TECHNIQUE ASSESSMENT

Immediate Stiffness of the C5–C6 Segment after Discectomy with the Cloward Technique: An in Vitro Biomechanical Study on a Human Cadaveric Model

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OBJECTIVE: To determine whether the Cloward technique of cervical discectomy and fusion increases immediate postoperative stiffness of single cervical motion segment after application of interbody dowel bone graft.

METHODS: We measured and compared the stiffness of single-motion segments in cadaveric cervical spines before and immediately after interbody fusion with the Cloward technique. Changes in range of motion and stiffness of the C5–C6 segment were measured in a bending flexibility test (flexion, extension, lateral bending and axial rotation) before and after a Cloward procedure in 11 fresh-frozen human cadaveric specimens from the 4th through the 7th vertebrae.

RESULTS: The Cloward procedure produced a statistically significant increase in stiffness of the operated segment in flexion and lateral bending when compared with the intact spine. The less stiff the segment before the operation, the greater the increase in its postoperative flexural stiffness (statistically significant). The Cloward procedure produced nonuniform changes in rotational and extensional stiffness that increased in some specimens and decreased in others.

CONCLUSION: Our data demonstrate that Cloward interbody fusion increases immediate postoperative stiffness of an operated segment only in flexion and lateral bending in cadaveric specimens in an in vitro environment. Thus, Cloward fusion seems a relatively ineffective method for increasing the stiffness of a construct. This may add to discussion on the use of spinal instrumentation and postoperative management of patients after cervical discectomy, which varies from bracing in hard collars through immobilization in soft collars to no external orthosis. (Neurosurgery 49:1399–1408, 2001)

Key words: Biomechanics, Cage, Cervical interbody fusion, Stability

In 1934, Mixter and Barr (28) correlated protrusion of the lumbar intervertebral disc with symptoms and signs of nerve root compression. Shortly thereafter, damage to the intervertebral discs of the cervical spine was recognized as an important cause of radicular symptoms and signs in the upper extremities. Since that time, the surgical management of cervical disc protrusions has undergone evolution from the posterior to the anterior approach (4, 16, 19, 24, 27, 37, 41). During the past 25 years, the anterior approach has become very popular; it is now the standard in spinal surgery and is associated with significant clinical success. Three common techniques of cervical interbody fusion described by Cloward (9–13), Bayley and Badgley (2), and Smith and Robinson (40) are currently in use in surgical practice. The Smith-Robinson and the Cloward techniques, which were developed in late 1950s and modified during the last four decades, are the most popular and widely used methods for cervical discectomy. Both have stood the test of time, although the Cloward procedure recently has fallen into disfavor among some neurosurgeons as a result of other alternatives available and the requirements for specific tools.

Many surgeons think that immediate postoperative stability after the Cloward or the Smith-Robinson procedure is sufficient to allow patients to recover without any bracing. Ralph Cloward, whose early patients wore cervical collars, later abandoned that practice (12). He thought that normal attitude head flexion without bracing was beneficial, because flexion compressed the anterior surface of the construct and enhanced vigorous vascularization and fusion. The majority surgeons instruct their patients to wear hard collars for at least 3 months during the postoperative period. Conversely, some surgeons willingly add anterior plating to interbody fusion in normal cervical discectomies (5, 6). We routinely place patients in hard collars for 8 weeks after cervical discectomy. On the other hand, we have noted successful clinical and radiological fusion in numerous patients who did not wear their collars, against surgeons' advice.

It is thought that the interbody graft of the Smith-Robinson technique is more rigid in side-to-side strain than the dowel or Cloward type of graft (39). In addition, the Smith-Robinson type of graft is thought to have greater distraction capabilities than the dowel graft (33). Much remains unknown so far regarding immediate postoperative stability after cervical discectomy and interbody fusion. The purpose of this study was to analyze the immediate stability of a single cervical segment after anterior interbody fusion with a dowel-shaped bone graft.

MATERIALS AND METHODS

Eleven cervical spine specimens from the 4th through 7th vertebrae were obtained from fresh human cadavers. All but two of the specimens were from men. The average age at the time of death was 59 years (range, 40–76 yr). The specimens were carefully dissected off surrounding muscle tissue, with care taken to preserve the integrity of the ligaments and intervertebral discs, and x-rays were then obtained of the specimens to exclude preexisting tumors or traumatic destruction. Information regarding osteophyte development and degenerative disease also was gathered from these x-rays. The C4–C5 and C6–C7 segments each were fixed with a pair of screws inserted vertically into vertebral bodies through the endplates so the C5–C6 segment was the only mobile segment. Next, x-rays were obtained of the specimens again to rule out conflict of the screws with the C5–C6 disc. The specimens were then deep frozen and stored at −20°C until the test. Before they were tested, the specimens were thawed to room temperature for at least 17 hours (*Fig. 1*).

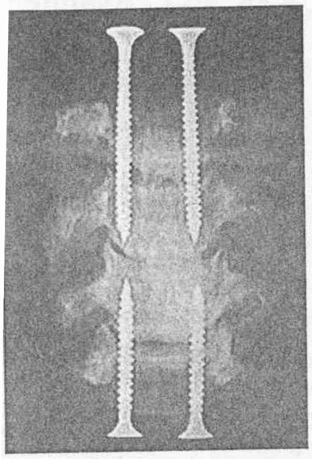

FIGURE 1. X-ray of a C4–C7 specimen prepared for biomechanical testing of the C5–C6 segment (antero posterior view). Two pairs of screws fix the C4–C5 and C6–C7 segments, and the C5–C6 segment remains mobile.

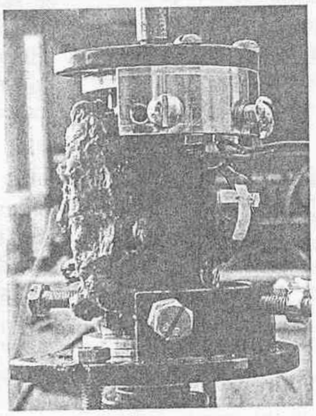

FIGURE 2. Photograph of a C4–C7 specimen mounted on the loading frame. The caudal end of the specimen is fixed with four bolts, and the top end remains free to allow unconstrained motions. Moments were applied to the upper free end of the specimen by means of a pulley attached to the upper clamp. The tensom eter spanned over the C5–C6 disc is attached with tiny screws to anterior surface of the C5 and C6 vertebral bodies.

Loading specimens

A special loading frame for testing specimens was designed and built in the laboratory of the Division of Automatics and Biomechanics, Technical University of Łódź. The lower end of each specimen was fixed in a loading frame, and the top end was allowed unconstrained motions. Rigid fixation of the lower end of each specimen was achieved by means of a special clamp with four bolts screwed into the vertebral body of the C7 vertebra (*Fig. 2*). Four pure bending moments of flexion, extension, right or left lateral bending, and right or left axial torque were applied to the upper free end of a specimen by use of pulleys. Each moment was generated by applying forces to the pulleys by means of 0.125-kg weights in equal increments to a maximum value of 1 kg for flexion, extension, and lateral bending and 2 kg for axial rotation. This resulted in incremental loading with bending moment/torque to a maximum value of approximately 1.2 to 1.3 Nm.

The moments were applied in three load-unload cycles to precondition the specimen with 30 seconds of creep allowed at each load step to reduce variations caused by viscoelasticity of the spinal ligaments.

Measurements of displacement

The motions of the C5 vertebra were calculated relative to the C6 and separately for flexion, extension, lateral bending, and axial rotation. For flexion, extension, and lateral bending, displacements were measured by use of a tensometer and calculated in millimeters. The tensometer was spanned over the C5–C6 interspace and secured to adjacent vertebral bodies of the C5–C6 segment with small screws (*Fig. 2*). Axial rotation was measured with a micrometer and calculated in degrees. The tip of the piston of the micrometer was positioned against the superior facet of the C4 vertebra. The sequence of loading was flexion followed by extension, lateral bending, and axial rotation. Each spine was first tested intact to provide a control for subsequent postoperative configuration.

The stability was assessed by measuring changes in range of motion and then depicted as stiffness, which is the ratio of maximum load applied (in Nm) to displacement (in mm or degrees) produced by this load. Thus, the stiffness was expressed in Nm/mm or Nm/degrees for each specimen. To provide a quantitative comparison between the intact and the operated segment, the after parameter was calculated. For each operated segment, stiffness was expressed in relative terms with respect to the stiffness of the same segment before the operation. Therefore, each specimen served as its own control. Relative stiffness thus was defined in the following manner:

$$\text{Relative stiffness (\%)} = (\text{stiffness}_{\text{Operated}} - \text{stiffness}_{\text{Intact}}) \times 100$$

A zero value means that the operated segment was as stable as before the operation. A negative value (<0) means that the operated segment was less stable than before the operation, and a positive value (>0) indicates that operated segment was more stable as compared with preoperative status.

Surgical technique

A 12.5 mm drill bit (Aesculap Instruments Corp., South San Francisco, CA) was used to drill the hole within the C5–C6 interspace. When necessary, anterior osteophytes and bony bridges were removed to enable drilling. Integrity of the posterior longitudinal ligament always was explored, and it was cut and excised with rongeurs when found intact underneath the hole. The 13.5-mm dowel bone graft harvested from the iliac crest of the same cadaver as the spine specimen was tapped in place, and care was taken to countersink the graft in relation to the anterior cortical edges of the intervertebral aperture. When the operation was completed, the tensometer was fixed again and the specimen underwent the same sequence of loading.

RESULTS

Results from 11 fresh cadaveric specimens before and after discectomy and fusion with the Cloward technique are presented herein as relative changes in stiffness.

Flexion

All but two operated specimens increased their stiffness (*Fig. 3*). The increase in stiffness varied from 3.5% up to 195% (*Table 1*). Two specimens (Specimens 6 and 13) decreased their stiffness postoperatively by 3.4% and 49%. A close look into those specimens revealed: 1) advanced degenerative changes with severe osteophyte formations, particularly at the C5–C6 level, as observed on plain x-rays, and 2) significant preoperative stiffness.

Those two specimens were excluded initially from statistical analysis because of their abnormally high preoperative stiffness. A decrease in stiffness in those two specimens did not seem to affect stability negatively at operated segments. Both excluded specimens with reduction of stiffness from abnormally high values preoperatively to values still high postoperatively. When expressed in absolute values, their postoperative stiffness far exceeded the stiffness of normal intact specimens and still seemed high as compared with postoperative stiffness of the remaining specimens (*Table 1*). Therefore, the postoperative biomechanical situation was similar in a group of "normal" and excluded specimens, although the latter decreased and the former increased their stiffness. As demonstrated in our study, very stiff segments may demonstrate decreased postoperative stiffness after the Cloward

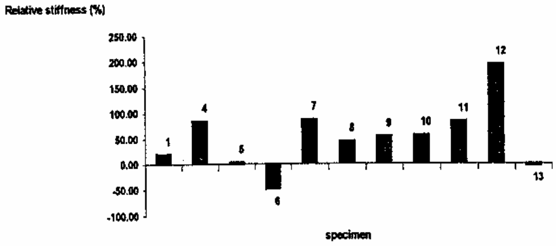

FIGURE 3. Flexion loading showing the ratio of increase in stiffness postoperatively (relative stiffness). Increases ranged from 3.5 to 195% of preoperative value. The ratio of increase seemed larger in specimens that were less stiff before operation. Stiffer specimens demonstrated a smaller ratio of increase postoperatively. Specimens 6 and 13 decreased their stiffness postoperatively. Those two specimens were extremely stiff before the operation, and advanced degenerative changes were observed on plain x-rays.

TABLE 1. Flexion Loading Test[a]

Specimen No.	Preoperative Stiffness (Nm/mm)	Postoperative Stiffness (Nm/mm)	Change in Stiffness (%)
1	1.05	1.26	20.00
4	0.53	0.98	84.91
5	0.84	0.87	3.57
6	2.11	1.06	−49.76
7	0.72	1.35	87.50
8	0.89	1.29	44.94
9	1.02	1.57	53.92
10	0.79	1.24	56.96
11	1.41	2.58	82.98
12	0.69	2.03	194.20
13	1.18	1.14	−3.39

[a] Stiffness of the C5–C6 segment before and after the Cloward procedure. Changes in stiffness showed as the percentage increase in preoperative stiffness of the intact specimen. (The intact specimen served as a comparison for the postoperative construct.) Negative values represent decrease in stiffness of the C5–C6 segment after the operation.

procedure, although this does not necessarily indicate destabilization in clinical terms. We think that in such stiff specimens, comparative analysis of relative changes in stiffness may seem misleading. Unless absolute values are taken into consideration, relative decrease in stiffness may be wrongly interpreted as relevant to spinal stability.

Statistical analysis of results in a group of nine specimens demonstrated a significant increase in postoperative stiffness (paired Student's t test and signed-rank test; $P < 0.05$). Another noticeable fact is that the less stiff the segment before operation, the greater the relative increase in postoperative stiffness. This seemed statistically significant ($P < 0.05$) only for flexion (*Fig. 4*).

After critical review by an independent reviewer, we included two rejected specimens in the statistical analysis, concurring with the opinion that in clinical settings, many patients will have such highly stiff spines. Results from repeated analyses confirmed that the Cloward procedure significantly ($P < 0.05$) stiffens an operated segment under lateral bending but has no such an effect under extension and axial rotation. For flexion, repeated analysis did not confirm statistical significance of a stiffening effect of the Cloward procedure.

Lateral bending

All specimens but one demonstrated increased stiffness postoperatively (*Fig. 5; Table 2*). Specimen 13 (one of two that were extremely stiff preoperatively) did not demonstrate any change in stiffness. The increase in stiffness varied from 25% up to 250% of preoperative value. Similar to the flexion test result, this increase was statistically significant for both the group of 9 and all 11 specimens (paired Student's t test, signed-rank test; $P < 0.05$). The hypothesis that the less stiff the segment before the operation, the greater the increase in stiffness postoperatively was not proved by statistical analysis for lateral bending.

Extension

Cloward discectomy and fusion resulted in increased stiffness of the operated segment in four specimens, decreased

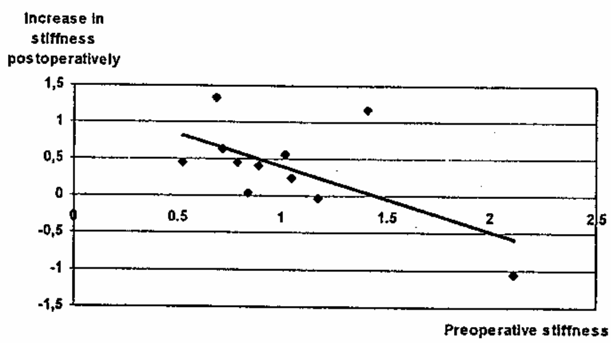

FIGURE 4. Correlation between preoperative flexural stiffness and the ratio of its increase postoperatively. The more stiff the segment before the operation, the greater the increase in its stiffness after the Cloward procedure. This proved statistically significant ($P < 0.05$).

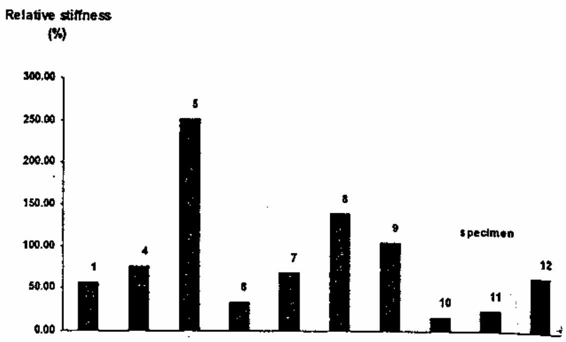

FIGURE 5. Lateral bending loading test showing the percentage increase in stiffness postoperatively. The increase rated from 0 to 252% of preoperative value. Specimen 13 did not change its stiffness postoperatively. The ratio of increase seemed larger in specimens that were less stiff before the operation. Specimens with greater preoperative stiffness demonstrated a smaller ratio of increase in their stiffness postoperatively. However, this was not proved statistically significant.

TABLE 2. Lateral Bending Loading Test[a]

Specimen No.	Preoperative Stiffness (Nm/mm)	Postoperative Stiffness (Nm/mm)	Change in Stiffness (%)
1	0.81	1.27	56.79
4	0.84	1.48	76.19
5	0.56	1.97	251.79
6	1.98	2.64	33.33
7	0.71	1.2	69.01
8	0.76	1.82	139.47
9	0.81	1.66	104.94
10	0.66	0.77	16.67
11	1.24	1.55	25.00
12	1.41	2.32	64.54
13	4.71	4.71	0.00

[a] Stiffness of the C5–C6 segment before and after the Cloward procedure. Changes in stiffness showed as the percentage increase of preoperative stiffness of the intact specimen. (The intact specimen served as a comparison for the postoperative construct.) Negative values represent decrease in stiffness of the C5–C6 segment after operation.

stiffness in five, and no change in two (*Fig. 6; Table 3*). There was no trend in changes of postoperative stiffness for extension, regardless of whether two highly degenerated specimens were included in the analyzed group.

Axial rotation

Results were similar to those obtained for extension. [illegible] specimens demonstrated an increase, one demonstrated [illegible]

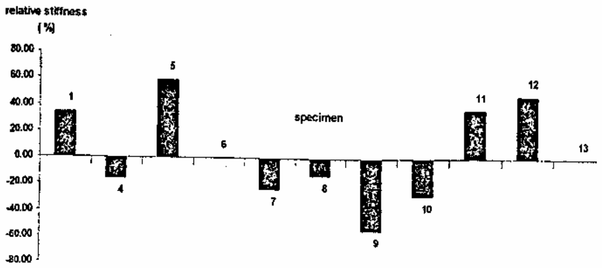

FIGURE 6. Extension loading test showing the increase in stiffness postoperatively, which rated from 34 to 58% of preoperative value. Two specimens demonstrated no change in stiffness postoperatively. Five specimens demonstrated decreased stiffness postoperatively (from 16% to 55% of preoperative value).

TABLE 3. Extension Loading[a]

Specimen No.	Preoperative Stiffness (Nm/mm)	Postoperative Stiffness (Nm/mm)	Change in Stiffness (in %)
1	0.87	1.17	34.48
4	0.98	0.82	−16.33
5	0.89	1.41	58.43
6	2.11	2.11	0.00
7	2.03	1.55	−23.65
8	1.15	1	−13.04
9	1.85	0.83	−55.14
10	1.03	0.74	−28.16
11	2.07	2.82	36.23
12	1.3	1.91	46.92
13	1	1	0.00

[a] Stiffness of the C5–C6 segment before and after the Cloward procedure. Four specimens increased in stiffness postoperatively between 34% and 58% of their preoperative value. Two specimens did not change stiffness postoperatively. Five specimens decreased in stiffness postoperatively (from 16% to 55% of their preoperative value).

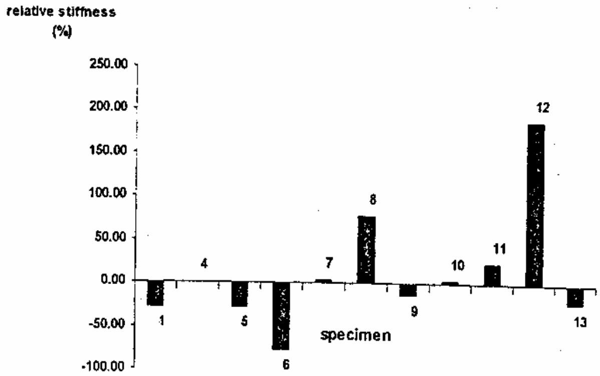

FIGURE 7. Axial rotation loading test. The increase in stiffness postoperatively rated from 3 to 190% of preoperative value. One specimen demonstrated no change in stiffness postoperatively. Five specimens demonstrated decreased stiffness postoperatively (from 21% to 77% of preoperative value).

TABLE 4. Torsion Loading Test[a]

Specimen No.	Preoperative Stiffness (Nm/degree)	Postoperative Stiffness (Nm/degree)	Change in Stiffness (%)
1	0.87	0.63	−27.59
4	0.29	0.29	0.00
5	0.87	0.63	−27.59
6	1.9	0.44	−76.84
7	0.33	0.34	3.03
8	0.18	0.32	77.78
9	0.55	0.48	−12.73
10	0.31	0.32	3.23
11	0.37	0.46	24.32
12	0.47	1.36	189.36
13	0.28	0.22	−21.43

[a] Stiffness of the C5–C6 segment before and after the Cloward procedure. Five specimens increased their stiffness postoperatively (the ratio of increase was between 3% and 190% of preoperative stiffness). One specimen did not change stiffness postoperatively. Five specimens decreased in stiffness postoperatively (from 21% to 77% of preoperative value).

change, and the remaining five demonstrated a decrease in postoperative stiffness (*Fig. 7*; *Table 4*). Again there was no trend in changes in postoperative stiffness.

DISCUSSION

Much discussion devoted to the biomechanics of interbody fusion can be found in the past and current literature. The majority of reports deal with lumbar rather than cervical arthrodesis. Even when devoted to cervical interbody fusion, those reports focus on the biomechanics of interbody fusion in the sense of clinical and radiographic proof of stability. In addition, they analyze the effects of fusion from a long-term perspective when bony remodeling and healing is completed (8, 17, 29, 30, 42). Little is known regarding immediate postoperative biomechanical environment at the fusion site from either a clinical or an experimental point of view.

In vitro biomechanical studies on immediate stability of a cervical spine after discectomy and graft insertion are poorly represented in the literature. We found only one study that addressed this problem in biomechanical testing in vitro on a cadaveric human spine model (38). However, this study, which was reported in 1989 by Schulte et al. (38), refers to the

Robinson-Smith technique. The few remaining studies on this issue are based on mathematical evaluation, which uses finite element models (FEMs) of the cervical spine for investigation (23, 25, 32, 36). To our knowledge, no in vitro biomechanical studies on immediate stiffness of the human cervical spine after the Cloward procedure have been published to date. Therefore, we attempted to determine the immediate effect of a Cloward bone graft on the stability of the cervical motion segment in an vitro biomechanical experiment.

The only study that may serve as direct comparison and reference is that by Schulte et al. (38). They described immediate biomechanical stability of the C5–C6 segment after discectomy and grafting with the Robinson-Smith technique. In their study, the specimen was tested in the intact state, after discectomy, after insertion of tricortical bone graft, and then after application of an anterior metal plate at the discectomized segment. Insertion of the Robinson-Smith graft resulted in a significant increase of stiffness in all loading modes, particularly in extension (decrease in motion of 45% as compared with the intact state). Similar reduction of motion after insertion of bone graft was observed in lateral bending (38%) and axial rotation (39%). Smaller reductions in motion were noted for flexion (16%). Data from this study may suggest that the Robinson-Smith technique stiffens the cervical motion segment more effectively than the Cloward technique. Schulte et al. (38) obtained reduction in motion in all four critical motions, whereas in the present study, reduction was observed only in flexion and lateral bending. Thus, the horseshoe bone graft interposed between intact endplates seems more effective in stiffening a discectomized segment than a cylindrical Cloward graft tapped between spongy bone of adjacent vertebrae. When comparing results of both studies, one should keep in mind some differences between their methodologies. In contrast to Schulte et al. (38), we: 1) cut the posterior longitudinal ligament, because this often becomes necessary in intraoperative situations in patients with posterior disc prolapse or osteophytes deeply invading vertebral canal, 2) loaded the specimen to a more maximum moment (1.2 Nm as compared with 0.45 Nm), and 3) used C4–C7 specimens compared with C2–T1 specimens.

We are not aware of any other in vitro studies that could serve as comparison and verification of the work of Schulte et al. (38) as well as of the present study. There are reports in the literature on FEM studies that address changes in stiffness after cervical discectomy and fusion (23, 25, 32, 36). These studies could serve for reference and comparison to in vitro investigations, although these are rather mathematical simulations that still require validation by experimental tests (22, 36). All FEM studies on stiffness after anterior cervical fusion that we found in the literature refer only to the Robinson-Smith technique (23, 25, 32, 36). Of these studies, one addresses the immediate postoperative stiffness (32), whereas three studies address stiffness at fused (healed) segments (23, 25).

In the first of the above-mentioned studies, Natarajan et al. (32) developed a mathematical model of intact and discectomized C5–C6 segments with loose- and tight-fitting grafts to investigate the biomechanical effect of the Robinson-Smith procedure. The loose-fitting graft model simulated the immediate postoperative situation, and the tight-fitting graft model simulated healed fusion. The model representing the immediate postoperative period predicted increased stiffness in only flexion and lateral bending and decreased stiffness under extensional and torsional moments. Predictions calculated by these authors somewhat contrast results obtained in vitro by Schulte et al. (38) (reduction in all four critical motions). Results of the present in vitro study are similar to the mathematical predictions of Natarajan et al. (32), in that we also obtained significant reduction of motion in only flexion and lateral bending. Another mathematical simulation of the biomechanical effect of the Robinson-Smith technique was performed by Maiman et al. (25). These authors predicted increased stiffness in all four motions at the operated segment. Data from their study are consistent with those obtained in vitro by Schulte et al. (38), although it should be remembered that Maiman et al. (25) analyzed the stiffness of the healed segment. They used an anatomically accurate, experimentally validated two-motion segment FEM (C4–C5–C6) of the human cervical spine. These authors proved an increase of stiffness for both the C5–C6 and the C4–C6 segments after not only the Robinson-Smith but also the Bailey-Badgley techniques. Although their work was focused on internal responses (stresses) of motion segments adjacent to the fused level, the evaluation of stiffness at the fused segment was a component of their investigation. A similar evaluation was performed by Kumaresan et al. (23) on a validated three-dimensional, anatomically accurate FEM of the human cervical spine. We investigated stiffness of different types of interbody fusion materials (titanium core, titanium cage, tricortical iliac crest, tantalum core, and tantalum cage) after Smith-Robinson and Bailey-Badgley procedures. Predictions from the Kumaresan et al. (23) study also confirmed an increase in external response under all modes of loading after both Robinson-Smith and Bailey-Badgley techniques.

Comparison of in vitro results with predictions of mathematical simulation should be made with caution, as mathematical models have inherent limitations (36). For example, the material properties of various spinal structures used in mathematical models are obtained from the literature, although it should be remembered that they vary from individual to individual. Limitations of mathematical models were quantified in a study by Pitzen et al. (36), who verified their FEM of C5–C6 anterior cervical fusion and plating with a biomechanical in vitro study on a human cadaveric model. The predictions of their FEM were always within one standard deviation of the results of the in vitro study (36). Thus, results of mathematical models should be interpreted as a trend, and the limitations of these models should be kept in mind (36).

Additional references to the present study are the results of in vitro investigations on the biomechanical effects of artificial interbody implants (21, 36, 44, 45). In view of the rapid development and increasing use of cervical interbody implants, referred to as cages, results of such a comparison would be of great importance for clinicians, providing them with treatment recommendations (3, 26). They were designed to overcome the drawbacks of standard interbody fusion with a stand-alone bone graft. In 1988, Bagby (1) reported the use of a stainless steel basket for spinal fusion. He developed smooth stainless steel cylinders with multiple holes drilled through their walls, describing them as baskets. The use of these implants was based on the experience of DeBowes et al. (15) in horse cervical spine fusion for wobblers syndrome. Interbody implants for cervical spine were developed and introduced recently in clinical practice. These internal fixation devices were designed primarily to bear loading during graft incorporation. They also were designed as spacers to restore and maintain the physiological disc space and as stabilizing devices to limit intervertebral motions and allow bony ingrowth at the same time. The majority of these devices are designed to match the interspace as does the Robinson-Smith bone graft. The design of others, like BAK/C cage (Spine-Tech, Inc., Minneapolis, MN), follows the idea of the Cloward dowel-shaped bone graft. A profusion of such implants is now commercially available and used in surgical practice. Many underwent in vitro biomechanical evaluation in either individual or comparative studies (21, 44, 45). We are not aware of any in vitro studies comparing biomechanical performance of artificial cervical interbody implants to traditional interbody bone grafts. Data from in vitro studies on biomechanical effect of cervical cages seem to prove their excellent performance as stabilizing devices. Recent clinical trials and reviews also confirm their excellent biomechanical features in ratio of successful fusion and maintenance of disc height (3, 26). In vitro biomechanical investigations have demonstrated that regardless of their design, cervical cages increase immediate stiffness in all four critical motions (21). It is interesting that cages shaped like the Robinson-Smith bone graft (flat and horseshoe shaped) are characterized by better in vitro biomechanical performance than those shaped like the Cloward graft (cylindrical and dowel shaped) (21). The former increased immediate stiffness more than the latter, as was demonstrated in studies by Kettler et al. (21) and Wilke et al. (44), although these differences did not seem statistically significant.

These findings might add to the discussion on comparison of immediate postoperative stiffness after Robinson-Smith and Cloward procedures with the use of bone graft. On the basis of data from the above-mentioned studies on the stabilizing effect of various types of cervical cages, one might conclude that the Robinson-Smith technique is more effective than the Cloward method in stabilizing the spine immediately after an operation. This could be in agreement with a parallel comparison between the present study and the in vitro study by Schulte et al. (38).

The important question arises regarding stiffness of the bone-grafted segment in the early and later postoperative period before complete healing of fusion occurs. Immediate postoperative stiffness describes the initial biomechanical situation at a fusion site, and as such it is important in the early postoperative period to ensure stability and prevent bone graft migration. This immediate stability at the grafted segment changes with time along with increasing subsidence of the bone graft, bony resorption, osteogenesis, and remodeling, which last as long as healing continues to complete fusion. Stiffness is influenced first by the subsidence of bone graft into adjacent vertebral bodies and second by processes of resorption and osteogenesis. Within the first days after surgery, the segment undergoes transient destabilization because of subsidence of the graft into adjacent vertebral bodies. Decreasing distraction height might destabilize the construct with a cylindrical-shaped bone graft but might also have a stabilizing effect by improving the fit at the graft-adjacent bodies' interface. Immediate stiffness decreases until the graft achieves such a degree of subsidence that the better fit at the graft-adjacent bodies' interface starts to stiffen the segment.

Whether this loss in stability exceeds the increase of stiffness gained immediately after graft insertion is an important question. Another question is whether the loss of stiffness that results from small subsidence can be reversed completely by continued larger subsidence. We are not aware of any studies investigating the effect of subsidence of Cloward bone graft on stiffness of the operated segment.

The present study demonstrated that Cloward interbody bone grafting resulted in a statistically significant increase of immediate segmental stiffness in flexion and lateral bending in an in vitro condition. In addition, statistical analysis proved that the less the initial flexural stiffness, the greater its increase after insertion of the dowel bone graft. The extensional stiffness and rotational stiffness were not uniformly affected by the Cloward procedure. This study confirms that tapping the dowel bone graft results in increased segmental stiffness in only two of four critical motions (flexion and lateral bending). How long the reduction of intersegmental motion lasts beyond the initial values is unknown. It might be that with resorption and remodeling of a graft and bone of adjacent vertebral bodies, the initially increased stiffness may gradually reduce until fusion occurs. It may also be that with increasing subsidence of a Cloward bone graft, the segmental stiffness increases again because of a better fit between the graft and the adjacent vertebral bodies. This study lacks the closer look into the biomechanical environment at the grafted segment that could be obtained with assessment of changes in the neutral zone. Although changes in total range of motion are indicators of stability, the neutral zone was proved to be the more sensitive and indicative in assessment of instability (34, 35). Another shortcoming of the study is the relatively short series of specimens and its limitation to cases with slight to moderate degeneration. The issue that deserves separate investigation is the biomechanical behavior of highly degenerated segments immediately after discectomy and interbody grafting. Two specimens with advanced degenerative changes and osteophyte formations decreased their stiffness after the Cloward procedure. Such specimens cannot be included in the analysis, because extremely advanced degenerative changes rendered them even stiffer than were the remaining specimens after the graft was tapped. The same approach was presented by Schulte et al. (38) in their similar study. They also excluded highly degenerated specimens from analysis. Although in our study, highly degenerated segments decreased their postoperative stiffness, the absolute values of their postoperative stiffness were still high and comparable to the postoperative values of the remaining specimens.

This study demonstrated that the Cloward construct is not very effective mechanically, but no one should disregard its clinical merit. We think that in some cases of one-level fusion, it remains a valuable surgical technique to achieve good clinical outcome. This technique has obvious advantages that mitigate its biomechanical drawbacks. Compared with the Robinson-Smith technique, it increases the space available while the surgeon is performing the disc debridement and visualizing the joints of Luschka and neural foramina. This technique allows the surgeon to perform especially severe osteophyte removal. For that reason, we prefer the Cloward technique in cases of advanced osteophyte formations, in which removal of osteophytes is more feasible and effective. In a soft disc, we prefer the Robinson-Smith technique. Clinical practice proves that in the majority of cases, segmental stiffness after the Cloward procedure seems to be sufficient to achieve solid bony union, especially in one-level fusions. Clinical outcomes of anterior cervical decompression and fusion are very good (12, 18, 20, 24, 31). This includes the Cloward procedure. Cloward (12) reported a 97% fusion rate with a good clinical result (relief of preoperative symptoms) in 94% of operated patients. In a recent report, Lofgren et al. (24) demonstrated an 86% fusion rate after the one-level Cloward procedure, with considerable clinical improvement in 61% of patients regardless of preoperative symptoms (radiculopathy and myelopathy).

Two facts are worthy of note: 1) good clinical results after interbody fusion do not necessarily correlate with preservation of height of the disc space, and 2) narrowing of the fused segment during the first postoperative months does not necessarily have a negative influence on good clinical results achieved immediately after surgery. Even the quality of fusion measured as segmental stability sometimes has nothing to do with good clinical results. The long-term analysis of interbody fusion after the Cloward procedure revealed that clinical results were not influenced by whether the surgically treated segment was mobile, regardless of pain in either the neck or the arm (24). Even considerable mobility as observed on dynamic x-rays may be consistent with good clinical results (24), although other studies demonstrated a clear association between bony union and a better clinical outcome (7, 43). In a study by Cauthen et al. (7), 80% of patients without segmental mobility had a satisfactory outcome as compared with 68% in the nonunion group. White et al. (43) demonstrated 73% excellent or good results in the group with union as compared with 53% in the group with nonunion. Conversely, clinical outcome with cervical cages seems to exceed that obtained with traditional bone graft in symptom relief and absence of subsidence (nearly 100% of patients had no recurrent symptoms and no subsidence) (3, 26). In this context, cervical cages seem an equal or even better alternative for traditional bone graft fusion including the Cloward technique. Interbody instrumentation of the cervical spine with cages has become a clinically established and increasingly popular procedure, but nonetheless, the long-term outcome associated with interbody fusion cages is still unknown. In cases of multilevel fusion, the Cloward procedure does not seem to be a reliable technique. The fusion rate was found to be inversely proportional to the number of levels fused. Connolly et al. (14) demonstrated a pseudoarthrosis rate of 15% for one- or two-level fusion and 46% for three-level fusion with the Cloward graft. Similar outcomes have been obtained with the Robinson-Smith technique. White et al. (43) reported an 80% fusion rate for one-level fusion and a 66% fusion rate for multilevel fusion. With such results, complementary stabilization with anterior plates seems justified. As demonstrated by Caspar et al. (6), adding a cervical plate to two- or even one-level fusion does not constitute overtreatment; it supplements the internal stabilization initially provided by the bone graft and yields a lower reoperation rate. In our experience, anterior plating with Cloward fusion is technically more demanding than with Robinson-Smith fusion. This is because drilling the interspace sometimes leaves too little space in the adjacent vertebral bodies to accommodate screws. Therefore, when we plan stabilization with an anterior plate, we prefer to use Robinson-Smith fusion. Another disadvantage of the Cloward technique is the extra blood loss from exposure of the cancellous bone of the vertebral bodies with resulting impaired visualization, difficulties with application of screws if stabilization with a cervical plate is required, and the extensive exposure of the iliac crest needed to collect the bicortical graft.

Our recommendation is that for one-level fusion, the Cloward procedure may be used without support of stabilization. One should realize, however, that this technique increases immediate postoperative stiffness only in two critical motions, and it is not known whether the increase gained in stiffness is lost during the further postoperative period. We would advise use of the Cloward technique in patients with advanced degenerative changes and severe bony spurs. One-level fusion with artificial dowel-shaped cages seems to be a good alternative to Cloward bone graft, especially implants such as the BAK/C, which have demonstrated biomechanical performance in in vitro studies. It should be remembered, however, that Cloward-like cervical cages subside more than horseshoe-shaped cages with their resultant decrease of gained increase in stiffness, loss of gained disc height, and kyphotic angulation at the affected segment (21). Because of this, horseshoe-shaped cages probably would be better alternatives than cylindrical cages, because the former are characterized by a minor degree of subsidence into adjacent vertebral bodies. Two- and three-level fusion with the Cloward technique may require plate stabilization because the fusion ratio may be unacceptable. Anterior plating with Cloward fusion is difficult, however, or not feasible because of problems accommodating screws in adjacent vertebral bodies. In such cases, we advise consideration of the Robinson-Smith technique. Analysis of the clinical and biomechanical effects of multilevel cervical cage fusion requires experimental studies and clinical trials.

CONCLUSION

This experimental study evaluated the immediate stiffness of C5–C6 motion segment after the Cloward procedure by use of an in vitro human cadaveric model in which four major planes of loading flexion, extension, lateral bending, and axial rotation were reproduced. The Cloward procedure increases immediate postoperative stiffness in only two of four critical motions. Therefore, it is a relatively ineffective method for increasing the immediate postoperative stiffness of a discectomized cervical motion segment.

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COMMENTS

Maciejczak et al. have provided an interesting biomechanical analysis of the stiffness of a single motion segment of the cervical spine after fusion by use of the Cloward technique. Although this experiment would have been particularly interesting had the Smith-Robinson technique been compared directly with the Cloward technique, comparison with the study by Schulte et al. (1), which did analyze the Smith-Robinson technique, provides interesting information. Whereas the Cloward technique as used by the authors demonstrated stiffness only in flexion extension, the Smith-Robinson technique, as used by Schulte et al., increased stiffness in all four motion directions. This is probably one of the reasons why the Smith-Robinson technique has widely replaced Cloward technique for anterior cervical fusion.

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1. Schulte K, Clark CR, Goel VK: Kinematics of the cervical spine following discectomy and stabilization. **Spine** 14:1116–1121, 1989.

The authors have performed a valuable service in revisiting the Cloward technique. One of the earliest means of providing interbody fusion in the cervical spine, it has stood the test of time. It has fallen into disfavor recently in a number of circles, simply because of other alternatives available and the requirement for specific tools. In addition, some have thought that the ability to remove osteophytes laterally is impaired by the focus of this technique on the central aspect of the disc.

As the authors have demonstrated, the Cloward procedure seems to stiffen the cervical spine in two directions, even when a simple bone graft is used without plating. This is in no part caused by distraction provided before graft placement. The Cloward procedure is somewhat less effective in stiffening the spine than other types of fusion, such as the Smith-Robinson technique, particularly when plating is used. The question becomes, however, how much is enough? Certainly the data from this article as well as from others suggest that we may be stiffening the spine more than necessary to promote bone healing. That is undesirable, as we have pointed out (1, 2). Overstiffening beyond what is necessary may not only lead to bone cell death, but more importantly, it may precipitate adjacent segment instability.

The authors' finding should lead us to be concerned regarding the widespread use of titanium plating for single-level procedures, if the amount of stiffening provided is that suggested by the authors. The new trend toward cervical interbody cages is of even more concern than plates. The latter can hardly be justified biomechanically on the basis of the present data. This study provides valuable biomechanical information as we consider rational treatment methods for cervical disc disease.

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1. Kumaresan S, Khouphongsy P, Stemper B, Daruwala D, Cheng J, Pintar FA, Yoganandan N, Maiman DJ: Development of biomechanically analogous cervical spine physical model. **BED Adv Bioeng** 39:155–156, 1998.
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Maciejczak et al. have used their laboratory to address their clinical question regarding the need for a rigid orthosis after Cloward cervical decompression and fusion. The experimental design is sound, although fatigue testing was not performed. The authors report an increase in immediate segmental stiffness in flexion and lateral bending. No significant change in stiffness was detected in extension or lateral bending.

Two specimens that were extremely stiff initially experienced a decrease in flexion stiffness with the Cloward procedure. The authors suggest that the less stiff the segment before surgery, the greater the relative increase in stiffness after surgery. This will not always be true. The increase in segmental stiffness is at least partially dependent on tensioning of the surrounding ligaments. If this is not competent, one would not expect either the Cloward or the Smith-Robinson type procedure to improve the stability of the segment. I predict the segment would be further weakened by the need to incise the anterior anulus.

I concur with the authors' recommendation that in the normal situation, a cervical collar is not needed postoperatively after a one-level Cloward procedure. I do not agree with the extrapolation of their findings and speculation that cylindrical cages will be more stable. They present no data to support this claim.

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