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Spinopelvic Fixation in Deformity: A Review

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Rigid spinopelvic fixation often serves as the crucial foundation for any form of thoracolumbar instrumentation in the treatment of complex lumbosacral spinal conditions. The growing experience with long fusions to the sacrum, defined as arthrodesis to the sacrum from the L1 vertebra or a more cephalad level, has highlighted the importance of rigid sacropelvic fixation. Other conditions requiring stable lumbosacral fixation include high-grade spondylolisthesis; degenerative stenosis caudad to a long fusion; flatback syndrome requiring an osteotomy; correction of pelvic obliquity; sacral fractures; and cases requiring sacrectomy because of a fracture, tumor, or infection [1]. The attainment of successful fusion is challenging in these cases, and the high complication and pseudoarthrosis rates are well documented in the literature [2–8]. The difficulty in achieving successful fusion may be attributed to the unique anatomic characteristics of the lumbosacral junction as well as to the unfavorable biomechanical forces that the healing bone graft and instrumentation in this area are subjected to.

Several anatomic characteristics of the sacrum make sacral fixation challenging. The sacrum consists of primarily cancellous bone with a thin cortical shell. The pedicles are large; therefore, any form of sacral screw instrumentation generally fails to engage the cortical walls. Furthermore, the dimensions of the sacrum limit the length of screws that can be used.

In addition to anatomic characteristics that make sacral fixation difficult, the lumbosacral junction is a transition from a highly mobile segment to a stiff segment, resulting in great stress concentrations when the biomechanics of this segment are altered by instrumentation and fusion. To function successfully, this segment must transmit the full weight of the body from the spine to the sacropelvis and then to one or both femoral heads. It must do this in static environments, such as sitting or standing, and in dynamic environments, such as walking and running. The forces seen across this segment include axial loading of up to three times body weight in activities of daily living; substantial shear, especially with a more vertical S1 end plate alignment; flexion/extension moments; and torsion.

This article reviews the different options for lumbosacral fixation for complex cases. These different techniques are grouped into the following categories:

1. S1 fixation
2. Sub-S1 fixation

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3. Iliac fixation
4. Iliosacral fixation
5. Anterior lumbosacral fixation
6. Structural interbody support

S1 fixation

All spinopelvic fixation starts with S1 fixation as a baseline. Only in rare circumstances, such as sacral resection for tumor or revision of significantly failed previous instrumentation, is sacral fixation not used. Understanding the sacral bony anatomy as well as structures at risk is the key to well-considered sacral fixation.

The sacrum consists of a fused section of bony somites, with a thin cortical shell and large medially convergent S1 and sub-S1 pedicles. The S1 pedicles have large dimensions, with a mean length of 46.9 ± 3.3 mm in women and 49.7 ± 3.7 mm in men, and are primarily cancellous in nature [9]. Several structures are in intimate contact with the sacrum and are at risk for injury during pedicle screw insertion. These include the iliac vessels, middle sacral vessels, lumbosacral trunk, sympathetic chain, and sigmoid colon [10].

S1 screws can be placed unicortically, bicortically, or tricortically. Unicortical fixation is mentioned only to be condemned. Because of the large cancellous nature of the S1 pedicle, poor fixation strength is achieved when only unicortical fixation is attempted. The screw can easily toggle, leading to loss of fixation and pullout. Bicortical fixation has been the standard for many years. The classic trajectory has been parallel to the end plate of S1 with appropriate medial convergence to avoid the common iliac vessels located on the anterior surface of the sacrum.

Tricortical fixation has been studied and advocated by Lehman and colleagues [11]. Directing the screw toward the medial sacral promontory allows purchase of the dorsal cortex, the anterior cortex, and the superior end plate cortex. This trajectory doubles the insertional torque of the bicortical screws inserted parallel to the S1 end plate [11].

Recent biomechanical studies have shown greater pullout strengths using bicortical purchase through the superior end plate of S1 as compared with bicortical fixation through the promontory [12]. Because of the dense condensation of bone in this area, markedly improved biomechanical stability is achieved with this trajectory. To date, there have been no studies comparing tricortical fixation with S1 end plate fixation. Both are stronger than conventional bicortical fixation.

There is a high rate of failure when S1 pedicle screws are used as the sole means of fixation for long fusions [6]. In such cases, supplementary forms of fixation or the addition of a structural interbody load-sharing and fusion procedure is recommended.

Sub-S1 fixation

Sub-S1 fixation options include alar screws, laminar hooks, and S2 screws. These are primarily used in conjunction with S1 fixation, which is often inadequate as a sole method of stabilization for long fusions.

Sacral alar fixation

A useful adjunct to S1 pedicle fixation is sacral ala fixation. This typically involves unicortical fixation into the cancellous bone of the ala. The screws are directed laterally in the ala. The internal iliac vessels, lumbosacral trunk, and sacroiliac joints can be injured when these screws penetrate the anterior cortex [10]. The screws are connected to the same rod as the S1 screws or may be placed through a Chopin or Tacoma block. These are specially designed plates that connect the S1 screw to the alar screw. Use of the Chopin block is appealing, but there is always the challenge of constrained screw starting points and trajectories. In addition, there is the problem of implant bulk competing with surface area available for bone grafting. The development of the Tacoma block followed. These were developed during a period when screw-rod and hook-rod connection mechanisms were less user-friendly. With the increase in top-loading systems and offset-connection mechanisms, the same concept can now be accomplished without the use of these blocks.

Unfortunately, sacral ala fixation is directed into low-density cancellous bone. A bicortical technique, although desirable, is not recommended, because the L5 nerve roots drape across the sacral ala bilaterally and the common iliac vessels are located directly on the anterior surface [10]. Biomechanical studies do show improved fixation of sacral ala screws in conjunction with S1 pedicle screws as compared with S1 screws alone, however, indicating its usefulness as supplementary fixation [13].

S2 screws

S2 screws are another option for supplementing S1 screw fixation. S2 has a short cancellous pedicle, and although not well studied, most of the fixation is likely achieved in the dorsal cortical bone. The screw is limited to resisting loads by means of in-line pullout rather than by means of cantilever mechanics as well as in-line pullout [14,15]. Bicortical placement carries risk because of the intimate application of the colon to the anterior sacrum at this point. When used, S2 screws have greater pullout strengths when directed laterally [15].

Hooks and sublaminar wires

Hooks and sublaminar wires are also options for sub-S1 fixation. Hooks may be upgoing or downgoing and are placed in the posterior neuroforamen of S1 as an adjunct to S1 screw fixation. Hooks may also be placed in a claw configuration, using the neuroforamen of S1, S2, and S3. Sub-S1 hooks have been studied by Stovall and colleagues [16] and have shown improved strength when compared with S1 screws alone. These researchers used the hooks in a downgoing or distraction mode, and an upward-directed hook with compression applied may theoretically function better.

The fixation provided by sacral hooks and sublaminar wires provides inadequate resistance to torsion and flexion forces across the lumbosacral joint [1,17,18]. Use of these devices is thus limited to being supplementary fixation in long constructs to the sacrum.

Jackson intrasacral rod technique

Intrasacral placement of the distal ends of the rods has been popularized by Jackson and McManus [19]. These researchers proposed the concept of the iliac buttress, which theorizes that the posterior sacral wall effectively resists flexion moments experienced by the distal ends of the rods. This technique avoids crossing the sacroiliac joints but requires specialized tools and is technically demanding. Particular attention is given to the trajectory of the S1 screw to allow optimal insertion of the rod into the ala, although still achieving good S1 screw purchase anteriorly. The rods are optimally directed into the sacrum from a posterior and superior sacrum aiming toward the posterior superior edge of the sciatic notch. The S1 screw may have to be countersunk into the sacrum to give the rod a direct path to the sacrum after it traverses the S1 screw head.

Biomechanical studies on this technique have yielded somewhat conflicting results [20,21]. Clinically, it has not been as widely adopted as other techniques because it is technically demanding. Furthermore, in patients who are osteoporotic, this construct may be prone to failure.

Iliac fixation

The use of iliac fixation has increased as a result of several biomechanical studies showing greater rigidity of spinopelvic fixation with this technique [6,14,22]. From a biomechanical standpoint, incorporation of the ilium into the construct broadens the lever arm in the pelvis, thus permitting better control [6]. Studies have shown that iliac fixation is biomechanically superior to any form of sacral fixation [6,14]. Experience with this technique in the setting of neuromuscular and nonneuromuscular scoliosis has shown improved fusion rates [17,23–27].

The landmark biomechanical study for spinopelvic fixation was performed by McCord and colleagues [14]. In this study, the concept of the pivot point was introduced and defined as the point at the middle osteoligamentous column between the last lumbar segment and the sacrum. The extension of the iliac fixation, be it by a smooth rod or screw device, placed it anterior to this pivot point. The farther the implants extended anterior to this point, the stiffer was the construct, because this changed the loading dynamic from a purely in-line pullout force to a cantilever bend and in-line pullout mode. This explains the superior clinical performance and the halo or windshield wiper sign often seen with this technique. This is a good sign initially in that it indicates that the iliac fixation point bears the load rather than the S1 fixation point. Continued progression of the halo is undesirable, however, because it may herald subsequent failure of the S1 fixation if successful fusion does not occur.

The specific options for iliac fixation include the following: a Harrington threaded sacral bar, a Kostuik transilial bar, Luque L fixation, Luque-Galveston fixation, the Galveston technique with screws, and iliosacral fixation.

Harrington threaded sacral rod

This was originally developed by Harrington [28] as adjunctive fixation when extending to the pelvis in scoliosis cases. His concept was to apply the threaded sacral rod through the posterior iliac wings and apply compression across the bar. This could then be connected to Harrington distraction rods through special connectors.

Conceptually, this was a good idea, because the technique is easy and carries low risk. Unfortunately, pseudoarthrosis rates have been high, which most likely stems from the poor biomechanical characteristics of this construct [4,18], with a high rate of dislodgement of sacral hooks [4]. In addition, as we have learned, distraction forces in the lumbar spine are particularly problematic as far as sagittal spine alignment is concerned [1,4,7].

Luque L fixation

Luque revolutionized spinal instrumentation with his concept of segmental fixation. Sublaminar wires were connected to smooth 0.25-in rods with bent ends to prevent migration. For fusions involving the lumbosacral segment, the L-shaped ends could be placed into the posterior ilium. This used the same anchor point as the threaded Harrington sacral bar.

The technique introduced by Luque [29–31] was straightforward and easy to do and led to better correction of deformities in the coronal and sagittal planes. Flatback deformities that characterized the use of distraction devices were minimized [1,4,7,29–31]. The construct was still not ideal biomechanically, however. Because of the independent nature of the two rods, there was pistoning between the rods, and this was not a significant improvement in pelvic fixation against torsion and flexion forces [6,18].

Kostuik transilial bar

Kostuik and Musha [32] described a technique involving the placement of bilateral screws into S1 and attachment of these screws to a transilial bar that is inserted 1 to 2 cm anterior to the posterior superior iliac spine (PSIS). The difference between this and the Harrington sacral bar is that Kostuik used a smooth rod and applied this from the midline, as opposed to two separate posterior iliac incisions used for the threaded Harrington sacral bar. In addition, Kostuik put some contouring into his bar or rod, allowing it to maneuver over the dorsal prominence of the midline sacrum, although still engaging the substance of the iliac wings. The bar is then attached to the longitudinal rods and the rest of the pedicle screws in the lumbar spine through special connectors. Kostuik reports a fusion rate of 97% in 93 patients with scoliosis with this technique [1].

This construct has theoretic biomechanical advantages over purely sacral fixation. It provides good resistance to anterior flexion moments experienced at the sacrum. The unfused sacroiliac joints are spanned, however. Also, there is a need for formal biomechanical studies to determine the comparative rigidity of this construct as well as additional studies to document clinical results [1].

Galveston technique

The introduction of the Galveston technique in the 1980s greatly improved outcomes and decreased complication and pseudoarthrosis rates, particularly in cases requiring long fusions [2,3]. This technique consisted of contouring rods that were inserted from the PSIS into each ilium. The rods were directed into the region above the sciatic notch. The longitudinal rods were then attached to the lumbar or thoracic spine using sublaminar wires or pedicle screws. This technique has performed quite well clinically in the neuromuscular setting, although higher pseudoarthrosis rates have been shown for adult deformities [17]. The greatest challenge was developing the clinical expertise to perform the appropriate rod bends, a nontrivial exercise.

The next step in this pathway was the development of the unit rod [33]. Here, a single rod had a prebent sagittal contour and bilateral iliac fixation in a single piece. This obviated the need for bending the Galveston portion. In the hands of skilled users, it obviated the need for the cross-link. In the hands of many clinicians, however, the top was simply cut off. This was a result of the "fiddle factor" of precisely estimating the rod length.

Iliac screw fixation

More recently, the use of iliac screws as a modification of the Galveston technique has resulted in a less technically demanding procedure. This is attributable to the availability of various types of connectors, resulting in modularity and eliminating the need for rod contouring [34]. Iliac screws may be partially or fully threaded and are easily connected to the longitudinal rods with special connectors. The modularity makes it possible to put more than one screw into the ilium, and screws can also be placed even in the face of a previous bone graft harvest [1,6,25]. Furthermore, screws have greater pullout characteristics when compared with the smooth contoured rods in the original Galveston technique, resulting in better fixation [35].

The starting point for the insertion is over the PSIS. Two trajectories can then be taken. One trajectory is directed toward the superior portion of the acetabulum. Another path is directed toward the anterior inferior iliac spine (AIIS). The latter is the preferred path by the authors, because there is a lower risk for violation of the acetabulum and longer screws can be used (typically, at least 100 mm in length) [1]. This technique is the most widely used strategy today when long fusions to the pelvis are performed. Biomechanically, it is the best strategy for improving construct performance.

Placement of iliac screws can be judged by the use of fluoroscopy. Orchowski and colleagues [36] have shown that fluoroscopy can detect violations of the medial wall of the ilium, sciatic notch, and hip joint. Fluoroscopy may not detect lateral iliac wall violation because of the complex concave nature of the lateral ilium. Clinical experience suggests that if one can obtain a true teardrop view of the ilium and the screw is contained within the teardrop, it should be in an all-osseous channel of bone in terms of the medial and lateral walls of the ilium. Recently, with the development of intraoperative true three-dimensional imaging with the O-arm (Breakaway Imaging, Littleton, Massachusetts), confirmation of screw placement can be done. Intraoperative images of iliac fixation are shown in Fig. 1.

The next step in iliac fixation has been the use of multiple iliac screws. This was originally introduced by the group at the University of Washington for use in grossly unstable situations, such as spinopelvic dissociation. They used stacked iliac screws in the long column of bone between the PSIS and the AIIS. They also used extremely long screws. This represents a merging of the thinking about pelvic fixation for traumatic injuries of the pelvis and spinal fixation.

In addition, some surgeons have now begun using divergent screws into the iliac wings. This begins to apply the concepts learned from long bone external fixation. In external fixators, the factors affecting overall construct stiffness include pin diameter, pin spread, rod rigidity, stacked rods, and, finally, triangulation.

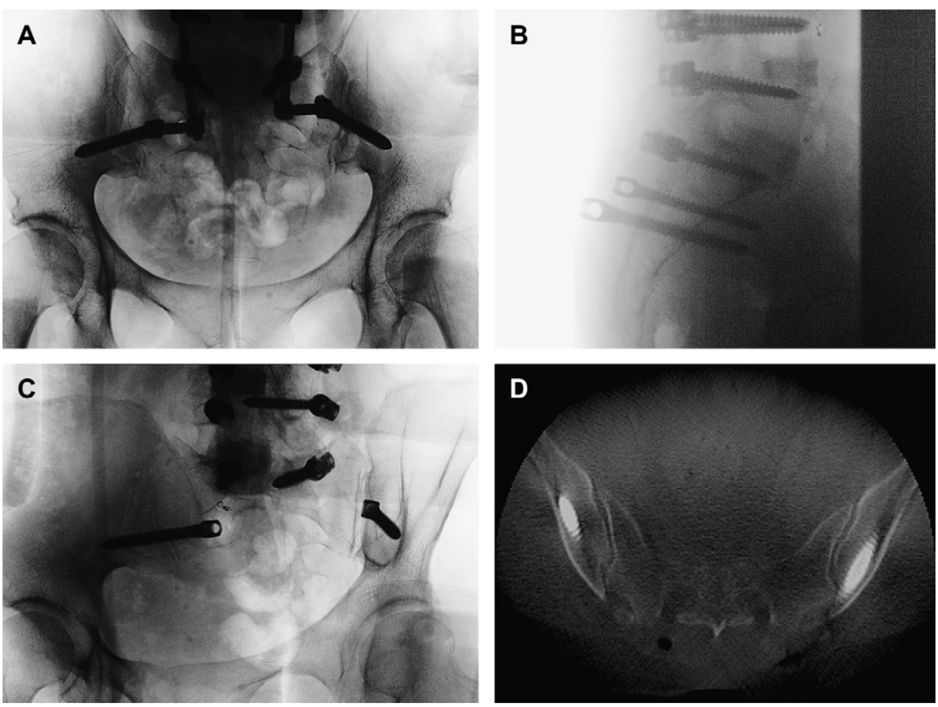

Fig. 1. Radiographic Appearance of Iliac Screws. (*A, B*) Intraoperative AP and Lateral views of the pelvis with iliac fixation at the base of the construct. (*C*) Left iliac oblique view of the pelvis demonstrating the right screw in the teardrop of the ilium. (*D*) CT scan demonstrating screws within the iliac crest.

The optimal initial iliac screw design and placement remain to be refined. The thinking behind the move from smooth rods in the Galveston technique and the use of screws was that with engagement of their threads, screws should lessen the posteriorly directed pullout that inevitably occurs when there is an anterior-based flexion moment. The data of McCord and colleagues [14] would suggest that if the screw is long enough to extend beyond the anterior pivot point, the forces acting on it should change from in-line pullout to cantilever bending. Thus, if the screw is long enough and placed into the teardrop of bone just above the sciatic notch, the cantilever forces should be directed against the strong cortical bone in this region. Optimal screw diameter is unknown. It may be a function of the fit and fill achieved by the screw in the column of bone in which the screw is placed. Similarly, there have been various screw designs. There have been some that were threaded at the tip, some that were threaded at the proximal shank, and many that are fully threaded. Screw tract preparation has not been specifically studied in the ilium, but undertapping by 1 mm makes sense. Whether undertapping by 2 mm (or achieving minimum pilot hole diameter in relation to final screw diameter) is beneficial remains to be studied.

Iliosacral fixation

Anatomically, there is an option for placement of a screw or rod through the outer table of the ilium, through the SI joint and into the lateral sacrum [37]. This bone channel has been well described and is regularly used in pelvic trauma applications for screw placement. Screws are directed from the outer ilium toward the L5-S1 facet. It has been done open and percutaneously. With the development of adjunctive devices for Cotrel-Dubousset instrumentation, a block was developed to accept this trajectory for screw fixation. This has biomechanical advantages over S1 fixation and alar screw fixation [5]. This technique requires greater dissection, however, and poses possible injury to the dorsal iliosacral ligament, leading to instability [1]. Farcy and colleagues [38] reported a high incidence of neural injury using this technique, and it has, at best, limited application today.

Anterior lumbosacral fixation

Kostuik and colleagues [39] have been the primary advocates for anterior lumbosacral fixation. These investigators have used cancellous bone screws along the trajectory originally described by Speed [40]. Typically, these were used in combination with structural bone graft. They seem to be particularly helpful in resisting extension moments, as might be expected given the necessity of anterior longitudinal ligament and annulus resection required for placement of femoral cortical ring allograft [39]. Kostuik and colleagues [39] have also used this concept in conjunction with an anterior locking screw plate at L5-S1 (necessary to avoid screws backing out and coming into contact with the great vessels) and then connecting this to an anterior screw-rod system. This has enjoyed only limited popularity to date. More recently, there has been a resurgence of interest in anterior plate fixation. The newer designs have been primarily developed for fixation at L5-S1 only, sitting below the bifurcation of the great vessels. The use of locking screws, similar to anterior cervical plates, is a strategy to minimize screw backout, which could be problematic in this location.

Anterior column support

Several studies have shown support for anterior interbody support for long fusions to the sacrum [8,18,38,41]. Steffee and Sitkowski [42] and Yashiro and colleagues [43] popularized the concept of anterior column support from a posterior approach in conjunction with interpedicular fixation. More recently, Harms has been the leading proponent of advocating structural anterior column support from an anterior or transforaminal approach [44]. This has intuitive appeal, because in the lumbar spine, most of the load is carried through the anterior column [44,45]. Polly and colleagues [46] have studied the effect of a single large cage compared with two smaller cages and found no difference. In the same study, an anterior location of a small cage was found to be superior to a posterior or central location for flexion loading. Lee and colleagues [47] have studied the number of levels of anterior column support necessary to limit S1 screw strain and found that there was little incremental benefit biomechanically to more than two levels of caudal structural interbody support.

Several studies have shown that anterior interbody support may not be necessary in cases in which adequate iliac fixation has been achieved [48]. Alegre and colleagues [48] have compared structural interbody support with iliac fixation and have found that iliac fixation is more important in reducing instrumentation loads than the structural anterior column support. In an ex vivo study in porcine spines, Cunningham and colleagues [22] found that use of iliac screws reduced lumbosacral motion significantly. When compared with interbody cages, iliac screws were found to be more protective of the S1 screws and more resistive to motion.

Special circumstances

There are special circumstances that demand more rigorous and innovative fixation techniques. One special scenario is when there is the absence of a sacrum, such as in sacral tumors mandating resection of the sacrum and lumbosacral agenesis. The fixation strategy can be characterized as reconstruction of the keystone, typically with a structural transverse biologic (eg, humeral shaft allograft) or nonbiologic (eg, titanium surgical mesh) support supplemented by nonstructural bone graft. Compression is restored across the iliac wings through the structural graft using a threaded Harrington sacral bar or adaptation thereof. Strong adjunctive iliac fixation is mandatory. This must then be connected to multiple spinal points of fixation. A true spinopelvic arthrodesis (eg, transverse process to ilium) must be achieved for long-term success.

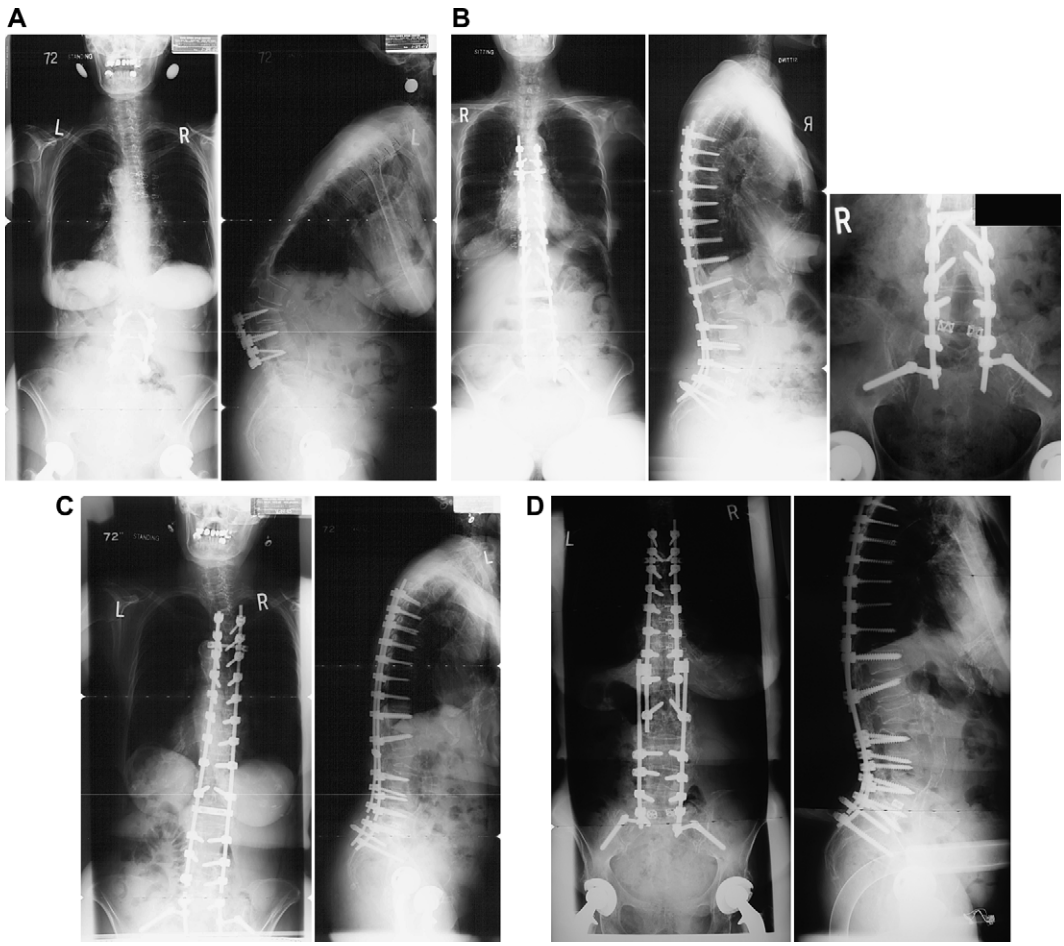

Fig. 2. (*A*) Osteoporotic compression fracture at L2 with sagittal plane decompensation. (*B*) Deformity correction with a L2 pedicle subtraction osteotomy, interbody fusion at L5-S1, and bilateral iliac fixation to reduce the strain on the sacral screws. (*C*) Sagittal plane decompensation after rod fatigue at L5-S1 without loosening of screws. (*D*) Revision with rod replacement without revision of screw fixation.

Another special circumstance is spina bifida, especially those cases with a severe kyphotic deformity and, typically, thoracic level deficits. Here, the dysplastic posterior elements and skin are the most substantial challenge. A special form of fixation is possible. Because of the nonfunctional neural elements caudally, sacral alar rod placement is viable [49]. This Dunn-McCarthy technique resists the kyphotic moments well [49]. Warner and Fackler [50] described a variation of the intrasacral rod placement that is similarly effective. The rod has a "Z"-shaped bend made, and it is passed through the first dorsal sacral foramen, through the sacral canal, and ventral through the ventral foramen. It then buttresses against the ventral cortical sacrum.

Failure mode analysis

The final issue for discussion in spinopelvic fixation is that of failure mode analysis. The initial failure mode is development of a pseudarthrosis. This can occur for a variety of reasons ranging from surgical technique (eg, inadequate bone generating material or graft; inadequate host bed preparation,

Fig. 3. (*A*) 42 year old female treated with an instrumented PSF without reduction for spondyloptosis. (*B*) Nonunion and progressive deformity treated with S1 pedicle subtraction osteotomy and extension of fixation to l3 and to the ilium. (*C*) Fracture of iliac fixation with progressive sagittal plane imbalance. (*D*) Revision with extension of fixation to T12 cephalad, and to ilium with 4 point fixation caudad.

Fig. 3 (*continued*)

such as failure to decorticate) to host biologic factors (eg, smoking; medications that interfere with osteoblast function, such as nonsteroidal anti-inflammatory medications; disease-modifying antirheumatic drugs; cancer chemotherapeutic agents; radiation therapy) and to fixation factors (eg, inadequate construct stability to allow osteoblastic bridging at the fusion site). Host biology issues are discussed elsewhere in this issue. Fusion seems to be best accomplished by placing structural grafts in the L5-S1 disc space. Posterolateral intertransverse process–sacral alar fusion is probably next best. In special circumstances (eg, sacral resection), the fusion must be an iliolumbar fusion with the bone spanning from the most caudal remaining vertebral segment to the ilium bilaterally.

In terms of fixation failure, S1 screw loosening, backing out, or breakage seems to be the first failure mode. With a long-segment fusion, especially without interbody support, isolated S1 screws are subjected to tremendous forces and often lose the race between biology and biomechanics. The screw usually breaks within the shaft of the pedicle, making salvage particularly challenging. If the screws are stainless steel, extraction is easier than with titanium, which has better surface osseointegration. If the screws loosen, removal is easy but salvage is more difficult, requiring a larger diameter screw than the hole that has been created. Sometimes, the pedicle anatomy does not accept a sufficiently enlarged screw; however, a new screw trajectory is often possible. If the screw was originally placed in a conventional trajectory parallel to the S1 end plate, a tricortical trajectory can be used. This usually has a more caudal starting point, allowing the engagement of intact dorsal cortical bone. Alternatively a sacral end plate grasping trajectory can be used. Hole augmentation in a grouting fashion can be used, but there is a risk of extravasation of the grouting material into the canal or anteriorly into the pelvis.

If fixation has included iliac screws, the failure is usually the rod, typically between the S1 screws and the iliac screws, as reported separately by Tsuchiya and colleagues [27] and Bellabarba and colleagues [51]. This has been the authors' experience as well (Fig. 2). Presumably, this is because there is persisting sacroiliac joint motion leading to rod fatigue or halo formation about the screws. This failure mode is the easiest to revise. Iliac screw fracture can also occur. Extraction may be difficult, but because of the size and anatomy of the ilium, another screw can be placed around the broken screw. As long as the bone quality is acceptable, the screw should have adequate purchase. If the screw has loosened, the salvage requires a bigger and longer screw or a screw tract redirected into adequate bone stock. This has been studied for loosened pedicle screws by Polly and colleagues [52], but it has not yet been studied for iliac fixation. Similarly, redirected screws have not yet been studied in the ilium.

Fracture below the level of fixation can also occur. If the fixation is sacral only, sacral fractures can occur below the instrumentation [24,53,54]. Detection of this problem can sometimes occur with good-quality plain films of the lateral sacrum. If these are long fusions, however, and 36-in films are obtained, the visualization of the sacrum may not be as clear. The loss of sagittal alignment without an obvious change in fixation should be a clue that there is potentially a problem caudal to the construct. This typically presents as sacral kyphosis. Because of the long moment arm, this can result in profound sagittal imbalance. Salvage of this situation may require a sacral osteotomy to restore global sagittal balance. In this situation, substantial iliac fixation is required to maintain the restored sagittal balance. Iliac fixation is a minimum requirement, but salvage may also require special adjuncts, such as stacked iliac screws or perhaps even divergent iliac screws. Fig. 3 demonstrates the use of sacral osteotomy and stacked iliac screws to salvage a failure of iliac fixation. If iliac fixation has been used initially, the pelvic ring itself may sustain a stress fracture. To date, these have usually been treated without surgery.

Summary

Spinopelvic fixation techniques are evolving and now seem to be converging. Good S1 pedicle fixation is the initial key anchor point. The tricortical technique tests out as the best. Supplemental fixation options are available. The most efficacious seems to be iliac fixation, followed by two-level structural interbody support. Achieving appropriate global sagittal balance also lessens the likelihood of implant pullout and places the fusion mass under relatively more compressive forces than tension forces. Regardless of the method of fixation, the ultimate determinant of long-term implant survival is the achievement of adequate biologic fusion.

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