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Early Results of Spinal Fusion Using Variable Spine Plating System

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Seventy-seven consecutive patients underwent application of variable spine plating (VSP) spinal plates between August 1984 and October 1985. Sixty-four percent had previous procedures at the same level or levels operated. Operative indications were spinal stenosis, segmental instability, unstable spondylolisthesis, herniated disc with instability, pseudarthrosis, unstable fracture, and failed surgery syndrome with evidence of one of the preceding. Overall results showed 30% excellent, 30% good, 34% fair, 6% poor. There were four deep wound infections and 19 patients with one or more broken screws. Screw alignment and the angular relationship of each screw to the spinal plate are considered important technical factors in minimizing screw failure. Vigorous distraction of the vertebrae using interpedicular screws is rarely indicated. Twenty-four patients required reoperation. We feel the procedure is relatively indicated in cases of moderate to severe instability, such as some cases of spondylolisthesis, failed surgery with marked segmental instability, the obese, deconditioned patient, or cases of spinal stenosis rendered very unstable by surgical decompression, and most strongly indicated in unstable lumbar and thoracolumbar fractures. [Key words: lumbar fusion, internal fixation, pedicle screws, spinal plates (Steffee), clinical experience]

INTERNAL FIXATION DEVICES for spinal disorders are in a phase of rapid evolution. All systems to date have experienced significant problems and complications. An ideal system would allow for rapid patient mobilization and comfort, and a minimum of pseudarthroses, wound infections, iatrogenic complications, and operative time. This paper reviews the early results of the variable spine plating (VSP) spine plate system developed by Dr. Arthur Steffee of Cleveland, Ohio.[23,24]

Spinal plates have been utilized for many years. Wilson,[26] Meurig-Williams, and Reimers designed plates for spinous processes. Sicard devised plates with a synthetic material that were screwed to the posterior aspect of the sacrum and pinned to the spinous processes.[21] These could not be used with wide decompression, and the fixation was not strong enough for a reduction or for sagittal contouring of the spine. Spinal plates were reported for anterior interbody fusions by Humphries, Hawk, and Berndt.[5]

Clinical screw fixation was described by Boucher in 1959.[1] Others have reported satisfactory results using pedicle screws with Harrington instrumentation or its modification.[25]

Roy-Camille (1976)[17-20] and Judet of France have developed a system of plates and pedicle screws for stabilization of the spine. Louis (1985) reported 266 cases of plate screw posterior lumbar-sacral fixation in 1982 and 1983.[9,10] Rodegertds[16] of Germany in 1985, and Yamamoto and Yamashita of Japan[27] recently reported experience of spondylolisthesis reduction and stabilization using sacral plate fixation with pedicle screws.

Other pedicular fixation systems are currently available, including:

Pedicle Screws and Rods

1) Harrington and Dickson[4]
2) Kostuik, Errico, and Gleason[6]
3) Long Beach System (Field, Wiltse, Zindrick, Widel, Thomas)[3]
4) San Francisco System (White, Zucherman, Hsu)[25]
5) Vermont System (Craig, Beynnon, Pope, Frymoyer)[7,8]

Pedicle Screws, Wires, and Rods

1) Luque[11]
2) White, et al[25]

External Fixation with Pedicle Threaded Pins

1) Magerl[12-15]

In the following review, we discuss our clinical experience with the procedure, technical aspects, complications, and the procedure's clinical efficacy.

MATERIALS

Dr. Arthur Steffee of Cleveland, Ohio developed titanium plates with beveled screw slots to allow both adjustment and fixation of the vertebrae.[22-24] Plates can be contoured to control the sagittal curve of the spine. They cannot be contoured in the axial or coronal planes.

Pedicle screws are made with two types of threads: bone threads and machine threads on the shank, to accept tapered nuts.

The VSP system allows for reduction in the sagittal plane and stabilization of the spine while fusion takes place. After wide decompression and exposure of the fusion bed, pedicles are accurately located, reamed, tapped, and two screws are inserted into each vertebral body. Corticocancellous bone graft is placed in the lateral gutter over the transverse processes. Plates are contoured and placed over the screws. The tapered nuts are tightened down to fix the vertebrae to the plate (Figure 1). In osteoporotic patients, methyl methacrylate cement may be injected into the vertebral body through the pedicle to anchor the screws (Figure 2A, B).[22,28] In unstable spondylolisthesis and fractures, anatomical reduction and fixation are facilitated.

METHODS

Surgical Technique in Detail. The patient is placed prone in the knee-chest position on the Andrews frame, with the abdomen free. A midline incision is made. The paraspinous musculature is elevated off the spinous process and lamina. A point is made to preserve the interspinous ligament and facet joints at the level above. Identification of the appropriate level should be made by morphology or x-ray localization. Laminectomy and decompression are carried out, or the apparatus can be applied with the guidance of image intensification. The facets and transverse processes are exposed. At L5, we prefer to preserve the attachment of the iliolumbar ligament. Each transverse process is decorticated posteriorly as well as the lateral faces of the superior facets, the pars, and the sacral ala. A flap of bone is taken from the sacral ala and folded toward the L5 transverse process if a

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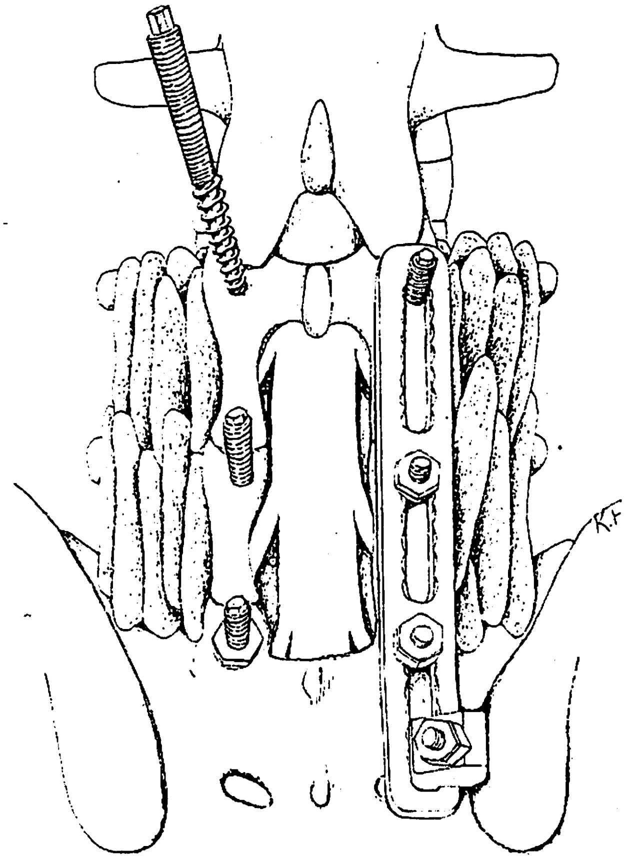

Fig 1. Application of system with posterolateral fusion and wide decompression.

fusion at L5–S1 is performed. Next, pedicle screws are inserted. In order to locate the pedicle, several landmarks may be used:

1) The transverse process, which generally corresponds to the level of the pedicle in the lumbar spine.
2) The caudal tip of the inferior facet.
3) The ridge at junction of the facet, transverse process, and the lamina (Figure 1).

The pedicle may be palpated with a probe or visualized directly if exposure is adequate. An image intensifier may also be used. We have devised pedicle guides to help accurately locate the pedicle when it is not directly visualized, but direct visualization or image intensification are more reliable. A ¼" bur is used to penetrate the posterior cortex (Figure 3) and a pedicular probe or awl is used to advance the bone hole into the pedicle and vertebral body. The probe should follow the path of least resistance into cancellous bone, producing a characteristic "feel" to the surgeon (Figure 4). The pedicle sounder probe or depth gauge is used to palpate the hole to ensure that it is surrounded by bone for 360°. Common errors in this step include too lateral placement of the screw hole, allowing it to exit out the lateral vertebral body, and then too deep probing with the depth gauge, allowing entry into the retroperitoneum. Also, other variations of screw tract placement outside of the center of the pedicle result in fracture of the adjacent pedicle wall. An appropriate size tap can be used to start the tract proximally and the screw inserted with the appropriate wrench, so that all of the cancellous threads are buried below the level of the posterior-most pedicle (Figure 5). Tapered nuts are placed on the machine threads down to the junction of the machine thread and cancellous thread, with the flat side facing posteriorly. The most readily accessible and visible pedicle is selected for screw placement first. The sacral screw is inserted last, because here there is a greater mass of suitable bone stock allowing more variability in screw placement. It is essential that the screws be placed in a straight line so that the plate can be easily inserted on top of them. If the screws are inserted at varied angles to each other, application of the plate without stripping the threads may be difficult or impossible. Screws can be bent to better align them; however, this weakens them. Bone graft is positioned over the decorticated surface in the lateral gutter before the plate is in place. A malleable aluminum template of the same length as a corresponding VSP plate is placed against the flat surface of the tapered nuts. The template serves as a guide to contour the plate using an AO plate bender.

The plate is then placed over the screws. It should slide easily over the threads onto the nuts. It is important not to strip the threads by forcing the plate down (Figure 1). Compression or distraction may be applied using screw alignment rods on adjacent screws and the T-handle nut wrench. Overdistraction can cause pedicle fracture and eccentric screw–pedicle pressure. We also suspect that this may cause gradual erosion of screw threads through the pedicle in some cases and cause radicular symptoms. We do not distract unless there is a specific indication to do so. The upper tapered nuts are then applied to tighten and lock the plate in place. When indicated, sacral buttress clamps and additional screws may be used to reinforce the sacral fixation. The lateral neural canals are re-explored to assure patency and that there is no encroachment from the bone graft chips, which sometimes may be pushed anteriorly by the descent of the plate. The opposite side plate and screws are applied in a similar manner and lateral roentgenograms are taken to assure intrapedicular placement of the screw and to assess the depth of sacral penetration by the sacral screws. It is desirable to have slight penetration by the sacral screw through the anterior sacral cortex for increased fixation. The portion of the screw above the posteriormost nut is then removed with a pin cutter. Gelfoam or fat grafts are applied over the exposed dura or nerve roots, as desired. Ambulation is begun on postoperative day 1 with a corset or body jacket. The orthosis is worn for a minimum of three months. Patients are instructed to limit their walking to less than 1 mile per day, and minimize sitting for 3 to 4 months.

CLINICAL SERIES

A retrospective review was carried out by the authors, based on standardized progress questionnaires. Patients were categorized in terms of result as excellent, meaning essentially no or minimal symptomatology and no need for medications; good, marked improvement over preoperative status with occasional pain and occasional use of analgesic medications (mild narcotics or non-narcotics), with minimal or no functional limitations due to symptomatology; fair, with some improvement over preoperative status, continued need for pain medication and significant functional limitations, and poor, with no improvement in preoperative symptoms or functional capacity or worsening of either or both, and need for regular analgesic medication.

At a multidisciplinary tertiary spine referral center, VSP spinal plates were applied to 77 patients between August 1984 and October 1985. Follow-up ranged from 22 to 36 months, with a mean of 27 months. Seventy-six patients had 1 year or longer follow-up from their last surgery. Age of the population ranged from 24 to 76, with a mean of 47. There were 46 men and 31 women. Forty-nine of 77 (64%) patients had had previous procedures in the area operated. In three cases, this was only chemonucleolysis. Thirty-eight of 77 (50%) were involved in workers' compensation or litigation. The number of levels fused ranged from one to five, with an average of 2.5. Operative time ranged from 1½ to 6 hours, with an average of 3 hours, 30 minutes. Plate size ranged from two to five slots bilaterally, with a mean of 2.7. The number of pedicle screws used ranged from four to 12, with a mean of 6.5.

All nonurgent patients had had extensive preoperative conservative

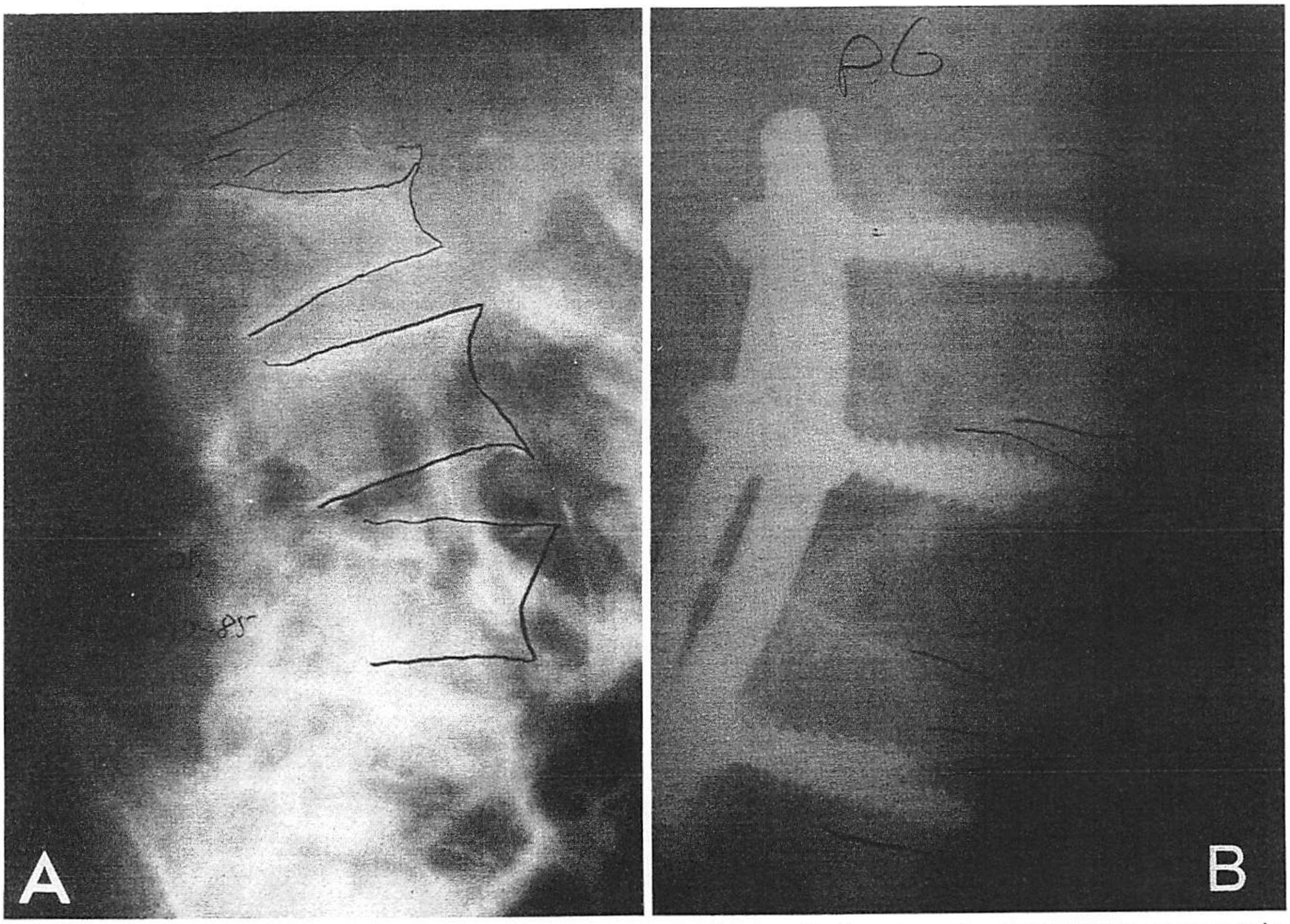

Fig 2. Pathologic unstable compression fracture due to severe osteoporosis with internal fixation using methyl methacrylate to compensate for loss of bone stock.

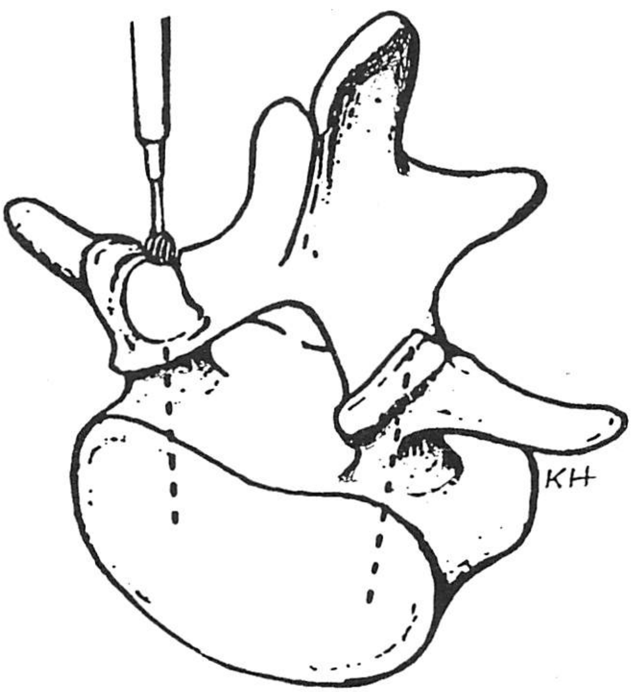

Fig 3. The posterior-most cortex over the pedicle is breached, using a bur or drill.

care for at least 3 months, and usually longer, which had failed. Each procedure was performed by two of the four authors, with an assistant. Two-thirds of the cases were performed in laminar air-flow rooms. Preoperative diagnoses included spinal stenosis, segmental instability, unstable spondylolisthesis, pseudarthrosis, herniated disc with instability, unstable fracture, and failed surgery syndrome with evidence of one of the preceding.

Indications for the operation were herniated disc and instability in 43%, spinal stenosis with instability in 24%, segmental instability in 11%, spondylolisthesis with instability in 7%, pseudarthrosis in 7%, herniated disc and spinal stenosis in 7%, unstable spinal fracture in 4%, and herniated disc, instability, and poliomyelitis in 1%. Instability was defined as segmental hypermobility (greater than 15° sagittal motion) or translational motion on stress roentgenograms and/or patients with predominant central back pain, tenderness over facet joints, inability to tolerate static postures, and pain reproduction on discography.

RESULTS

Overall results by the above criteria showed 23 patients (30%) in the excellent category; 23 patients (30%) in the good category; 26 patients (34%) in the fair category, five patients (6%) in the poor category.

In those patients who had workers' compensation claims or were involved in litigation (38 patients), excellent results occurred in 13%, good results in 26%, fair results in 50%, and poor results in 10%.

When patients were grouped according to those who had no pending litigation or workers' compensation claims (39 patients),

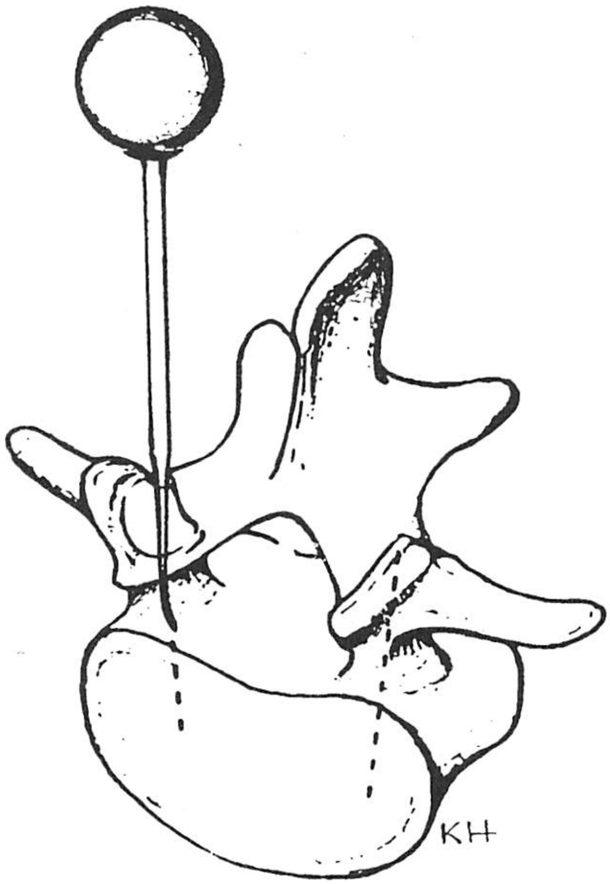

Fig 4. Through the posterior cortex defect, a pedicle probe is used to extend the tract into the vertebral body.

there were 46% excellent results, 33% good results, 18% fair results, and 1% poor results.

When the patients were grouped according to those who had previous surgical procedures (64%), there were 17% excellent results, 29% good results, 46% fair results, and 8% poor results.

Fifty-one of 77 patients (66%) had returned to work or the expected activity level for their ages at the time of last follow-up.

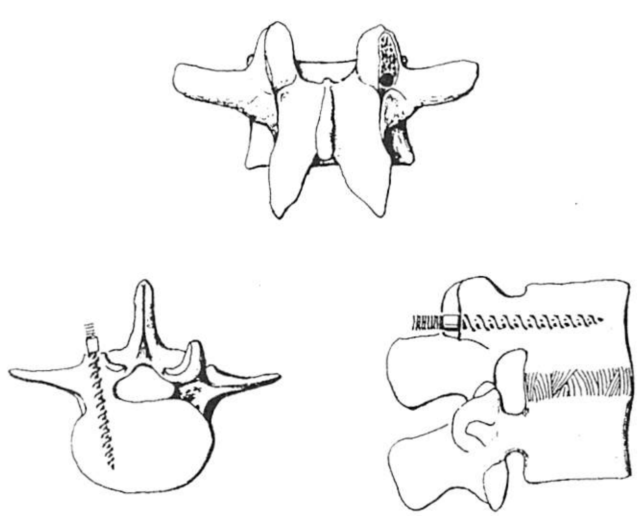

Fig 5. The large threads should all be within the substance of pedicle and through the pedicle but should not engage the anterior cortex.

COMPLICATIONS

As of March 1987, there have been four deep infections. Two were diagnosed within 2 weeks of surgery and two within 1 to 2 months after surgery. The latter were both due to indolent anaerobic pathogens. These were treated unsuccessfully with 6 weeks of intravenous antibiotics; both had to have removal of hardware and delayed closure. Both had resolution of infection after implant removal and delayed wound closure. Both were workers' compensation cases; one had a fair result and one had a good result. The other two patients who were treated with early postoperative incision and drainage had ultimate good results. In one, implants were removed, and in the other the wound was left to close over the implants by secondary intention because of marked preoperative spinal instability.

There were 19 patients with one or more broken screws (Figure 6). In five patients, there were instances of moderate trauma associated with screw breakage. Four of five were doing well before the traumatic episodes, and three of four who were operated on were improved after removal of the metallic implants. At the time of last follow-up, 13 patients who had broken screws required reoperation. In all, 24 of 77 (31%) patients required reoperation. Sixty-seven percent of these had one or more previous procedures prior to VSP plating. Diagnoses at the time of reoperation are listed in Table 1, and the results of reoperation in Table 2.

DISCUSSION

Zindrick et al carried out biomechanical studies of pedicle screw design, resistance to pullout, and cyclic loading.[28] Their conclusions include:

1) Large diameter, fully threaded screws inserted deep enough to engage the anterior vertebral cortex result in the most secure fixation. There was no difference in resistance to pullout with a screw depth to 50% of the anterior posterior length of the vertebral body and to depth extending to the anterior cortex.
2) Pressurized methyl methacrylate greatly increases pullout strength of screw fixation.
3) The strongest sacral fixation sites were the S1 pedicle and 45° placement into the ala.
4) Pedicle dimensions vary, and must be considered prior to attempting screw insertion.
5) The degree of osteoporosis appeared to have the greatest effect upon screw fixations.

The incidence of broken screws was a problem in this series. This occurred mostly in younger patients and is probably related to increased activity level in this population as well as to the more rigid

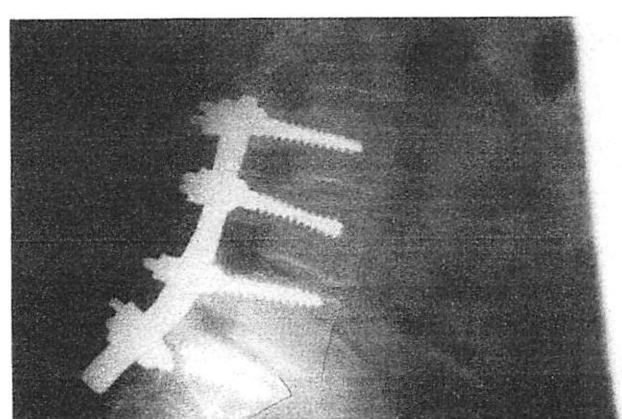

Fig 6. Two fractured S1 pedicle screws.

Table 1. Diagnosis at Reoperation

Diagnosis at reoperation	*Frequency*
Infection	3
Broken screw	4
Broken screw and pseudarthrosis	8
Broken screw, pseudarthrosis, infection	1
Segmental instability adjacent segment	4
No detectable pathology	4

grip at the bone screw interface in this higher density bone. Screw design has been altered by the manufacturers since this series. We have less frequent screw failure with these newly designed screws, although breakage remains a problem.

The specific manner in which the screw is placed into the pedicle in relation to the often sagittally curved spinal plate seems to be a factor which may contribute to screw failure. When the pedicle screws are placed at different angles, so that they are not in alignment with each other, the screws either have to be bent into alignment or forced into alignment by the plate during its application (Figure 7). This, of course, would be expected to result in shortening of the fatigue-life of the screw. Additionally, to the extent that the angle of the screw varies from a perpendicular relationship to the portion of the plate to which it is affixed, the screw will be forced to either bend or seat in a position which generates constant torque. As seen in the Figures, a bending moment will be generated as the anterior and posterior nuts affix the screw to the plate if the plate is not perpendicular to the line of the screw (Figure 8).

It is of great importance not only to have the pedicle screws in accurate alignment with each other in a longitudinal axis, but also to have the screw-plate relationship as close to 90° at each level as is possible. Variance from the latter may result in constant unidirectional torque of the screw against one wall of the pedicle (Figure 9), which we suspect may cause symptoms, weakening of the screw, or undesirable shifting of the vertebra-to-adjacent-vertebra angular relationship. When the angular relationship of the screw to the plate is at variance from 90°, it is possible for the foramen to be narrowed by changing the angle of the vertebral bodies, moving them into increased extension (Figure 10).

Eight of our first 30 patients developed leg pain within 1 or 2 months postoperatively. In this group, screws were routinely distracted at the time of plate application. We believe this resulted in some constant eccentric pressure on the pedicle which may have resulted in pedicle erosion (Figures 9, 11). Symptoms were controlled with selective blocks, and in most cases resolved with time. We found these symptoms to be unusual in subsequent cases in which no or minimal distraction of the screws was employed. Attention must be paid closely to the neuroforamen if distraction is used, as a neuroforamen of an adjacent level may be encroached on while distracting (Figure 12).

We have had concerns over the problem of stress transfer to adjacent levels with this system. The rigidity of fixation would be expected to result in increasing stress on the adjacent mobile

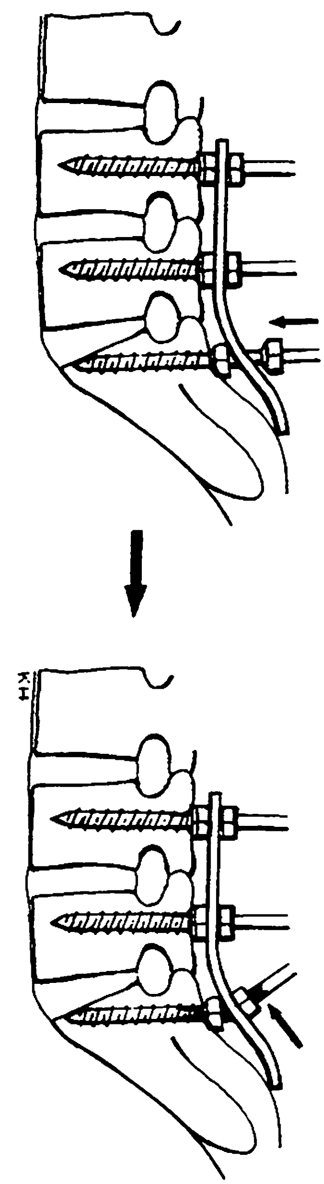

Fig 7. Variance of plate screw angle to 90° can result in screw weakening and bending.

segments. In addition, unless the screws are placed lateral to the facet joints, which requires more extensive exposure, the inferior facet of the vertebral segment above is somewhat weakened. This theoretically could make the segment more vulnerable to degeneration in the future. Postoperative bending films revealing hypermobility of the first mobile segment above the Steffee plating were not uncommon. We have routinely performed preoperative discography in these cases so as to avoid leaving a badly degenerated segment unprotected above the plated segments. In one patient who required revision surgery, the initial two-level plating stopped below a degenerated disc. The patient did quite poorly 3 to 6 months postoperatively, and had to have extension of the fusion up one more level, with an excellent result subsequently.

The infection rate using this technique has been higher than in other fusion techniques in our hands, even though prophylactic antibiotics were used in all cases, and clean air laminar flow was used in most. This would appear to be due to increased operative time, the large amount of implant surface area, and high percentage of

Table 2. Early Results After Reoperation*

Excellent	5
Good	6
Fair	9
Poor	4

*Included implant removal in all cases.

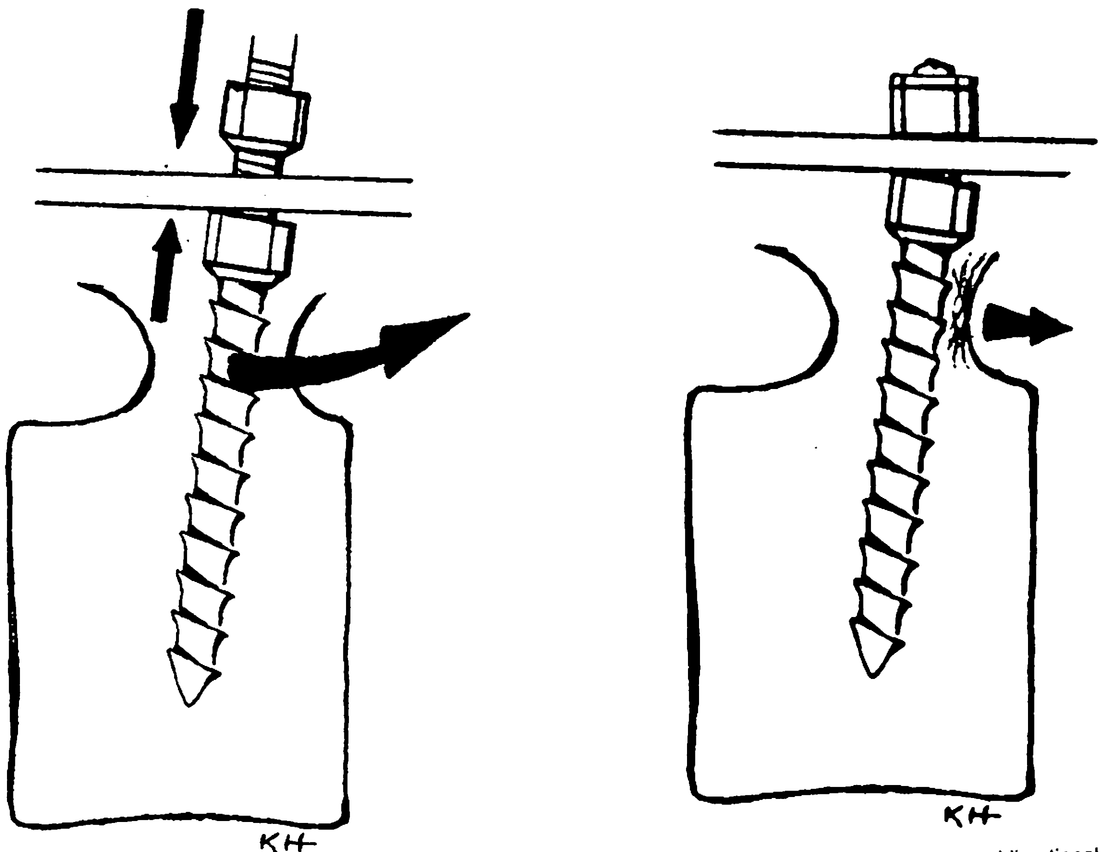

Fig 8 and Fig 9. Tightening of nuts when screw is set in position varying from 90° in relationship to the plate results in a unidirectional torque which may possibly result in screw weakening and delayed pedicle erosion or fracture.

revision cases in this series. Laminar air-flow, sterile hoods, minimizing operating room traffic and personnel, and other infection-minimizing techniques, such as have been adapted for total joint arthroplasty, are recommended by the authors for this procedure.

A problem with the presence of metallic implants is that postoperative evaluations by magnetic resonance imaging (MRI) and computed tomography (CT) scan are not useful because of metal artefact. No patient with a pseudarthrosis had visible motion on stress roentgenograms with the plates in place, unless there were multiple bilateral screw fractures.

We are most hesitant to use the system in chronic patients with psychological overlay. This is because continued pain complaints tend to be attributed to undemonstrable operative site pathology and to the implants themselves, resulting in a second procedure to remove them. In four patients undergoing second procedures, absolutely no pathology could be identified, and in four others, the problem was presumed to be due to the level above the fusion. Most of these particular patients did not do well.

INDICATIONS

Because of the increased operative time, risk of infection, and technical difficulty, we do not consider that the VSP system is appropriate for most cases of spinal fusion. It is an excellent technique in the treatment of unstable thoracolumbar and lumbar spine fractures, especially at the lower lumbar levels (Figure 13). It provides immediate rigid internal fixation and restoration of sagittal alignment with invasion of a minimum number of levels to obtain solid fixation, as opposed to Harrington rod techniques. It is relatively indicated in treatment of severe instability such as some cases of spondylolisthesis, failed surgery with marked segmental instability, and in the obese and deconditioned patient with segmental instability in whom restoration of immediate stability would be desirable to facilitate early postoperative mobilization (Figure 14).

The VSP spine system allows adequate fixation even when posterior elements are totally removed. The sagittal spinal curve can be accurately controlled and restored to normal, leaving adjacent segments in anatomic sagittal angular alignment. This system allows for adequate sacral fixation without great technical difficulty, compared with other techniques. If desired, spondylolisthesis may be reduced in a controlled fashion (stabilization is more important than reduction). The difficulty of this is proportional to the severity of the spondylolisthesis (Figure 15).

Rigid fixation seems to result in higher fusion rates. Motion across the fusions could not be seen in any patient on bending films unless there were multiple and bilateral screw fractures. In nine of 13 patients reoperated on with broken screws, lack of bony union was found at surgery. In 24 patients requiring reoperation, no patient without a broken screw was found to have a pseudarthrosis. We therefore contend that the clinically detectable pseudarthroses rate of nine of 77 patients (11%) is favorable in light of the average number of levels fused in the series (2.5).

CONCLUSION

VSP spinal plating system is a useful adjunct to the spine surgeon's armamentarium. The procedure is time consuming, technically

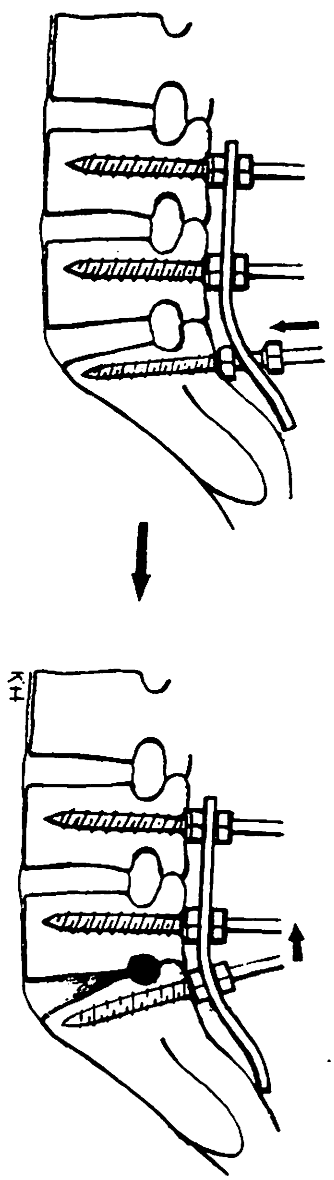

Fig 10. When plate screw angle varies from 90° and the screw does not bend on tightening, vertebral angular relationship changes and may result in lateral stenosis.

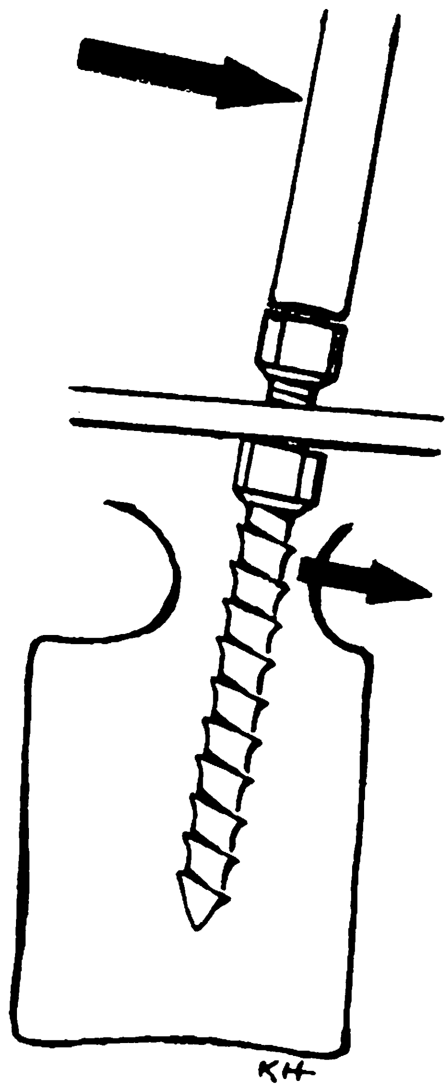

Fig 11. Extreme distraction of the screws results in constant forces unilaterally against the pedicle which may result in fracture or erosion of the screw through the pedicle.

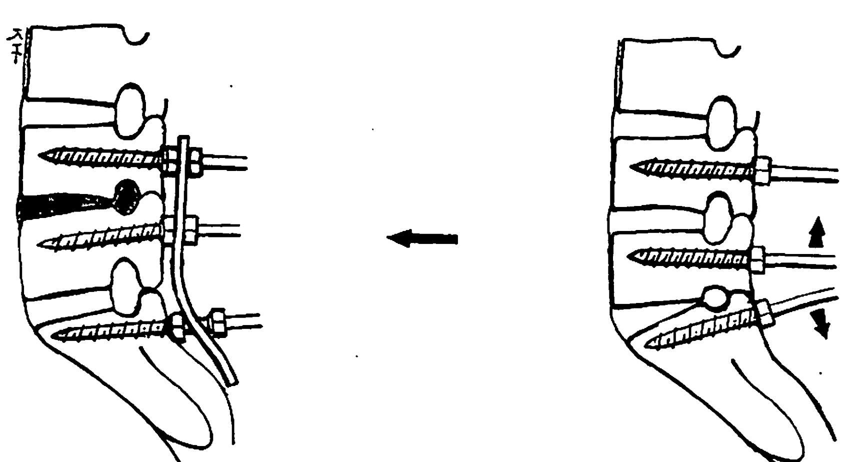

Fig 12. Distraction of one vertebral segment may result in stenosis of adjacent segments.

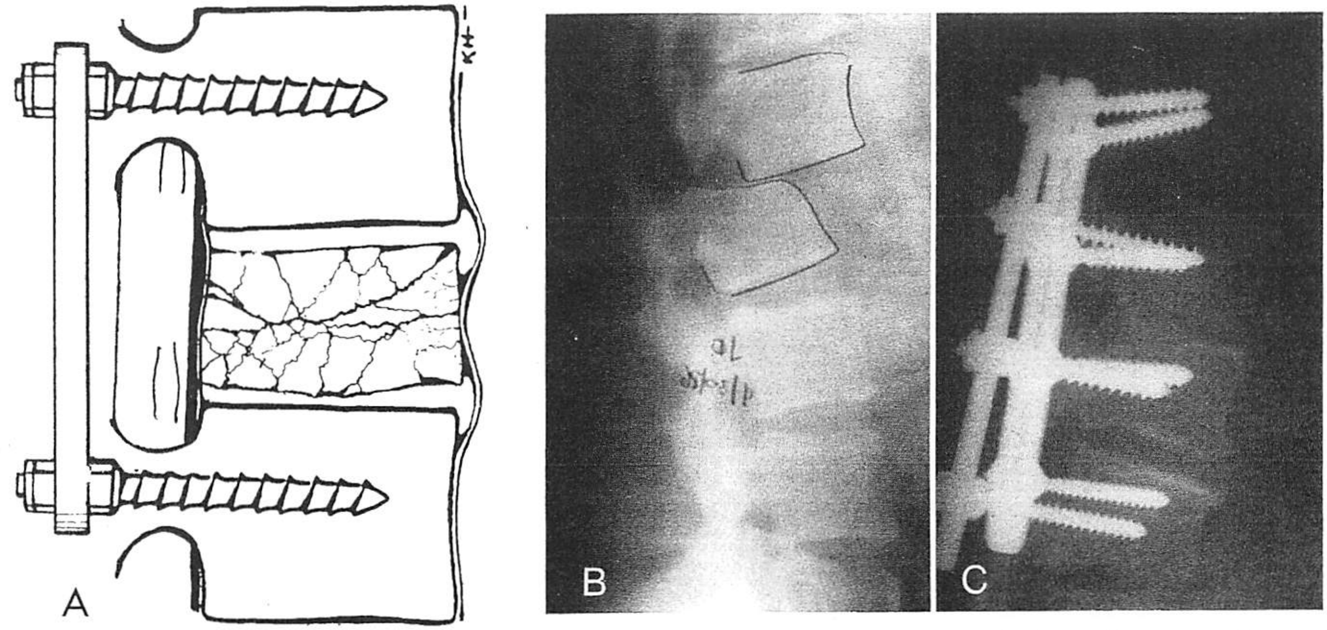

Fig 13. Unstable fracture dislocations may be immediately restored to stability with ablation of relatively few mobile segments. Pre- and postreduction lateral roentgenograms.

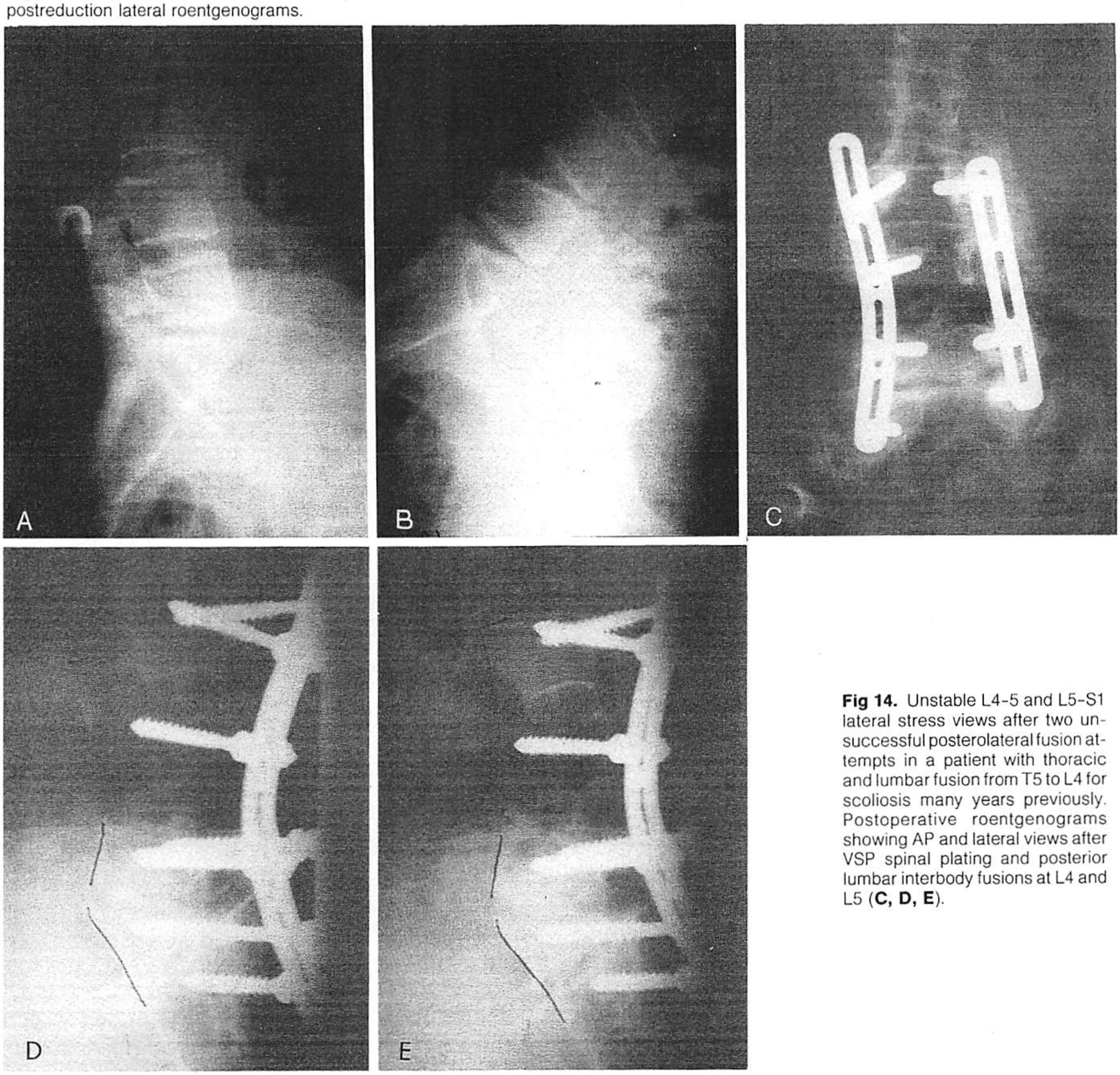

Fig 14. Unstable L4-5 and L5-S1 lateral stress views after two unsuccessful posterolateral fusion attempts in a patient with thoracic and lumbar fusion from T5 to L4 for scoliosis many years previously. Postoperative roentgenograms showing AP and lateral views after VSP spinal plating and posterior lumbar interbody fusions at L4 and L5 (**C, D, E**).

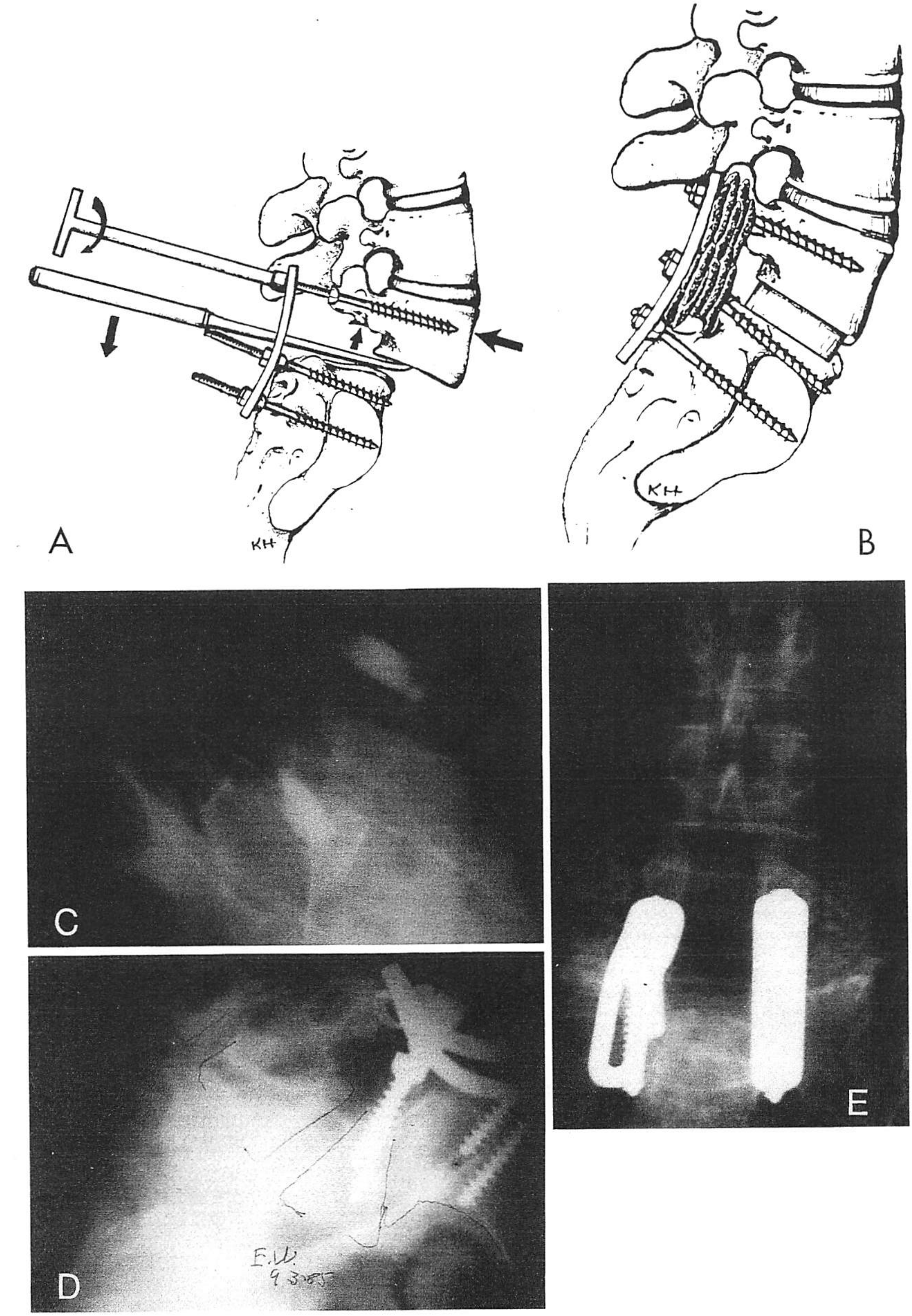

Fig 15. **A,** Reduction of spondylolisthesis is possible but difficult when the degree of slippage is great. **B,** VSP plating, posterolateral fusion and interbody fusion offer the greatest stability. **C,** Third degree congenital spondylolisthesis lateral view. **D, E,** Postoperative VSP plating and partial reduction.

difficulty, and is associated with increased complications. It requires hands-on experience in the technique that should be obtained under supervision of surgeons skilled in its use. It is indicated in cases of marked instability, especially when wide decompression is necessary. It should be considered when instability is present and when solid fusion is considered mandatory for a successful outcome. Further improvements in instrumentation design have been developed since this series which may allow for better results.

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