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U. Quint
H.-J. Wilke
F. Löer
L. Claes

Laminectomy and functional impairment of the lumbar spine: the importance of muscle forces in flexible and rigid instrumented stabilization – a biomechanical study in vitro

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U. Quint (✉) · F. Löer
Orthopaedic Clinic University of Essen, Hufelandstrasse 55, D-45 122 Essen, Germany
Tel. +49 201 4089 261
Fax +49 201 494833
e-mail tok030@sp2.power.uni-essen.de

H.-J. Wilke · L. Claes
Department of Trauma and Biomechanics, University of Ulm, Ulm, Germany

Abstract Laminectomy is the accepted treatment for spinal canal stenosis in cases where conservative treatment has failed. Opinions diverge on the resulting clinical instability and the necessity of instrumented stabilization. The present biomechanical study was performed to determine the functional impairment following laminectomy and the stabilizing effect of flexible and rigid devices. This was the first time that the effects of agonist and antagonist intersegmental lumbar muscle forces acting on intact, unstable and instrumentally stabilized functional spinal units have been investigated. Six human cadaveric lumbar spines were tested in a spine tester. The coactivation of agonist and antagonist muscle forces resulted in increased stability under the load conditions of bending and rotation; a slight increase in the range of motion was noted during flexion. The functional impairment following laminectomy was corrected by ligamentoplasty and by means of muscle forces. Ligamentoplasty appears to be an alternative to decompression with spondylodesis, especially in patients with well-developed muscles.

Key words Spinal biomechanics · Intersegmental muscle forces · Operative decompression · Instrumented stabilization

Introduction

The gradual development of degenerative spinal canal stenosis [28] results from disc degeneration with narrowing of the intervertebral space; this leads to weakening of the capsule-ligament pretensioning and subluxation of the facet joints [29]. The resulting instability is accompanied by hypertrophy of the facets, vertebral arch, and flaval ligament [26]. A special form of spinal canal stenosis with degenerative pseudolisthesis is characterized by loss of the intrinsic support of the motion segment concerned [27].

When conservative treatment with analgetics, physiotherapy, corsets and epidural injections fails [55], it is accepted that operative decompression of the stenotic area is necessary [45, 64]. Imaging procedures help to plan the surgical approach and to decide which tissues need to be removed at operation [63]. Depending on the initial findings, this may involve removal or remodeling of the vertebral arch, resection of the flaval and interspinal ligaments [45], widening of the lateral recessus accompanied by resectioning of the entire facet joint or the medial facet joint [28], or selective root decompression [7].

So far no consensus has been reached on how much of the vertebral structures should be removed [6, 8]. Moreover, there are divergent opinions on the functional impairment to be expected following extensive [25] or limited decompression [44]. The dorsal osseous and ligamentous elements and the degree of disc degeneration are decisive for the stability of the functional spinal unit [45].

A positive correlation has been found between the extent of decompression and subsequent segmental instability and the slipping of vertebra [55]. Moreover, the distinction between stable and unstable spinal canal stenosis [51] appears to be significant with respect to the consequences of decompression procedures. It is assumed that surgical decompression results in postoperative instability. Following decompression of an unstable spinal canal stenosis (i.e., pseudolisthesis), progressive slippage of the vertebra was observed in 100% [33], 65% [25], or 40% of cases [60]; following decompression of a stable spinal canal stenosis, the corresponding figures were 54% [39], 40% [25], 30% [52], and 4.6% [62] of the cases.

In some clinical studies the amount of instabilities differ with the definition and the methods used for its description. The definition of postoperative segmental instability is usually based on clinical symptoms (pain and neurogenic deficit under physiological loads) and a pathological deformation of the functional spinal unit (FSU) under loading [65]. Among the diagnostic tools now in clinical use are radiographs performed in functional positions [13], myelographic studies conducted during left/right bending (anteroposterior) and flexion/extension (sagittal) [14], and computed tomography during left/right rotation [21]. Furthermore, radiological stereophotogrammetric procedures [59], motion analyzers using ultrasound [66], and invasive 3D kinematic analysis systems [56] are employed in vivo. The precise effect of coactivation of the deep intersegmental muscle forces in vivo is still unknown but is a stabilizing influence [42], and pathologic movements in symptomatic patients have been assessed [37]. The participation of the passive and active spinal structures involved and measuring instability becomes more difficult in vivo.

The segmental functional impairment resulting from the interplay of diverse factors such as body weight, metabolism, physical exertion, posture, the complex regulation of muscle forces, and the extent of the vertebral structures removed cannot be assessed precisely by clinical studies alone. A search of the literature uncovered no reports of mechanical analysis of the isolated spine before and after decompression procedures and subsequent instrumented stabilization using agonist and antagonist intersegmental muscle forces. The question of whether instrumented stabilization should be undertaken at all is currently under discussion. In cases where the use of a stabilizing system is indicated, there is no consensus concerning the degree of stability required. Is it sufficient to use a flexible system which preserves function, or is it always necessary to perform spondylodesis, which is invariably accompanied by functional loss?

The hypotheses to be tested in our study were that operative decompression by laminectomy results in functional impairment of the FSU and a range of motion comparable to that of an intact FSU can be achieved by dynamic instrumentation. In addition, the effect of agonist and antagonist muscle forces on the loading of functional spinal units was to investigated in order to prove the hypothesis that coactivation of the intersegmental muscle forces can achieve segmental stability on the intact FSU and on the destabilized FSU after laminectomy. The objective of the study was to demonstrate the primary stability associated with ligamentoplasty and the employment of a rigid internal fixator by application of agonist and antagonist muscle forces.

Materials and methods

The in vitro tests were performed in a spine tester with six fresh frozen human lumbar spine specimens (L2 to S2) [68]. The average age, size, and weight of subjects at death were 47.6 ± 9.8 years, 171.2 ± 7.7 cm, and 78.7 ± 18.9 kg. Radiographic and macroscopic examination of the specimens did not reveal any osseous anomalies, destruction, or high-grade degenerative changes.

Preparation of specimens

The specimens were first dissected to remove all muscle and fatty tissues. The ligamentous structures and points of insertion of the psoas and multifidus muscles were left in place in order to identify the areas of insertion. To fix a three-dimensional goniometric linkage system across the motion segment, Schanz screws were inserted in the anterior vertebra. In addition, AO mini spongiosa screws (2 mm drill, AO cortical screw 2.7 mm in diameter with a subcapital drilled hole for the wire cable) were fixed at the insertion points of the multifidus and psoas major muscles. The sacrum and the most cranial vertebra (L2) were mounted in polymethylmethacrylate (Technovit) with the intervertebral disc L3/4 aligned horizontally. During the tests the sacrum was fixed and the cranial vertebra were unconstrained.

Experimental set-up

To change the position of a vertebral body in a functional spinal unit, in vivo moments are applied to the lumbar end plates via abdominal and back muscles; in addition, forces are applied to the intersegmental muscles at their point of insertion into the cortex of the vertebral body. This was reproduced in vitro by the application of muscle forces via wire cables attached with screws to the area of insertion of the muscles at L4. The actual motion in this experiment was produced by pure moments up to 7.5 Nm applied to the gimbals of the spine tester for flexion/extension (± M*x*), right/left lateral bending (± M*z*) and left/right axial rotation (± M*y*). The FSUs were unconstrained for measurement of the physiological movement executed in response to the applied load. Three load-and-unload cycles were performed for preconditioning; the data from the last cycles were then evaluated. No preload was applied to the specimens to avoid deflection or bending. During the testing, the specimens were kept moist with a saline solution. The agonist muscles were defined to be those that apply moments in the direction of external moment imposed on L2, while antagonists oppose the external moment.

With the goniometric linkage system used in this experiment (Fig. 1), the three-dimensional relative movement occurring between the centers of the vertebral bodies can be uniquely described in terms of all six movement components (i.e., three translations, three rotations). Because the weight of the goniometric linkage system is only 164 g, the torque acting on the Schanz screw in the vertebral body can be neglected. The measurement accuracy of the system used is 0.1 mm and 0.1°, with a relative measurement error of 3% [69].

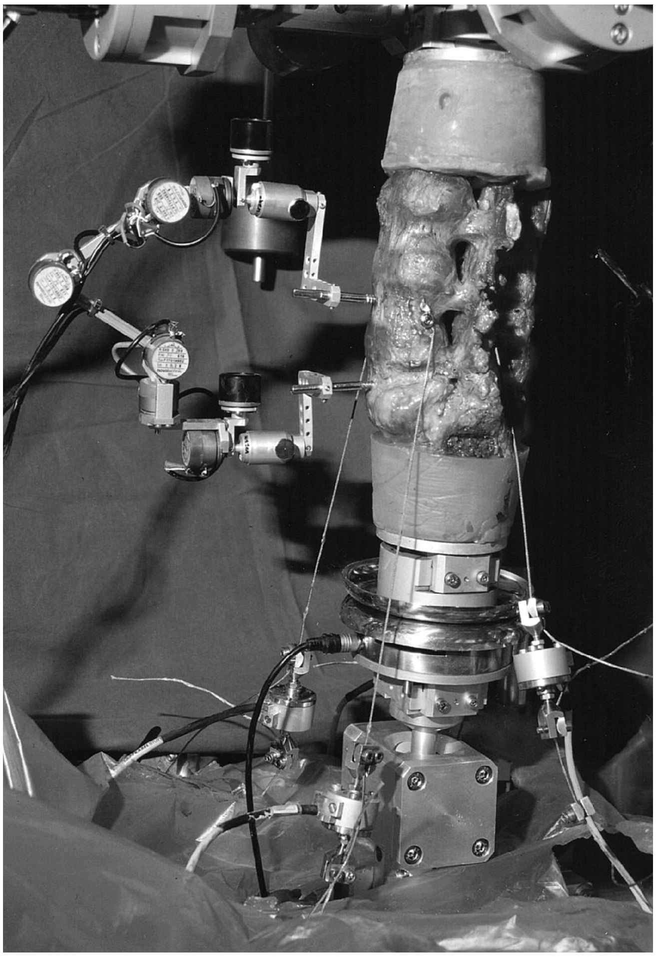

Fig. 1 View of the spine tester with the gimbals above for application of pure moments and the cable wires with integrated load cells for controlling the applied load of 30 N or 90 N for coactivation of intersegmental muscle forces

Application of intersegmental muscle forces

The psoas muscle originates ventrally with a superficial layer on the lateral vertebral bodies and is connected to the trochanter minor of the femur. It thus flexes the lumbar spine in the fixed-leg position [9]. The numerous anatomic elements of the sacrospinalis muscle constitute a functional unit, and it is considered likely that individual strands are used separately [32]. The multifidus muscle originates at the processus mamillaris of L4 and is connected to the crista sacralis lateralis. It thus extends the lateral spine.

The most important groups of muscles which act agonistically and antagonistically in a caudal direction, namely the psoas major and the multifidus, which act on L4, are simulated by two pairs of force vectors (Fig. 2). The total effect results from the force applied, the direction of traction of the wire cable, and the position of the screws on the vertebral body [70, 71]. The directions used for the various muscles were: multifidus muscle, angle $\alpha 24°$ sagittally and angle $\beta 14°$ frontally; psoas muscle, angle $\alpha 18°$ sagittally and angle $\beta 6°$ frontally.

For the purpose of flexion, two cables with 90 N each were applied from ventral, while one-third of the force, i.e., 30 N, was applied by two symmetrical cables from dorsal. During lateral bending, 90 N was applied ipsilaterally from ventral and dorsal, and 30 N applied contralaterally by wire cables. Rotation to the left was achieved by applying 90 N via the wire cables at front left and rear right while applying 30 N via the cables at front right and rear left (Figs. 1, 2). The forces were believed to be within physiological limits [9, 36, 43].

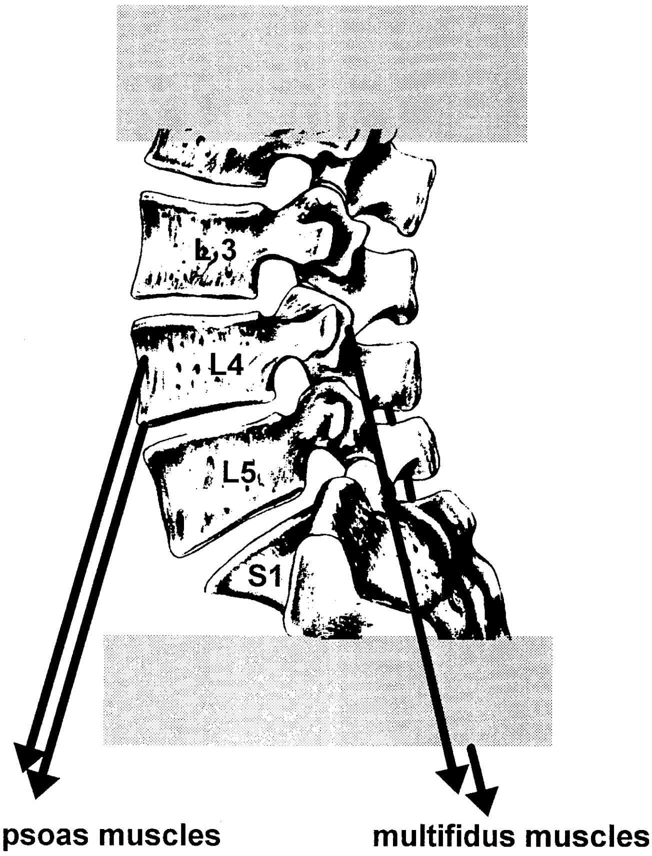

Fig. 2 Sketch of the lumbar spine specimen embedded in acrylic cement with L2 and S1/2 with L3/4 horizontally. Applied vectors of the multifidus and psoas muscles for coactivation of agonist and antagonist muscle forces to L4

Operative decompression

Using normal surgical punches, we performed a laminectomy involving excision of the spinal process with the supra- and interspinal ligaments, the entire lamina of L4 with the flaval ligament, the facet joint, and its capsule. At the end of the series the connection of the FSU L4/5 was performed via the longitudinal anterior and posterior ligaments and the annulus fibrosus with the nucleus pulposus.

Stabilization methods and materials used

The biomechanical model of the human vertebral column was employed to compare the primary stability achieved by the two types of instrumentation. The destabilized situation following laminectomy was the same for both stabilizing procedures.

The Graf ligamentous system [19, 20] uses special transpedicular screws (length = 40 mm, diameter = 6 mm) which are tensioned by semielastic ring bands. A longitudinal tension-measur-

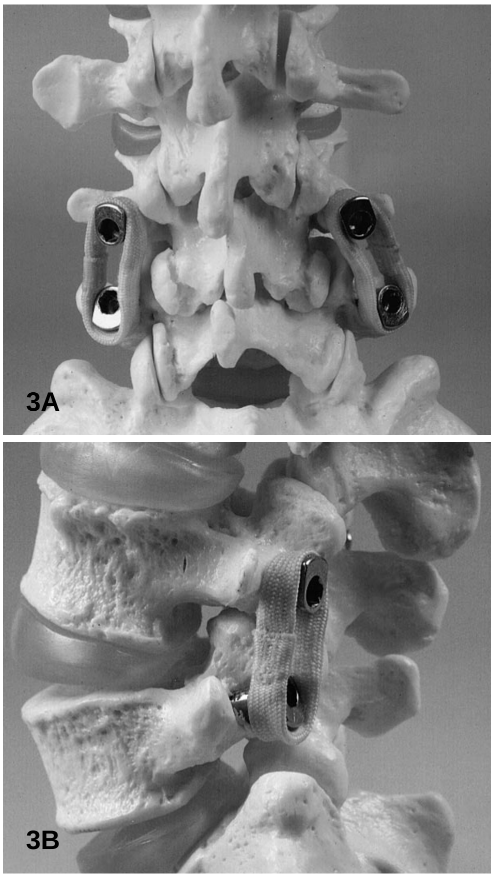

Fig. 3 A, B Ligamentoplasty with the flexible Graf system surrounding transpedicular screws in L4/5. The semielastic ring bands were pretensioned to stage 1 (50 N) with the tension measuring device. **A** Dorsal and **B** lateral view

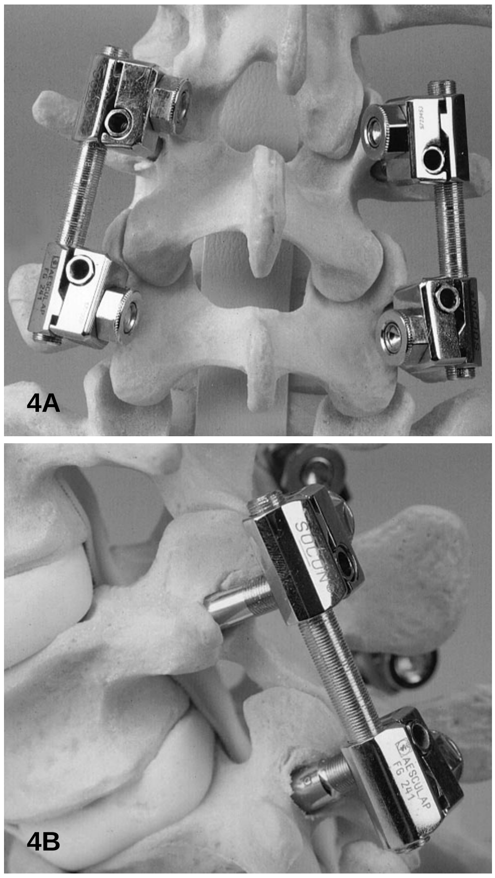

Fig. 4 A, B Instrumented stabilization of the functional spinal unit (FSU) L4/5 with the SOCON internal fixator using transpedicular screws and rod-shaped connections. **A** Dorsal and **B** lateral view

ing device is employed for pretensioning at tensioning stage 1 (50 N) [31] (Fig. 3).

For instrumentation exhibiting angular stability, the SOCON fixator [35] was attached in a neutral position with transpedicular screws (length = 50 mm, diameter = 7 mm) and rod-shaped longitudinal supports (Fig. 4).

Statistical analysis

Owing to interindividual differences, the mean value of the six lumbar spine specimens tested was taken as the representative range of motion (ROM) [60]. The amount of segmental motion, expressed in degrees, measured up to the highest loading condition, is shown as a bar chart of mean and standard deviation values [50]. The Friedmann test [16] was used to demonstrate significant differences ($P < 0.05$) between the intact FSU, the FSU following laminectomy, and the FSU following the two stabilizing procedures. The Wilcoxon test [67] was used to determine the conditions under which statistically significant differences occur with and without coactivation of muscle forces ($P < 0.05$). The data were viewed as exploratory data; for the majority of tests, level adjustment was not carried out.

Testing procedure

During the tests, we measured first the intact functional spinal unit L4/5 and then again the FSU following laminectomy. In this destabilized situation, a comparative primary stability study was performed on the transpedicular screws and the flexible ring bands used in ligamentoplasty and the rigid rod system of the internal fixator, each compared with and without coactivation of muscle forces.

Results

Segmental motion is characterized by the relationship between the applied load and the resulting movement. The figures show the values of the ROM (Fig. 5), neutral zone (Fig. 6), and coupling effect (Fig. 7) in degrees of angle of L4/5 up to the pure moments of ± 7.5 Nm for flexion/ extension, right/left lateral bending, and left/right rotation, representing the mean values with standard deviation and application of agonist and antagonist muscle forces (Fig. 5).

Range of motion in an intact FSU and following laminectomy

Following laminectomy of L4, the ROM was increased under all loading conditions in comparison with the intact FSU L4/5 (Fig. 5). Removal of the vertebral arch with the supra- and interspinal ligaments, flaval ligament, joint, and capsule was associated with an increase in the ROM of 14.3% during bending, 32% during flexion, 35% during extension, and 117.4% during rotation.

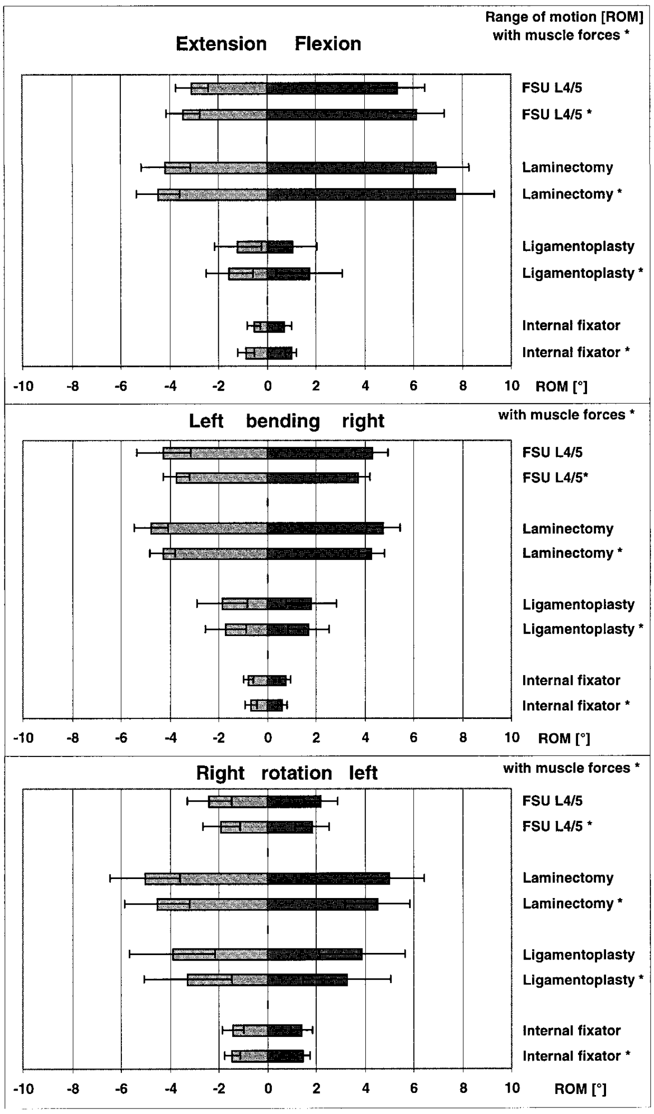

Fig. 5 The range of motion (ROM) was defined as the angular deformation of the FSU L4/5 under maximum load (± 7.5 Nm) for flexion/extension, right/left bending, and left/right rotation as shown on a bar chart of mean values and standard deviation (representative ROM). An increase following laminectomy, a distinct decrease following ligamentoplasty, and a residual ROM following instrumentation with the internal fixator can be seen. With coactivation of muscle forces the ROM was decreased in the intact FSU, following laminectomy, and using a flexible instrumented stabilization

Neutral zone following laminectomy

The neutral zone is considered a better indicator of lumbar instability than the ROM [41]. Following laminectomy the neutral zone was increased 60% in bending, 100% in rotation, 112.5% in extension, and 175% in flexion (Fig. 6). In a comparison of the two variables ROM and neutral zone, the highest increase in ROM was noticed under rotation and the highest increase in the neutral zone under flexion.

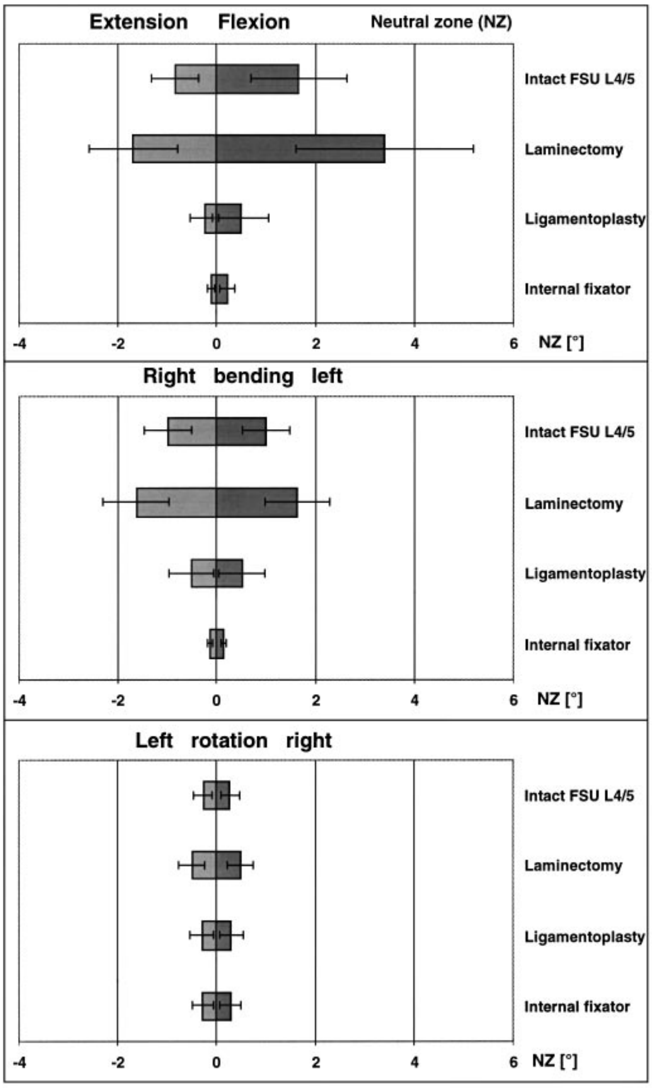

Fig. 6 The neutral zone (NZ), defined as the difference at zero load between the angular positions corresponding to the loading and unloading phases of the test cycle, was increased following laminectomy

Coactivation of intersegmental muscle forces

With coactivation of the deep intersegmental muscle forces of the psoas and multifidus muscles acting on L4, the ROM was decreased during bending or rotation and slightly increased during flexion (Fig. 5). A decrease in the ROM was observed when the muscle forces were applied to the FSU during rotation (intact FSU –21.7%, laminectomy –10%) and during bending (intact FSU –12%; laminectomy –12.5%). The stabilizing effect of muscle coactivation was achieved in the FSU under the load condition of rotation and bending. A slight increase of the ROM followed flexion (intact FSU +14.5%; laminectomy +11.2%).

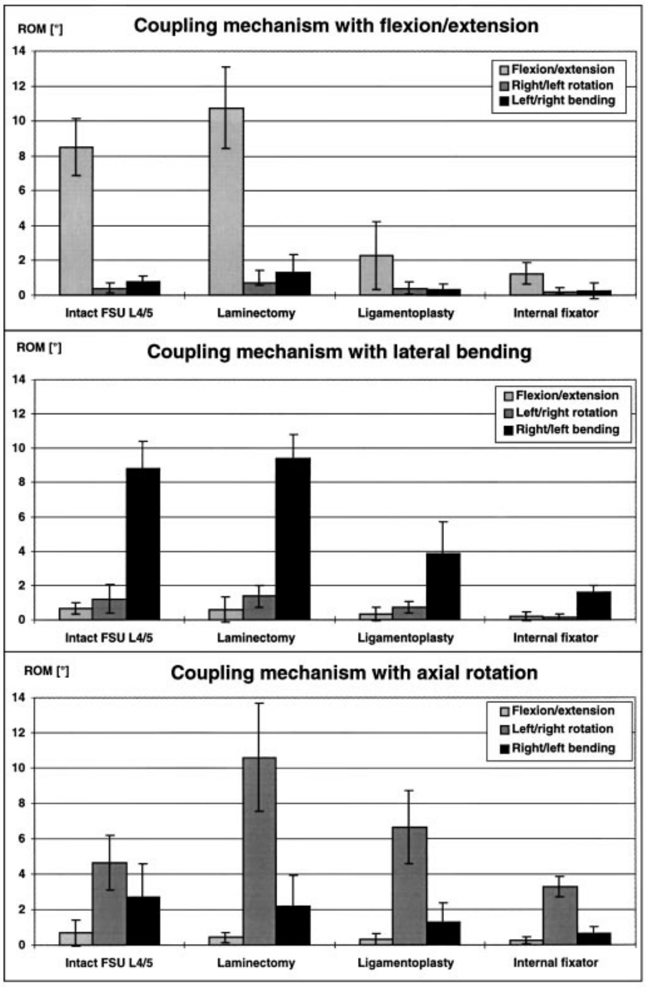

Fig. 7 Under the load component of rotation (± M*y*), simultaneous bending was observed. Similarly, rotation was noted when bending moments (± Mz) were applied. This coupling mechanism, observed in the intact FSU, was not changed following laminectomy. However, it was decreased following instrumented stabilization by means of ligamentoplasty and the internal fixator

Comparison of the stability achieved by ligamentoplasty and by the internal fixator

The defect situation in the six human cadaveric lumbar spine specimens following laminectomy of L4 and supplementary stabilization by coactivation of the muscle forces was the same for both devices. Using dynamic flexible fixation with the ring bands (see Fig. 3) it was possible to significantly lower the ROM following laminectomy. The highest stabilization effect was observed during flexion; the decrease in the ROM (and neutral zone) up to 85.7% (85.2%) flexion, 62.5% (68.7%) during bending, and 22% (40%) during rotation. With coactivation of the muscle forces, the difference in the ROM was measured under the load conditions of extension +7.7%, flexion +11.2%, bending –10.3%, and rotation –20%. The application of the muscle forces resulted in higher stability of the ligamentoplasty in bending and rotation.

Changing the instrumentation to the internal fixator (see Fig. 4) was associated with a marked gain in stability. The neutral zone (Fig. 6) was minimized (e.g., in flexion 0.2 ± 0.1°) and the decrease in the ROM (Fig. 5) following stabilization with the internal fixator was measured under the load conditions of flexion 89.5%, extension 87.2%, bending 84.3%, and rotation 71.1%. No significant change in the ROM was observed with coactivation of muscle forces. The stability of the internal fixator was higher than that of the ligamentoplasty.

Coupling mechanism

The largest values of coupled motions were found under the load component of rotation, when bending took place, and, conversely, rotation took place with bending moments. No increase in this coupling effect was noted following laminectomy, whereas instrumented stabilization led to a significant decrease ($p < 0.05$) in the coupled motions (Fig. 7).

Discussion

The present in vitro experiment describes for the first time the effects of agonist and antagonist muscle forces acting on the intact lumbar functional spinal units (FSUs), instable lumbar FSUs, and lumbar FSUs that have been stabilized by flexible and rigid instrumentation.

The measurements of ROM with and without coactivation of muscle forces yielded significant differences for both the intact FSU and the laminectomy. With both agonist and antagonist muscle forces, the ROM was decreased during bending and rotation and increased during flexion and extension.

The Graf method of dynamic fixation following laminectomy allowed segmental motion comparable to that observed in the intact FSU. By switching to an internal fixator, the FSU was stiffened even further until only a residual ROM was measured. During lateral bending and rotation, the coactivation of muscle forces on a motion segment that has undergone flexible instrumentation results in further stabilization and reduced ROM under the load conditions of bending and rotation. On the other hand, no significant change was noted when muscle forces were applied to an FSU following rigid stabilization.

Laminectomy is employed in vivo to achieve dorsal decompression, and in the present in vitro study a pronounced increase of instability was observed. The values of the ROM for extension (intact 3.1°/laminectomy 4.1°/ligamentoplasty 1.2°), flexion (intact 5.3°/laminectomy 7°/ligamentoplasty 1°), bending (intact 4.3°/laminectomy 4.8°/ligamentoplasty 1.8°) and rotation (intact 2.2°/laminectomy 5°/ligamentoplasty 3.9°) were evaluated. As a result of the different sizes of the transpedicular screws (Graf 6 mm diameter, 40 mm length; SOCON 7 mm diameter, 50 mm length) it was possible to perform a direct comparison of the two systems. In the studies described below, more severe degenerative disc pathology was excluded.

In vitro testing of human cadaveric spine specimens (n = 9, 10 Nm, mean age 47 years) by Lang et al. in 1992 [31] produced the following results. The ROM of FSU L4/5 was determined in comparison with the intact segment following bilateral facetectomy and ligamentoplasty by applying tensioning stage 1 during extension (intact 4.1°/bilateral facetectomy 6.6°/ligamentoplasty 1°), flexion (6.7°/7.8°/1.4°), right bending (5.2°/6.8°/1.7°), and right rotation (1.6°/4.9°/3.5°). The conclusion reached during this study was that the ROM for flexion/extension and axial rotation was significantly reduced, whereas the ROM during lateral bending was stabilized [31].

In the in vitro study (n = 13, 10 Nm, mean age 59.8 years) conducted by Strauss et al. in 1994 [57], the ROM of the intact, postlaminectomy, and Graf-instrumented FSU L4/5 was measured under the load conditions of flexion/extension (intact FSU 11.55°/laminectomy 14.28°/ligamentoplasty 4.45°), bilateral bending (9.92°/10.18°/4.39°), and bilateral rotation (5.43°/7.12°/5.83°). The conclusion of this study was that the Graf fixation system reduced the ROM under certain loading conditions. Laminectomy displaced the point of balance ventrally and Graf instrumentation restored the balance point to a dorsal position [57].

A comparison of the studies shows that the lowest effect of the ligamentoplasty was achieved in rotation. This result is important, because our own study demonstrated that laminectomy results in the highest degree of instability with an increase of 117% for the ROM and 100% for the neutral zone.

When rigid dorsal instrumentation was performed with a SOCON internal fixator in our own study, the average residual ROM was 12% during extension, 16% during flexion, 14% during bending and 28% during rotation. This shows that a residual ROM is still present when the FSU is stabilizes using a rigid device.

In another in vitro study (n = 6, 7.5 Nm, mean age 43 years) conducted by Nolte et al. in 1993 [40], the mobility of intact specimens of L2-L4 and instrumented specimens placed in a spine tester exhibited a representative ROM of approx. 20° during flexion/extension, 20° during bilateral bending and 10° during torsion. The values obtained for the instrumentation (SOCON) examined were: 4° during flexion/extension, 4° during bilateral bending, and 5° during bilateral rotation [40]. In comparison to these results we were able to demonstrate in our own studies the high stability on flexion (0.5°), extension (0.7°), and left bending (0.7°), as well as the lesser stability on right rotation (1.4°) exhibited by the SOCON fixator.

The effect of simulated muscle forces was investigated in experiments in vitro performed by Adams et al. [1], who simulated the vector sum of the muscle forces by a combination of compression, bending, and shear. El Bohy et al. [15] applied moments due to eccentric loads and measured facet pressure. The muscle forces were applied by Panjabi et al. [42] to the middle of the spinal process in the form of two vectors directed laterally, anteriorly, and inferiorly. With the application of muscle forces the ROM increased during flexion loading, decreased during extension and rotation, and was unaffected during lateral bending.

With the spine tester used for our experiments [68] repeated measurements with changing loads on FSUs under functional conditions and with coactivation of muscle forces were practicable. The application of four physiological vectors of muscle forces acting agonistically and antagonistically to a FSU has become technically possible for the first time.

Various research teams have used assisted electromyographic (EMG) techniques to investigate the effect of the back muscles on the stability of the vertebral column. High muscular activity on the contralateral side was demonstrated during lateral bending [4]. Axial rotation activated the agonist muscles with ipsilateral tensioning of the rotary and multifidus muscles as well as increased activity of the deep-seated antagonist muscles [5]. Moreover, it has been demonstrated that the ROM during flexion/extension depends on the activity of the sacrospinalis muscle [61].

Unfortunately the magnitude of the physiologically effective muscle force is not known to date. On the basis of EMG studies [11, 12, 43, 49], however, it is assumed that the development of the muscle forces parallels the applied forces. The values assumed in the literature on the basis of various methods [9, 17, 34, 36, 38, 43] were averaged; values of 90 N for the agonist muscles and 30 N for the antagonist muscles appear probable on the basis of current knowledge. In accordance with the force vectors, 90 N was applied in the direction of movement (agonists) to simulate the effect of a ventral and dorsal pair of muscles; at the same time, 30 N was applied opposite to the direction of movement (antagonists).

The application of various forces as a function of the direction of motion in the present study is the first step toward the development of physiological muscle force coactivation on a lumbar motion segment and corresponds to the present status of technical development. A literature search has not yielded any studies involving complex spinal column testing at a comparable technical level.

In the present study the coactivation of agonist (90 N) and antagonist (30 N) muscle forces was associated with greater stability with respect to the load components of lateral bending and axial rotation; this was already evident in the intact FSUs and noticeable in the laminectomy situation. Coactivation of muscle force for the load components of lateral bending and rotation in FSUs that had undergone flexible instrumentation produced a distinct rise in stability. As in the study by Panjabi et al. [42], an increased ROM was found during flexion. The conclusion of another study using ten constant vectors for coactivation of muscle forces was that different muscles perform different functions in vitro [70, 71] depending on the vectors applied and the geometry of the FSU. It was also shown that the deep intersegmental muscles stabilize the spine in rotation and lateral bending.

In another biomechanical study 24 specimens were tested in axial rotation in a torsion apparatus. The overall incidence of anterior and posterior annular tears as assessed by discography, magnetic resonance imaging, and histology was greater in discs where larger amplitudes of rotation were observed [23]. In our own study using radiography and macroscopic and microscopic inspection, advanced grades of disk degeneration were excluded.

One limitation of this biomechanical study is the difficulty of transferring results obtained in vitro to the situation in vivo, since the effects of the complex regulation of muscle forces, metabolic processes, and the repair capability of the living organism were not taken into account. Furthermore, the causes and effects of the observed postoperative functional impairment need to be studied in greater depth in vivo; owing to the lack of suitable methods, no precise characterization of the three-dimensional functional impairment observed after laminectomy has yet been undertaken and there is as yet no generally recognized classification. In the present study the segmental functional impairment observed following decompression was defined in terms of the increasing deformation of the FSU under constant load [30].

Chronic low back pain without neurological deficits generally responds to conservative treatment which includes physiotherapy aimed at stabilizing the trunk, medical treatment administered to strengthen the back, and instructions on everyday movement sequences which place the least stress on the vertebral column. The influence of muscle forces in vitro on the stability of the motion segment has been demonstrated in our own study.

Moreover, gradual differences were demonstrated in the primary stability achieved by flexible and rigid instrumentation. Spondylodesis carried out in vivo with rigid stabilization results in a loss of segmental motion. The negative consequences of rigid stabilization include a lessening of the ability of the FSU to withstand strain [54], with a concomitant negative effect on osteogenesis [58]; excessive stress on the implant resulting in fracture [10]; and complications related to the ventral access to the vertebral column which is additionally necessary [46, 48]. These disadvantages can be eliminated by employing the technique of flexible stabilization with Graf ring bands. Clinical differences between patients treated by the preservation of function or by stiffening of FSU's should be expected in the symptom level, with more pronounced pain reduction achieved by fusion than by ligamentoplasty [2, 3].

When flexible dorsal implants are employed without vertebral fusion, there is no necessity for either an additional ventral procedure or for postoperative immobilization by a corset. Restoring the normal point of balance by lordosis-inducing pretensioning [21] presupposes sufficient dorsal decompression, since the width of the spinal canal and the neural foramina decreases with increasing lordosis [24].

Subjective assessments made on our own patient population indicate that dorso-ventral fusion and ligamentoplasty result in pain reduction of 90% and 60% [2, 3], respectively. Ligamentoplasty and dorsoventral fusion are thus apparently on different pain levels. For both ligamentoplasty and dorsoventral fusion, satisfactory relief of radicular pain and neurogenic deficits is attributable to adequate decompression of neurogenic structures [2, 3, 46, 47].

On the basis of empirical data, supplementary fusion is usually undertaken in conjunction with operative decompression performed in younger patients [33, 53]. In older patients, decompression is frequently performed without instrumented stabilization [18, 22], since these patients may not live long enough to suffer from the consequences of the resulting clinical instability. In light of the age structure of the population and the increasing morbidity of the older population [7], this strategy is urgently in need of revision. In older patients, in particular, degenerative disc disease is often present in addition to spinal stenosis, with the result that the predamaged intercorporal connection alone is not sufficient to maintain physiological alignment following laminectomy unless there is natural stiffening as a result of spondylophytes and narrowing of the intervertebral space caused by intervertebral disc degeneration. Instrumented stabilization by means of ligamentoplasty performed according to Graf's method apparently offers a viable alternative to decompression without fusion, in particular in patients with good muscles and a low degree of intervertebral disc degeneration.

The present biomechanical study in vitro has clinical relevance in that it demonstrates the various degrees of instability under different loading conditions following laminectomy. A stabilizing effect of coactivation of the deep intersegmental muscle forces was determined for intact, decompressed and semi-rigid instrumented FSUs in bending and rotation. The degree of segmental instability has to be taken into consideration in each individual case in regard to the extent of surgical decompression and the need for additional stabilization.

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REVIEWER'S COMMENT

The authors have performed an in vitro biomechanical study of the effect of laminectomy on the function of the lumbar spine. They found that ligamentoplasty corrected the instability created by a laminectomy. While the study has been well conducted and the results analyzed with care, some important comments must be made. First, the authors assume that in cases of central and/or lateral stenosis, the standard procedure is laminectomy. Although they are right in stating that "so far no consensus has been reached on how much of the vertebral structures should be removed," they still assume that complete laminectomy is the way to go and therefore applied that procedure in their experimental set-up. State-of-the-art decompressions, however, respect the vertebral arch, and only partial facetectomy is performed whenever possible. Complete laminectomy as described here is only seldom needed, and destabilization of the spine after decompression should certainly not be the rule. A second and perhaps even more specific criticism of the conclusions of this paper resides in the fact that only L4 laminectomy was performed. Most often decompression has to be performed at more than one level. To what extent the results with the laminoplasty as presented here can be extrapolated to a multilevel destabilization is unknown. The conclusion that "ligamentoplasty seems to be an alternative to decompression with spondylodesis" is therefore misleading. The authors should extend their experimentation to multilevel decompressions and combine the biomechanical study with a controlled, prospective trial comparing the different techniques in clinical practice.

R. Gunzburg
Eevwfeestkliniek, Harmoniestraat 68, B-2018 Antwerp, Belgium