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REVIEW

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Internal fixation on the lower cervical spine – biomechanics and clinical practice of procedures and implants

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Abstract The decision to opt for a particular internal fixation procedure of a traumatized unstable lower cervical spine should be based on analysis and implementation of scientific and clinical data on the biomechanics of the intact, the unstable and the implant-fixed spine. The following recommendations for surgical stabilization of the lower cervical spine seem, therefore, to be justified. Firstly, the surgical procedure should be to bring about decompression, realignment, and stability. Secondly, the anterior approach should be the primary and preferred one. With regard to surgical and positioning technique, this access clearly involves fewer problems than the posterior approach; if required, unrestricted additional cord decompression can take place; implant fixation is technically simple, and the fusion is under direct compression, thus allowing optimal fusion healing. The awareness of instability and type of implant permits functional therapy, above all for the paraplegic patient. Thirdly, for traumatic conditions, posterior methods should be reserved for exceptional indications. The restriction to this approach is that the anterior column must be intact and a multi-segmental fixation must be used. Posterior fixation seems, therefore, to be more appropriate for degenerative, rheumatoid or tumorous instabilities than for traumatic instabilities. The cerclage wire technique depends on intact osseous posterior elements, while after laminectomy only implants fixed with screws can create safe stability. The disadvantages of the posterior access for the proprioception of the cervical muscles and the subjective symptoms of the patient are known and must be taken into account. Fourthly, combined techniques are indicated for highly unstable or particularly complex injuries. On the cervicothoracic junction, or in cases of Bechterew's disease, the decision is justifiably made in favor of this technique, which can be performed as a one-stage or two-stage operation. Finally, whenever possible, selection of the implant should take into account the foreseeable developments in diagnostic procedures, and therefore, in view of the modern imaging techniques likely to be used in any follow-up examinations required later, the implant chosen should be made of titanium.

Keywords Lower cervical spine · Trauma · Instability · Biomechanics · Clinical practice

Introduction

In 1969, Cheshire commented that it was his impression that the decision in favor of a particular – anterior or posterior – procedure of stabilization of an injured cervical spine was, for most surgeons, probably based on pure intuition [13].

Thirty years later, Glaser et al. [26] took up this issue again. In a tentative study on the range of surgical indications for the treatment of certain (standardized) cervical spine injuries, they reporting finding “a relatively high level of disagreement”.

It is, of course, not desirable to establish hard rules for the treatment of specific spinal injuries; occasionally, being able to choose between a number of options for the treatment of special types of injuries will certainly be an advantage. But the question arises of why the study by Glaser and colleagues listed the entire range of options (functional treatment, halo-fixation, anterior stabilization, posterior stabilization and even combined stabilization techniques) for most injuries.

From a subjective point of view, every spinal surgeon will achieve the best results with their preferred method. Orthopedic surgery obviously tends to permit a rather pluralistic choice of potential treatments. Objective, and therefore comparable, results are only attainable for specific, precisely outlined and clearly defined indications; however, in spinal traumatology such indications are not available. Even though there is international agreement on instability being the most important indication for spondylodesis, only a few authors comment on the degree of instability [1, 38, 54].

Following a brief period of confusion, the results of the biomechanical studies of the past 15 years have provided safe ground in this terrain beset with personal experience, impressions and tradition. They have established clear landmarks, offering orientation and improving navigation in a difficult territory full of imponderable risks.

Unlike clinical results, the results of these studies, which had a decisive impact on implant development, are surprisingly uniform. Therefore, a summarized assessment against the background of clinical experience appears appropriate. In the process, it might also be possible to clarify why theory and practice are so far apart in this field.

Stock taking

Internal fixations on the lower cervical spine were initially posterior procedures: Hadra [29] in 1891 was the first to describe a method using a wire cerclage around the spinal processes C5/6 – an implant used until today. In the following years, Gallie [24] and Brooks and Jenkins [9] focussed on the instabilities of C1/2, while Rogers [56] and Bohlmann [8] used specific wiring techniques – through the base of the spinal processes – to further develop the cerclage wire technique for the lower cervical spine, which became widely used as a technically simple technique.

In 1972, Roy-Camille [57] introduced rigid posterior fixation using plates screwed to the articular processes of the lower cervical spine. The direction of the small-fragment screws marks the further development of posterior

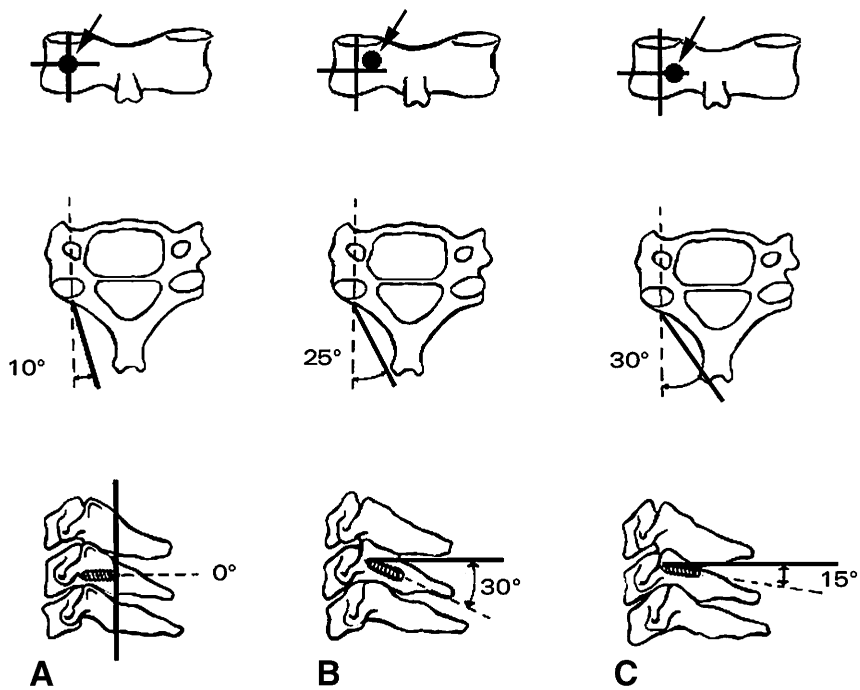

Fig. 1 Anatomic position of posterior screw direction (modified according to An [3]): **A** Roy-Camille, **B** Magerl, **C** An

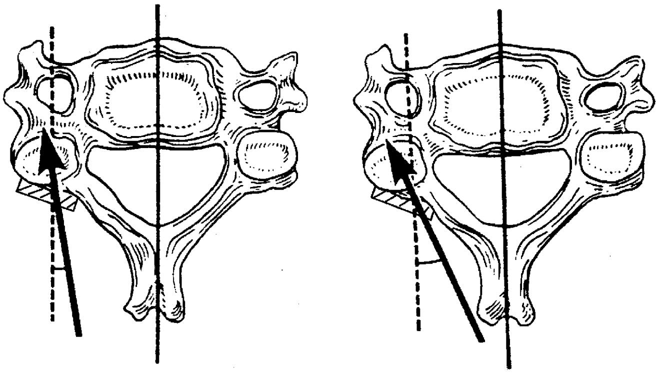

Fig. 2 *Left:* safe fixation of a posterior plate; *right*: problems with regard to screw direction

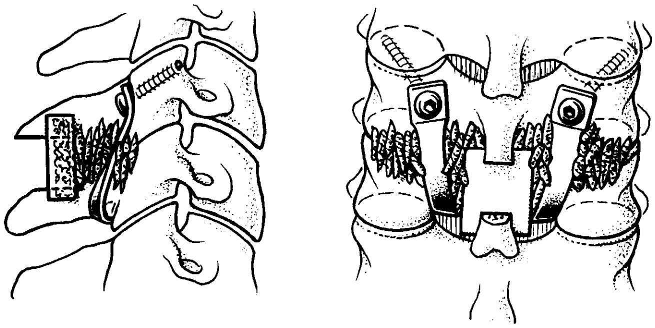

Fig. 3 Hook-plate assembly

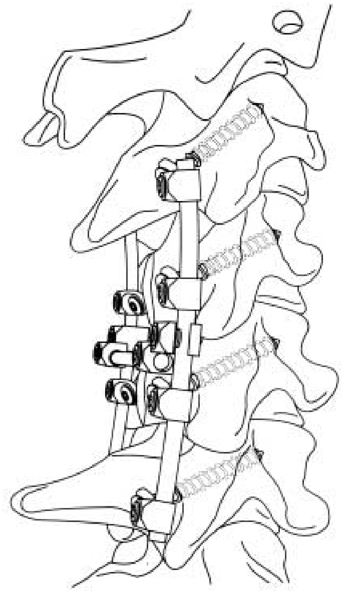

Fig. 4 Cervifix assembly

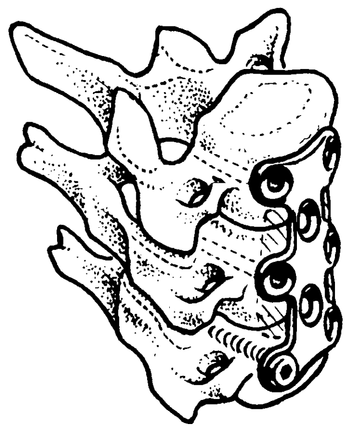

Fig. 5 Bisegmental Orozco plate

fixation: only the primary screw of the Roy-Camille technique permits proper countersinking of the screw head in the plate; however, the hole spacing did occasionally result in intraoperatively undesirable screw positions.

Magerl and co-workers [44] and An [3] made suggestions on screw direction (Fig. 1) that achieved maximum purchase in the articular bone mass and considerably improved screw retention, as biomechanical measurements revealed [14]. The resulting inclination of the screw head, however, would not permit safe plate fixation (Fig. 2). Magerl's hook plate, developed for monosegmental fixation, thus requires specific bending (Fig. 3) and is technically demanding [35].

The Cervifix system (Fig. 4), developed by Jeanneret [36], is a successful compromise between anatomical adaptation and biomechanical reliability. Unlike with the plates, whose hole spacing occasionally necessitated mechanically questionable screw directions (Fig. 2), with this system the screw position is determined before mounting the longitudinal rod. Once mounted, it is connected with the screws by means of variously shaped connecting flanges. Since screw direction can be freely chosen, multisegmental stabilization is possible even after extensive laminectomy. The same period saw the establishment of clamp fixing systems [33]. However, like the Brooks method, they depended on intact laminae.

Anterior fixation became possible after 1952, with the development of the anterolateral approach [5, 15, 55]. At that time, after removal of the damaged disc and/or decompression of the cord, only a corticocancellous bone graft – whose shape depended on the surgeon – was implanted without any implant fixation. Due to the considerable technical problems postoperatively, such as graft dislocation or secondary kyphosis [43] with subsequent neurological complications, above all with additional posterior instabilities [45], several authors [15, 55] suggested additional fixation of the intercorporal graft by means of a wire cerclage. Obviously, this cerclage is much more easily fixed to the posterior than to the anterior structures.

The importance of anterior implant fixation was then recognized, above all, by Orozco Delclos and Llovet Tapies [51], who, initially, like Böhler [7], screwed on a triple-tube plate for "graft fixation" to the anterior struc-

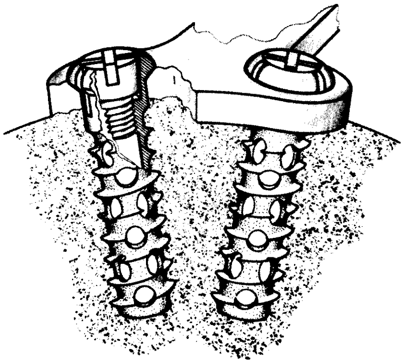

Fig. 6 Function of the angle-stable locking screws with CSLP

tures. Later they introduced the specifically developed H-plate, which appeared to be capable of not only fixing the graft, but also of permanently securing the reduction result (Fig. 5).

The mechanical weaknesses of the angle-unstable H-plate led to the development of the angle-stable cervical spine locking plate (CSLP, Fig. 6) by Morscher and co-workers [49]. For the time being, this titanium implant, together with the many similar systems on the implant market, marks the state of the art in the development of anterior fixation systems for the lower cervical spine.

Biomechanical results

In its widest sense, biomechanics is the use of mechanical rules in an undetermined biological environment [73]. This describes all the problems involved in published studies: in vivo, mechanics alone does not determine the stability of an assembly; there is also no standardized biological model, since human biology between the age of 20 and 50 is subject to considerable changes.

Nevertheless, standardized in vitro tests permit comparison of implant systems and allow investigation of the interrelations between implant and spinal column. White provided in 1989 a clear summary of very general recommendations, taking into account clinical and ethical issues [72].

All biomechanical studies on cadaver spines [6, 10, 14, 16, 25, 28, 30, 37, 40, 47, 48, 53, 58, 63, 64, 65, 66, 68] have in common that the laboratory specimens were stripped of their soft tissue and proximally and distally fixed in plastic blocks. Then the intersegmental measuring points were determined and defined flexion and torsion moments were introduced into the specimen. Various intersegmental instability types (complete and incomplete) were then applied, which were subsequently bridged by the various fixation methods.

The specimens were then again subjected to standardized loads for measurements of the mobility of both the intact and the unstable segment. The respective instabilities were then fixed with commercial implants, and in most cases a comparative evaluation was carried out. Anterior testing included the angle-unstable H-plate [64, 69], the Caspar plate [16, 28, 53, 66], the CSLP [10, 28, 40, 47, 53, 64], and the "Acromed" plate [40]. Posterior testing encompassed the sublaminar wire cerclage technique according to Brooks [16, 66, 69], the Rogers cerclage technique through the base of the spinal processes [16, 25, 47, 66, 74], the triple-wire technique according to Bohlmann [16, 40, 66], mono- and multisegmental plate spondylodeses [25, 40, 53], the Halifax clamp [25], the hook plate [16, 66, 69], the Roy-Camille plate [16, 63], and the Cervifix [36].

For some test setups, subsequent testing included the investigation of the rigidity attainable with combined techniques (anterior implant/posterior implant) [16, 40, 47, 66, 69].

The test setups were by no means internationally standardized ones, but all results attained with human [10, 16, 25, 47, 63, 64, 69], bovine [40, 66], porcine [28, 53] or canine [74] cervical spines were similar: with complete intersegmental instability, the rigidity of the posterior screw-fixed techniques was superior to that of the anterior techniques. The highest degree of rigidity was achieved with the combined techniques. Under laboratory conditions, none of the wiring techniques was capable of bringing about the degree of stability of the intact motion segment.

The fact that a small-sized anterior plate turned out to be unstable when subjected to flexion forces did not surprise anyone knowing the biomechanic rules. After all, the center of rotation for flexion/extension is located on the anterior lower cervical spine. When complete instability is produced and a more or less rigid implant is mounted at this location, introduction of a flexion force will, of course, cause the motion segment to bend upward (Fig. 7) – just as unilateral plate fixation on any other bone

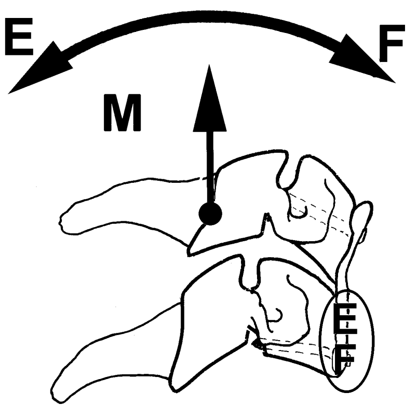

Fig. 7 With complete instability, introduction of flexural moments (*M*) posterior of the anterior plate will result in the implant bending up or loosening of the plate (*E* extension, *F* flexion). The instantaneous axis of rotation for flexion/extension is located in the anterior implant

will allow gap formation on the side opposite the plate. Due to anatomical reasons, a lag screw cannot solve this problem in the cervical spine.

Blauth, in a very elegant study [6], analyzed the advantages and disadvantages of the angle-unstable anterior plates, and his view was that angular instability offered more latitude.

Regarding the surgical technique, this is certainly true, for with CSLP the screw direction is largely design-determined (Fig. 6). Moreover, he associated the rigidity of the system with the mono- or bicortical screw position.

This highlights another aspect of fixation: that of screw anchoring. Reports of thorough investigations that involve in vitro analyses of screw retention on the lower cervical spine are available. These studies are very important for an understanding of the function of implants screwed to bones. Like Blauth and co-workers [6], Ryken et al. [58] were able to show that bicortical anterior fixation produces a higher pull-out resistance than unicortical anterior fixation. Some authors refer to unicortical fixation as being “unreliable”, which can be demonstrated, above all, with the CSLP: since the screws are firmly interlocked with the plate, they cannot loosen. Consequently, cyclical flexion loads do not result in individual screws loosening, as was very often the case with the anterior H-plate [1, 6, 54, 68], but result rather in extrusion of the entire implant (Fig. 8).

The rigidity of an angle-unstable system, on the other hand, is certainly not dependent only on the rigidity of the plate, but also and most critically on the contact pressure between plate and bone. Obviously, this is easier to attain by means of bicortical screw fixation, since cancelleous bone has less resistance to offer to the thread pressure than cortical bone substance. This was confirmed by Spivak [65], who found that with unicortical assembly the rigidity of a screw/plate system could only be increased by means of locking bolts.

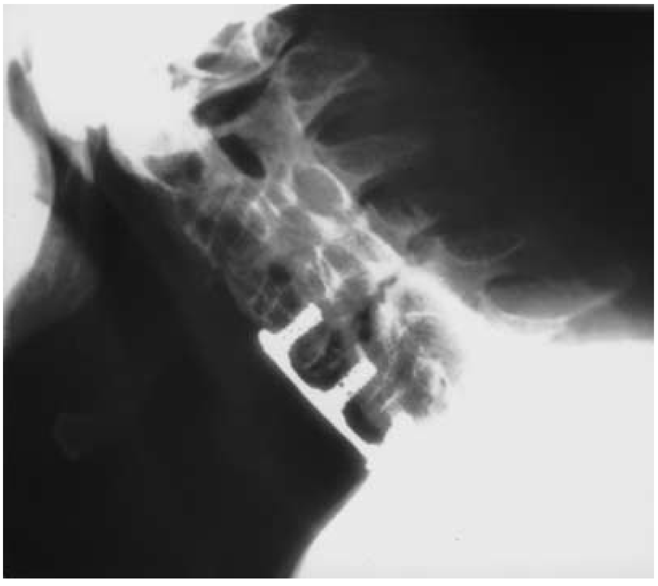

Fig. 8 Typical break-out of a CSLP in a patient with Bechterew’s disease

Extensive CSLP analyses revealed, as early as 1995, that this system in particular has its weakness in the bone/implant interface, and that it depends on good bone stock more than any other system [64]. It does, however, offer a high degree of implantation safety, because the posterior wall does not have to be perforated.

On the posterior structures, analyses of the stability of screw retention revealed that it very much depends on the length of the screw passage through the bone [31], with posterior bone density being much higher than anterior density. The extreme lengths are marked by the short Roy-Camille screw and the transpedicular screw. It is true that the latter makes the highest demands on the anatomical knowledge of the surgeon, but on the other hand it permits fixation even after extensive laminectomy [2, 37, 48]. The bone purchase of the Roy-Camille screw is only very poor, and leads in at least 50% of cases to damaged intervertebral joints [14, 35]. Using the screw directions recommended by Magerl [44] or An [3], however, always yields supreme results, even though the Magerl method involves the risk of intraoperative nerve damage due to projecting screw tips, which occasionally come very close to the ramus dorsalis of the nerve root. Chronic pain in the neck may, thus, under certain conditions be explained by mechanical irritation of this ramus [19].

The results of these in-vitro investigations may be summarized as follows:

1. The lower the segment-inherent stability, the higher are the demands to be made on the fixation method.
2. While posterior ligament severance alone will not particularly impair the flexion stability of the intact motion segment, it will cut its torsional stability by 50%.
3. Posterior wire cerclage assemblies seem to be of equal efficiency with other posterior fixations regarding their flexion stability. With complete instability, they can prevent neither torsional nor translational dislocation.
4. The highest degree of flexion rigidity is offered by posterior screw-fixed plate/rod systems, with the screw insertion technique according to Magerl and An, or combined methods.
5. Among the monosegmental posterior single procedures, it is the hook plate assembly with H-graft that provides the highest degree of primary rigidity.
6. With complete intersegmental instability, the anterior plate assembly alone is as rigid as the implant itself, the screw retention force being the second limiting factor.
7. Maximum anterior screw retention can only be achieved through bicortical screw position.

8. In cases of unicortical fixation, locking screws will increase the rigidity of the screw/plate system, but this may fail completely under high flexural loads. The stability of this system is very much dependent on bone quality.
9. The rigidity of the Cervifix corresponds to that of the posterior plate assemblies, with the former showing more elasticity in the static test.
10. The highest degree of safety/rigidity is attained by combined posterior/anterior methods.

Of course, these results are only "snapshots". The only study of the permanent stability of a certain fixation method is that of Whitehill et al. [74], who as early as in 1984 were able to prove in vivo that osseous fusion is superior to any temporary stabilization method.

Clinical results

Contrary to the biomechanical investigations, there are hardly any clinical analyses comparing anterior and posterior fixation methods. Even a comprehensive overview in an article by An published in 1998 [3] omits this issue. It appears to be a characteristic feature that the publications dealing with stabilization methods implemented on the lower cervical spine only elaborate on methodological issues.

A review of the publications of the past 30 years quickly reveals that the results of the past 10 years must not be compared with those of the 1960s, because at that time there were no generally accepted results available on the biomechanics and function of cervical spine implants or their instability. Moreover, overall general comparison of anterior and posterior methods is not permissible, because until the mid-1980s the term "fusion" was universally used in the USA for all anterior or posterior grafting procedures with or without implant fixation, which gained popularity only later. Mere graft implantation can, of course, not be compared with today's methods of anterior plate fixation.

In the Capen report (1984) from the paraplegic center Ranchos Los Amigos, a study on exclusively traumatized patients [12], posterior operations still constituted by far the majority. On the posterior structures, Rogers' wiring was used, and on the anterior structures the Robinson method *without* additional metallic fixation. Posterior cerclage was classified as the "method of choice". This has undergone a complete change, and presently the anterior approach with implant fixation of an autologous bone graft is globally recommended [11, 32, 41].

Graham et al. [27] were able to prove a continuous decline in the rate of complications after operations on the lower cervical spine, from 4.4% in the early 1980s to less than 3% toward the end of the decade. The trend showed that after a brief intervening decline (1983/84), the anterior interventions predominated. Presently, they are at a constant level of nearly 70%.

Now that posterior and anterior stabilization procedures have been analyzed and assessed, comparative analysis is possible.

Posterior methods

All biomechanical tests prove the superior stability of posterior screwed systems, as does clinical experience – but certain problems have to be accepted. They concern mainly positioning, damaged cervical muscles, including their proprioceptive system, and finally the potential risk of injury to specific neurovascular structures due to a protruding anterior screw [19, 31]. As a result of the lack of a cross-connection, represented in anterior implants, for example, by the plate brackets of the H-plate, safe posterior fixation requires the use of a multisegmental plate/screw combination, at least for dislocations, because in such conditions there is no torsional stability left [40].

The potential complications encountered with sublaminar cerclage wiring are also by no means always harmless, and are classified as epidural, subdural or intramedullary bleeding; in addition, dural perforations and leakages may occur [21].

Wellmann et al. [71], in an excellent, instructive clinical study published in 1998, including a review of current publications, described the advantages and disadvantages of the posterior methods. They concluded that cerclage wiring had been used more often and over a longer period than the other methods because its application was cheap and easy. However, they made it clear that osseous integrity of the anterior column was one of the most important prerequisites for the use of this method. Therefore, they considered it to be particularly efficacious if the degree of instability was not high and/or the load was low. Beyond that, however, they commented: "Wire performs poorly, however, when affixed to osteoporotic bone, when forces other than flexion must be counteracted and when posterior spinal elements are absent". For this reason, they believed that, in most cases, additional external fixation was required postoperatively. Wellmann stated a rate of wound infection of 5%. The rate of fusion for his 43 patients reached an average of 97%.

In an earlier publication, a study on 74 patients with posterior plate fixations, Heller et al. [30] stated a rate of 9% for method-related complications; the rate for infections and pseudoarthroses was 1.3%; and a remarkable 3.8% of patients suffered from considerable postoperative pain in the neck.

There are not as many reviews of purely traumatized patients. Anderson and co-workers followed up 30 patients with posterior plate fixation for an average of 17.8 months postoperatively, and found no complications [4]. Apart from the fact that the type of instability is mentioned in only a very few publications [1, 38, 54], he pointed out that nearly all neurological additional injuries had receded by the time of examination. In three patients, at the time of follow-up, osseous fusion had progressed distally and proximally across the implant fixation, without this being intended intraoperatively. In three other patients, loss of correction occurred, and individual screw loosening was seen in another group of three patients.

In 1996, Seibert et al. reported on 26 patients with posterior plating after trauma [60]. Apart from a rate of over 10% of infections (n=3), most patients attained only satisfactory ratings; some obtained good ratings, but none a very good rating, due to permanent postoperative pain in the neck.

With a series of only 26 patients, of course, considerable routine is not to be expected, but the trend of the results supports the authors' own experience (see below).

There is very little information available on results with the posterior hook plate in traumatized patients. In 1991, Jeanneret reported on 70 cases, 51 of which were followed-up [36]. In all patients fusion was achieved. One technical failure required a renewed spondylodesis. In one patient with a dislocation, closed reduction caused disk protrusion into the vertebral canal with subsequent paraplegia. The Cervifix has so far been presented only in a single publication on 20 patients [36]; accordingly, implant-related complications have not been found yet.

Anterior methods

While posterior implant stabilization has never been in question, the demand for a securing implant for anterior fusion was not made before the 1970s, when the complications resulting from non-fixed graft implantation, which was still practiced right into the 1980s even on traumatized unstable cervical spines, were no longer acceptable [43].

It might be important for an understanding of this development to know that the anterior methods were developed primarily for degenerative spondylarthrosis after root and/or spinal cord decompression, i.e., for a stable motion segment.

It would, therefore, not be fair to compare the results of anterior fixation of the past 10 years with the results of anterior grafting between 1960 and 1980. In striking agreement, all publications of the past 10 years [1, 6, 11, 32, 41, 49, 68] point out the absence of pseudoarthrosis after instrumentation of anterior lege-artis stabilization. The implant loosenings [6] often involved in traditional H-plate fixation significantly decreased in number after the introduction of the CSLP or bicortical screw fixation [32].

However, it is not only the mechanical component that is of decisive importance, but also correct assessment of the instability and knowledge of the load capacity of the assembly chosen [68].

The anterior approach also has its own morbidity: typical problems concern the visceral structures, e.g., esophageal injury [49, 50] and paralysis of the recurrent laryngeal nerve [6, 32, 49]; however, occasionally lesions of the A. vertebralis also occur [62].

In 1991, Aebi et al. [1] reported on 86 patients in whom 93 cervical spine motion segments had been fixed. Follow-up, on average 40 months after the first surgery, revealed zero complications and 100% fusion, no infection and no broken plate, but they did find one broken and one loosened screw. They suggested the use of titanium screws, which they had already used for their patients, because it was an easy means of reducing screw loosening in cancellous bone.

In the same year, Ripa et al. conducted a follow-up examination on 92 patients who had undergone the same treatment [54], and found the complication rate to be less than 2% and a fusion rate of 98.9%. They noted a 13% rate of technical errors with falsely positioned screws, shown by radiographs included in the publication. In four patients (5%) loosening of screws occurred, and one patient suffered from dysphagia, indicating the need for local revision.

Morscher et al. [49] reported on 80 CSLP-stabilized patients. They found no pseudoarthroses, but they did discover two cases of paralysis of the recurrent laryngeal nerve, one perforated esophagus and two broken screws.

In an investigation by Hofmeister and colleagues [32], involving 61 stabilizations performed on the lower cervical spine, one esophageal complication, two cases of paralysis of the recurrent laryngeal nerve and two infections were found. The manner in which Blauth classified his patients [6] deserves particular attention, because it comes closest to taking into account the developments in anterior fixation. He put his patients (n=191), operated on between 1972 and 1994 using the anterior approach and his angle-unstable plate system, into two groups (1972–1983: n=89; 1984–1997: n=102). He ascribed the results achieved with the first group to the learning curve; and he was certainly justified in attributing the results obtained with the second group to the biomechanical knowledge gained over the previous 10 years. While in the first group there were still six cases of implant loosening and one broken implant, these problems were virtually halved in the second group. And a follow-up examination (n=144) revealed kyphotic loss of correction in 12 patients from the first group, but only in four patients from the second group. With subjective discomfort stated as not being mild, only one asymptomatic pseudoarthrosis was found, i.e., a fusion rate of 99.5%.

Combined methods

From the point of view of testing or measuring technique, combined posterior/anterior stabilization leaves no doubts [16, 47, 69]. Clinical results confirm this, but they also highlight the practical problems involved in the combina-

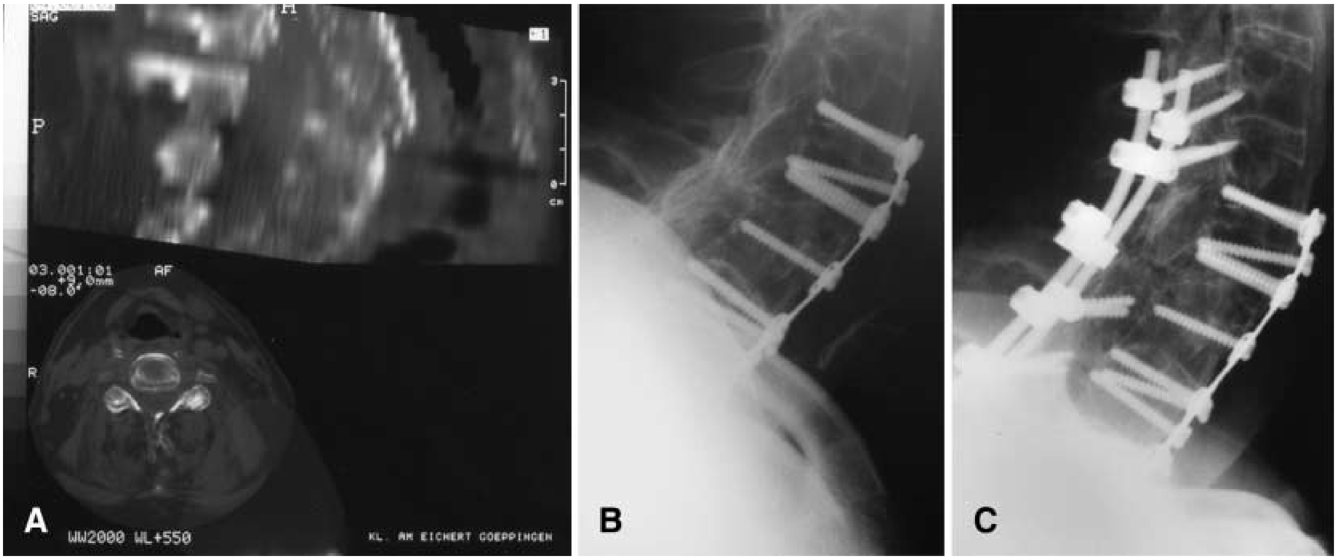

Fig. 9 Fracture of C6/7 with Bechterew's disease: **A** lateral reconstruction on a computed tomography (CT) scan, **B** primary anterior fixation with a flexible implant with postoperative application of a cervical support, **C** additional posterior fixation with the Cervifix in the second stage

tion of approach-related complications, above all in regard to one-stage operations.

McAfee and Bohlman [46] reported on 24 patients. Ten of them showed traumatic instability. The combined method involved anterior decompression and fusion with posterior triple-wire stabilization. In 1998, Vecsei presented 21 patients from a group of solely traumatized patients [70], for whom posterior/anterior intervention was indicated because of instability or dislocation after anterior intervention or due to additional posterior vertebral canal narrowing and a dislocation healed in false position. No approach-related complications were discovered and all fusions healed, provided the patients survived the additional injuries and/or the complications of general surgery. In more than 50% of the cases, the authors combined the anterior H-plate or CSLP with posterior cerclage wiring according to Rogers. They considered this procedure as generally indicated for highly unstable flexion/distraction injuries or simple irreducible injuries and for additional rheumatism-induced spinal changes.

Jónsson et al. [38] reported on 40 patients with CSLP and additional posterior plate fixation. They found the typical complications, such as a posterior infection and an anterior esophagus perforation, and noted that CSLP did away with the need for additional posterior stabilization.

It is also our experience that the combined approach is limited to a few indications only:

1. Fractures in combination with ankylozing spondylitis (Bechterew's disease)
2. Injuries of the cervicothoracic junction.
3. Multiple traumas with prolonged artificial respiration.

It is the cervical spine fracture in combination with Bechterew's disease, above all, that can make high demands on the analytical and organizational skills of a spinal surgeon, because the following aspects need careful consideration:

1. The reduced bone quality and consequently lessened screw retention force of an anterior, unicortically mounted system such as the CSLP.
2. The high mechanical load the fractured area is subjected to as the only mobile segment of the spinal column.
3. The tendency for a CLSP to caudally break away from the bone, because of its inner rigidity. In order to avoid this, by reducing the high loads exerted on the bone/screw system, it may be indicated to first apply a long, elastic anterior H-plate with bicortical screws [64]. Subsequent reliable posterior fixation within a few days, however, is mandatory (Fig. 9).

If the cervicothoracic junction is injured, additional external immobilization postoperatively will not be effective. Since these injuries are often also extremely unstable, we consider a planned, combined procedure to be indicated here, too, with the primary approach in our view being dependent on the local need for decompression (Fig. 10).

Comparative investigations

In a clinical study covering the period from 1982 to 1991 and involving patients from Ulm University Hospital, 119 patients with trauma-induced instabilities of the lower cervical spine were analyzed (Table 1). Eighty-one patients with an average age of 37 (range 16–77) underwent clinical, radiological and functional follow-up examinations after an average postoperative period of 4 years (range 1.5–10 years).

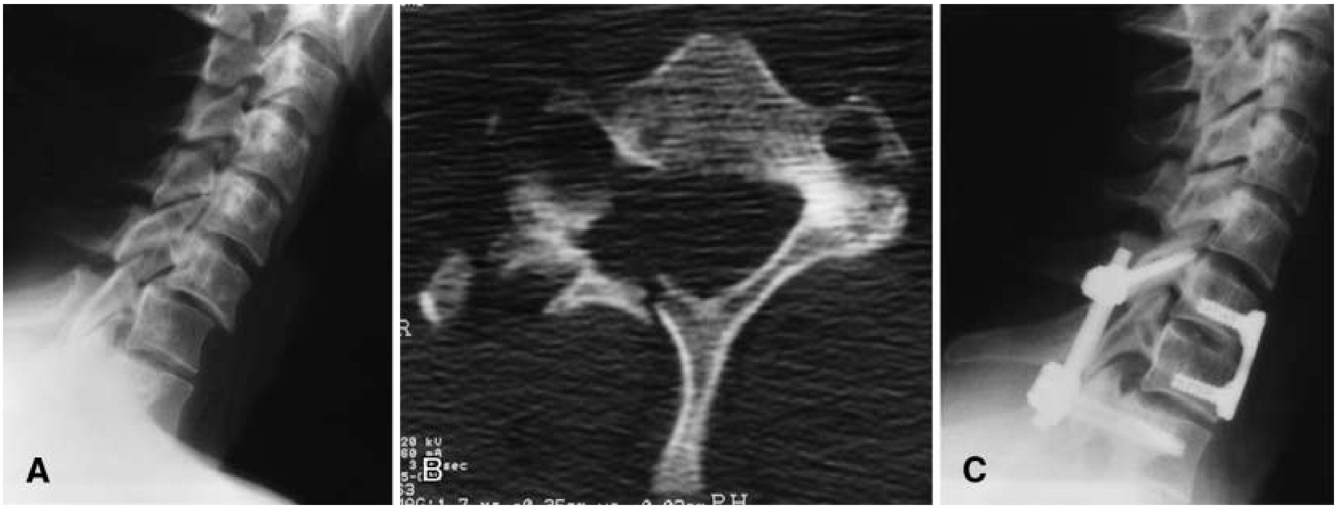

Fig. 10 Rotational subluxation of C6/7 with unilateral fracture of articular processes and primary root damage at the same level: **A** lateral view, **B** CT section view, **C** postoperative result. Being fractured, the articular process of C7 could not be used

Table 1 Breakdown of injury types

	n
Flexion/distraction injury	93
Hemiluxation	23
Luxation	6
Luxation fracture	64
Compression injury (fracture)	24
Torsion injury	2

Table 2 Follow-up results

	Anterior (*n*=51)	Posterior (*n*=24)	Combined (*n*=6)
Pseudoarthrosis	0	1 (5%)	0
Malalignment	7 (14%)	5 (20%)	0
Implant loosening	6 (31%)	3 (12%)	0
Subjective complaints	12 (24%)	11 (56%)	3 (50%)
Mean impaired function (degrees)	25°	30°	30°

Fifty-one of the patients followed-up had received anterior fusions: 40 had been monosegmentally and 11 bisegmentally fused. Twenty-four patients had been stabilized via a posterior approach: 11 monosegmentally and 13 bisegmentally. In six cases with complex instabilities, a combined anterior/posterior operation had been performed, in three cases monosegmental and in three further cases bisegmental fusion had been carried out.

At the time of follow-up, all combined and all anterior spondylodeses had attained fusion. One posterior pseudoarthrosis was discovered. At the time of metal removal and/or follow-up, 31% of the anterior plates implanted were loose. By comparison, there were three (12%) loose implants after posterior fusions (two broken cerclage wires and one unhitched hook plate). No loose implants were discovered in the combined anterior/posterior fusions.

Subjective complaints were noted for 24% of patients with anterior fusion, whereas 56% complained about pain in the neck after posterior fusion carried out on the cervical spine. The rate of complaints after combined fusion was of the same magnitude.

In 27 patients (53%) with anterior fixation, anterior spondylophytic changes were found in the area of the longitudinal ligament; with posterior fusions, however, these changes were found in five patients only. In all patients with combined anterior/posterior stabilizations, the abovementioned regressive phenomena were found. The radiographically documented intersegmental measurements of flexion/extension mobility revealed an average degree of functional impairment of 25° for the anterior methods. By comparison, the posterior as well the combined methods, with 30° for each category, showed a significantly higher degree of impairment of mobility (Table 2).

Discussion

One hundred years after the first surgical stabilization procedures were carried out on the cervical spine, and 50 years after the development of the anterior approach, the results published so far on the various methods of treatment of the traumatized, unstable lower cervical spine still seem to leave all options open. Even though the risks of instability after conservative treatment of unstable injuries were clearly formulated as far back as 20 years ago [34], conservative approaches are still being presented as valid alternatives of treatment [39], in spite of the superior rehabilitation results of surgical stabilization, in particular for a paraplegic patient. However, closer inspection reveals the disadvantages of these alternatives,

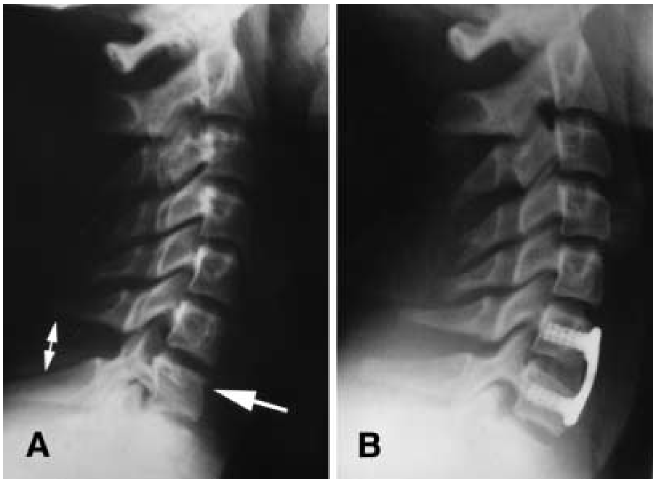

Fig. 11 Complete discoligamentous instability in a 15-year-old patient with enlargement of the interspinal gap and a longitudinal band torn from the bone, **A** preoperatively, and **B** postoperatively after disk removal, implantation of a cancellous bone block and stabilization with CLSP

with the 6 weeks bed rest and skull extension certainly not being the least significant one.

Of course, operative stabilization may occasionally confront the surgeon and the patient with conditions that are diametrically opposed to the primary objective of traumatological surgery: “restoration of function and avoidance of late effects”.

The significant decline in implant-related complications in the publications of recent years, however, can be interpreted as indicative of the fact that our learning potential has been fully utilized, last but not least assisted by the comparative biomechanical studies, for they showed us not only the function of the various implants on the cervical spine, but also their interaction.

On the other hand, only intensive cooperation between biomechanical and clinical researchers will allow conclusive interpretation of results – a fact which can be gathered, for example, from the following. A synoptic review of scientific and clinical data of the past 10 years on stabilization methods performed on the lower cervical spine reveals a strikingly unanimous and complete turnabout in the approaches recommended. Until the early 1980s, the posterior (technically non-critical) wire systems were favored, even for pseudoarthrosis after primary, anterior non-instrumented fusion [22, 42]. Since then, however, it is the anterior plate systems that have become the winners, although they were initially not necessarily recommended by the results of the biomechanical studies, because the primary flexion stability attainable was insignificant.

The clinical advantages of this approach, however, were so obvious that, by means of in vitro studies, it was possible to optimize these systems for routine clinical application. Unproblematic positioning by itself, which may be of crucial importance especially in polytraumatized patients, speaks in favor of this approach. Moreover, surgery is carried out within biological gliding tissue layers and bone transplantation is performed with a good transplant base being available, allowing for optimal fusion under compression. Alignment can be carried out without effort. The cervical collar, which is occasionally required for certain types of instability until positive healing or additional posterior stabilization, is easy to apply. On the other hand, there are of course visceral problems, which are absent in the posterior approach.

The fears raised by the frequent recurrence of loose implants with the anterior H-plate of the first generation are hardly reflected by clinical symptoms [6, 41]; however, approach morbidity is clearly higher.

The understanding of the difference between angle-unstable and angle-stable plates and the analysis of the influence of mono-and bicortical screw assemblies on the fixation strength of the system marked the decisive breakthrough in the development of the optimal implant for the anterior approach. Now it is possible and even recommendable – with complete instability and good bone stock – to use only an angle-stable anterior system with monocortical screws to bring about safe spondylodesis (Fig. 11).

Undoubtedly, the screwed posterior methods are capable of producing a higher degree of primary stability. The intraoperative technical effort, however, is much greater, and positioning is more critical. In addition, due to large muscle-shipping, there is the risk of postoperative fibrosing and scarring in these patients, evident at all stages in the form of demonstrable functional disturbances and subjective complaints.

However, the obvious absence of any anterior support is one of the most important arguments against a posterior method. If in such cases the decision is made in favor of a solely posterior approach, a mechanically efficacious osseous fusion should be made possible. But this can only be brought about with the hook plate or multisegmentally with an internal fixator combined with transplantation of cancellous bone. Otherwise, a system collapse would be programmed (Fig. 12).

The clinical reorientation process is illustrated by two publications by Lowery and co-workers. In 1995 Lowery still recommended posterior plates for pseudoarthrosis on the lower cervical spine after anterior non-instrumented fusion [42]. But 3 years later, after 2- to 7-year follow-up examinations of patients with pseudoarthrosis after anterior instrumented fusion, he pointed out that while anterior implant failures occasionally impressed in radiographic examinations, there were no positive clinical counterparts [41]. He held that in many cases local revision was made superfluous by spontaneous healing; moreover, anterior re-fixation was attainable at a high rate of success without any problems – a statement that was confirmed by Philips et al. [52].

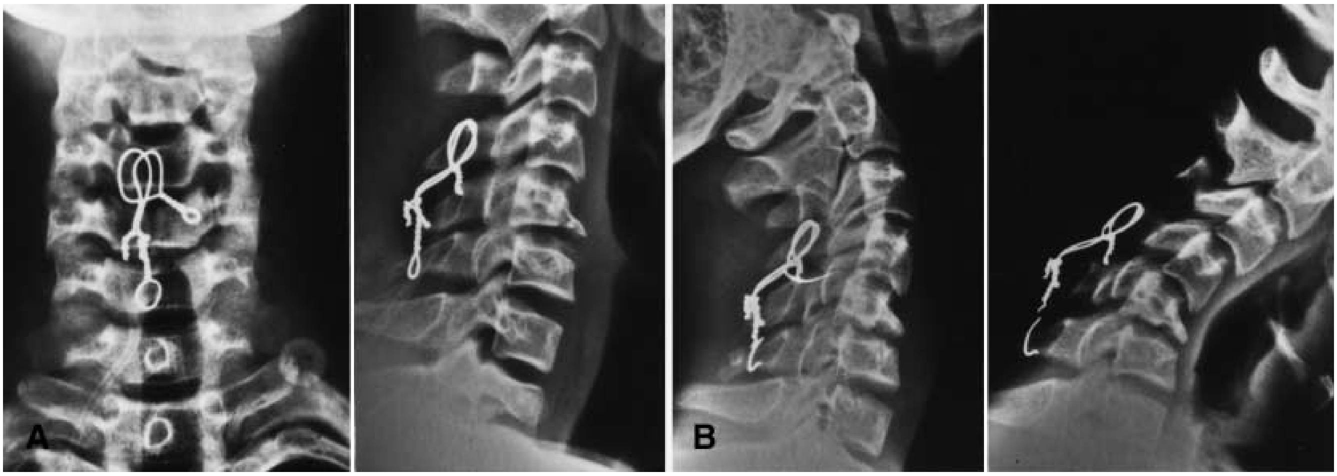

Fig. 12A, B Cervical spine compression-distraction injury with posterior ligamentous instability. **A** Primary posterior stabilization after reduction by the modified cerclage method according to Gallie. **B** Implant failure 2 months postoperatively due to lack of anterior support

The importance of bony fusion for permanent stability has so far not been disputed [20, 67, 74]. Therefore, bone transplantation should by no means be dispensed with, in spite of the fact that graft removal morbidity is not negligible. However, a careful technique can largely prevent this morbidity [59].

The investigations available and presented above have brought forth facts that can no longer be ignored. The demand that spinal surgeons should be aware of what they are doing is therefore not far-fetched.

They should know the consequences of destabilizing routine operations on the cervical spine [17, 61], and also those of surgical segmental arthrodesis [23]. Careful analysis of the injured segment and positive knowledge of the degree of stability to be achieved with the implant used are, however, of the utmost importance.

The possibility should also be kept in mind that an implant might show little stability in an experimentally specified load situation, but nevertheless be clinically indicated and recommended. In such cases, while the surgeon should aim to use an implant that is clinically indicated and recommended, he or she must have a high degree of perception and understanding of the load potentials offered by the implant in question. Then the decision about whether additional external immobilization is required will not be difficult to make – even though it should not be taken indiscriminately [18]. Likewise, the decision about whether the implant by itself will permit the degree of intersegmental stability we assume to be required for osseous fusion of the unstable motion segment should also be straightforward.

The conclusion is thus obvious, that technical problems and implant failures are not necessarily attributable to the method, be it anterior or posterior, but mostly to erroneous analysis of the conditions prevailing and to inappropriate technique/technical skills [6].

On the one hand, we are faced with the results of scientific investigations, on the other hand, we are confronted with interpretations. Circumstances and subjective experience often result in arguments that blur the boundaries between evidence-based and opinion-based discussion.

The conclusion drawn by Coe et al. [16], for example, is to be interpreted along these lines, when they recommended the mechanically unreliable cerclage wiring technique, despite unequivocal experimentally determined values, and being obviously unaware or negligent of the potential problems.

In view of the development of surgery on the lower cervical spine, facts are available that suggest the following recommendations:

1. The surgical procedure should be to bring about decompression, realignment, and stability.
2. The anterior approach should be the primary and preferred one. With regard to surgical and positioning technique, this access clearly involves less problems than the posterior approach; if required, unrestricted additional cord decompression can take place; implant fixation is technically simple; and the awareness of instability and type of implant permits functional therapy, above all for the paraplegic patient.
3. For traumatic conditions, posterior methods are reserved for exceptional indications. The restriction to this approach requires the anterior column to be intact and a multi-segmental fixation to be performed. Posterior fixation is therefore less recommendable for traumata than for degenerative, rheumatoid or tumorous instabilities. The cerclage wire technique depends on intact, osseous posterior element; while after laminectomy, only screwed implants create safe stability. The disadvantages of posterior access for the proprioception of the cervical muscles and the subjective symptoms of the patient are known and to be taken into account.

4. Combined techniques are indicated for highly unstable or particularly complex injuries. On the cervicoth racic junction or in cases of Bechterew's disease, the decision is justifiably made in favor of this technique, which can be performed as a one-stage or two-stage operation.
5. Whenever possible, selection of the implant should take into account the foreseeable developments in diagnostic procedures; and therefore, in view of follow-up examinations required later and modern imaging techniques, the implant chosen should be made of titanium.

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