generally continue to present a complex problem. The development of more rigid bio-mechanically stable posterior fixation as evidenced by the use of iliac screws, trans sacral bars and Trans iliac bars has resulted in a significant decrease in pseudoarthrosis rates. However it should not be forgotten that for long fusions to the sacum, anterior column support is necessary. The use of simple anterior fixation devices to help retain structural allografts, structural autografts or cages is recommended.

As a result, pseudoarthrosis rate have fallen to approximately three percent. flatback deformity continues to exist, but at minimal rates. It is recommended that all long fusions be done with the patient in the prone position with the posterior approach with the hips and knees in the neutral or extended position and the abdomen lying free.

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