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Biomechanical evaluation of two cervical spine stabilization systems

JANUSZ POPKO, PAWEŁ SZEPAROWICZ

Department of Pediatric Orthopaedics and Traumatology, Medical Academy in Białystok, ul. Waszyngtona 17,15-274 Białystok, Poland

EUGENIUSZ SAJEWICZ, JAROSŁAW SIDUN

Białystok University of Technology, Mechanical Faculty, ul. Wiejska 45l, 15-351 Białystok, Poland

ANDRZEJ CZUŻ

Department of Orthopaedics, District General Hospital, ul. Skłodowskiej 26, 15-950 Białystok, Poland

PIOTR MAJCHER

Department of Rehabilitation, Medical Academy in Lublin, ul. Janczewskiego 8, 20-950 Lublin, Poland

In our paper, we wanted to compare biomechanical effectiveness of the Romadier–Bombart wire stabilization with the Martin hook and rod stabilization. We used 8 human spine specimens and we measured linear and angular displacements under loading, using an Instron testing machine. By applying force in three different positions we simulated extension, flexion, and lateral bending of the specimens. The results of our experiment show that both methods give sufficient and comparable stabilization. We suggest that in clinical practice, because of the technical difficulty of the Romadier–Bombart method, the Martin system should be preferred as the safer.

Key words: cervical spine injury, stabilization, biomechanical evaluation

1. Introduction

Injuries of the cervical spine disrupting the spinal cord are among the most difficult problems in trauma surgery. Stabilization obtained due to anatomical reconstruction of the spinal canal provides the best conditions for regression of the neurological deficit, allowing early rehabilitation and help with nursing care [7]. Anterior stabilization of dislocations and fractures of the cervical spine, preferred by many authors, is not always justifiable. From a biomechanical point of view, anterior stabilization does not provide complete stabilization and does not insure against secondary dislocation due to graft protrusion or loosening of plate screws [2]. This can lead to complications like oesophageal fistula and lack of correction.

In his study, GUSTA [6] found that the use of anterior stabilization in posterior column cervical injuries provided worse stabilization and biomechanical effectiveness when compared with wire stabilization fixed on the arch and spinous process.

ULRICH et al. [14] found better stability of the injured segment after using wire stabilization fixed to an arch and the Magerl hook plate rather than anterior plate stabilization. One important benefit of anterior surgical approach is better tolerance, lower blood loss, and reduced surgical trauma for the patient.

The goal of our study, a continuation of our former research [3], is to compare the biomechanical effectiveness of wire stabilization and the Martin techniques of spinal stabilization.

2. Materials and methods

Our research was carried out on 8 cervical human spines (C2-Th1) collected from cadavers 1–3 days after death and frozen at –20 °C in plastic bags of double thickness. They were wrapped in cotton cloth soaked in 0.9 % NaCl. Prior to testing, the specimens were thawed to +5 °C and kept in moisture till the beginning of the experiment. The surrounding soft tissue and muscle were dissected off the cervical spines, with care being taken to preserve bone, spinal ligaments, articular capsules and intervertebral discs. The methods of experiment adopted by us have been previously used by PELKER et al. [8]. Local ethics committee approval was obtained for the study.

2.1. Biomechanical tests

Biomechanical tests were performed using an Instron testing machine (figure 1) in Białystok University of Technology. The outermost vertebrae were fixed to a jointing sleeve connected with a frame, especially designed for this experiment, which was fixed on the test machine. This fixing method allowed the application of axial, sagittal and frontal loadings to the specimen and left it unconstrained at the C2-Th1 levels which helped us to remain closer to the original physiological condition. A method for embedding outermost vertebrae used by some authors is adding additional constraints. Each specimen was subjected to the following tests:

- measurement of the intact cervical spine without any stabilization;

• measurement of the injured cervical spine with hook and rod stabilization (the Martin system);

• measurement of the cervical spine with wire stabilization (the Romadier–Bombart method).

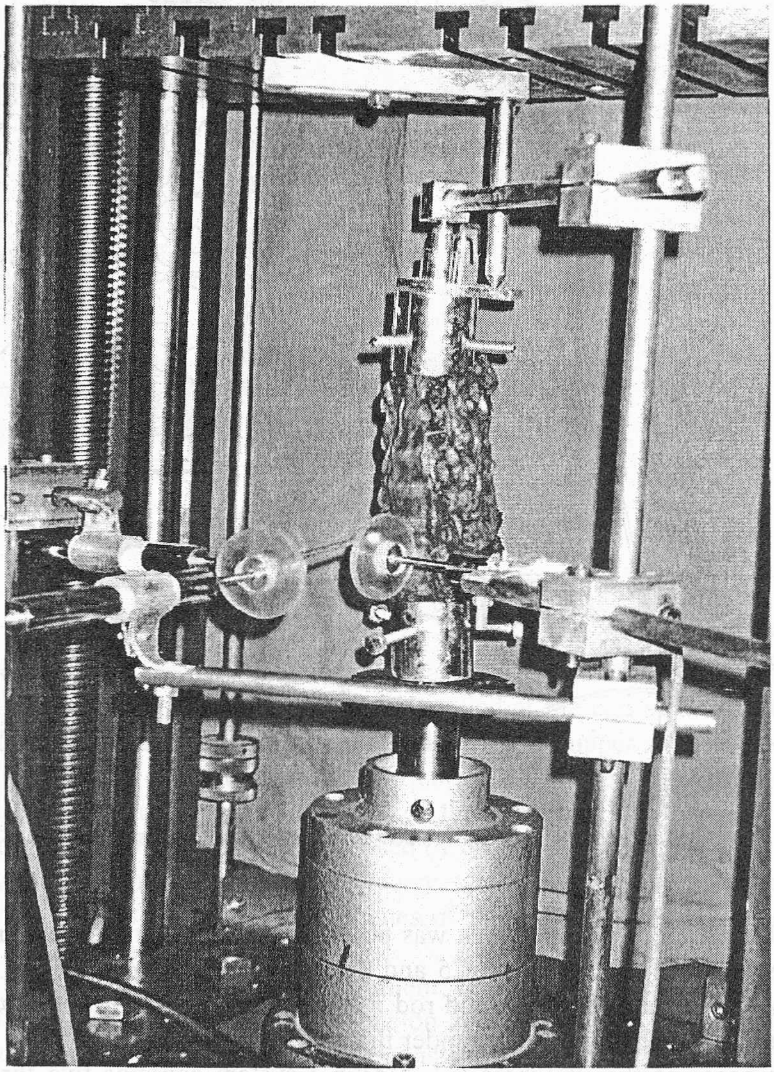

Fig. 1. The Instron testing machine

We then measured the lineal displacement and rotation angle of the cervical spine under loading (figure 2). The measurement of displacement within the injured cervical spine allowed us to compare wire stabilization (the Romadier–Bombart method) [9], [10] with hook and rod stabilization (the Martin system) in the same type of injury.

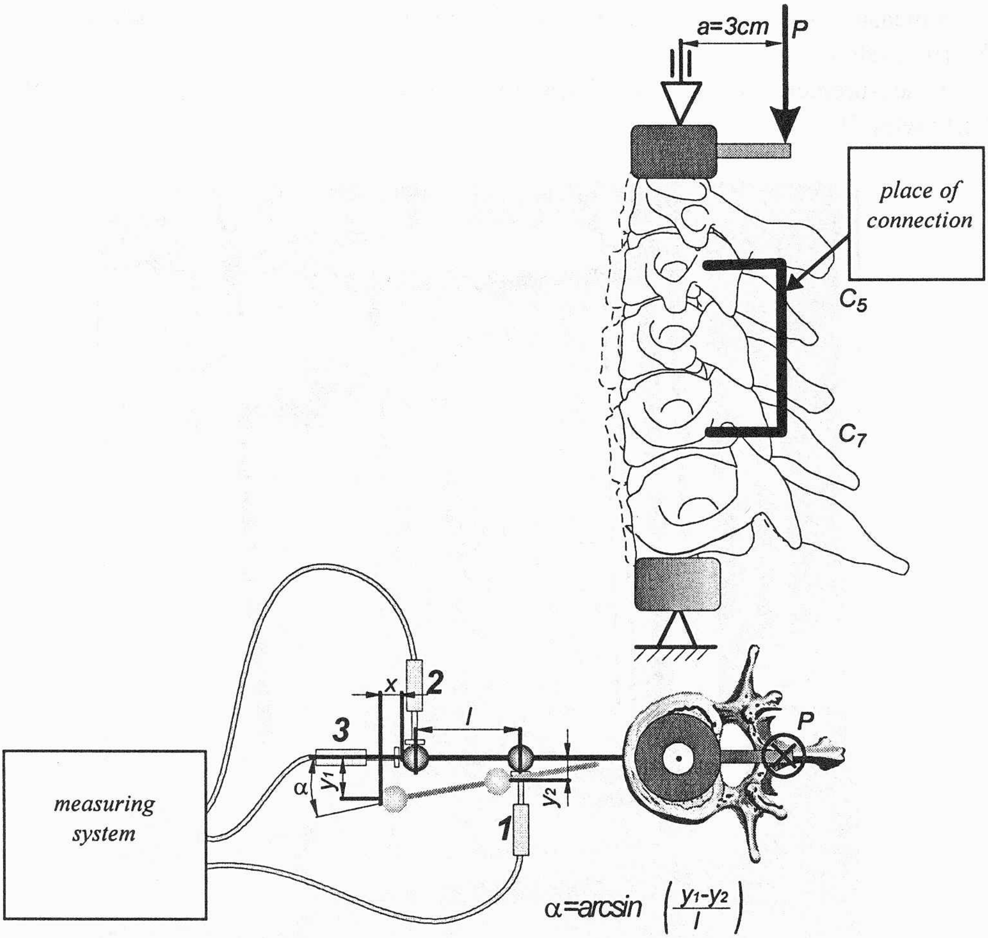

Fig. 2. Diagram of the measurement of linear and angular displacements

Destabilization of the specimen was performed by sectioning intervertebral disc and joints between the vertebrae C5 and C6 by scalpel. Section C5–C7 was stabilized either by wire or by hook and rod method. The wire was fixed (according to the Romadier–Bombard method) under the arch of the C5 vertebrae and around the spinous process of the vertebrae C7. Martin's system contains two threaded rods and two hooks with adjacent springs (figure 3) as described before [11]. Compression was made by placing hooks on the arches of the vertebrae C5 and C7. A similar method was used by SUTTERLIN [13]. Each specimen was tested with both stabilizing systems.

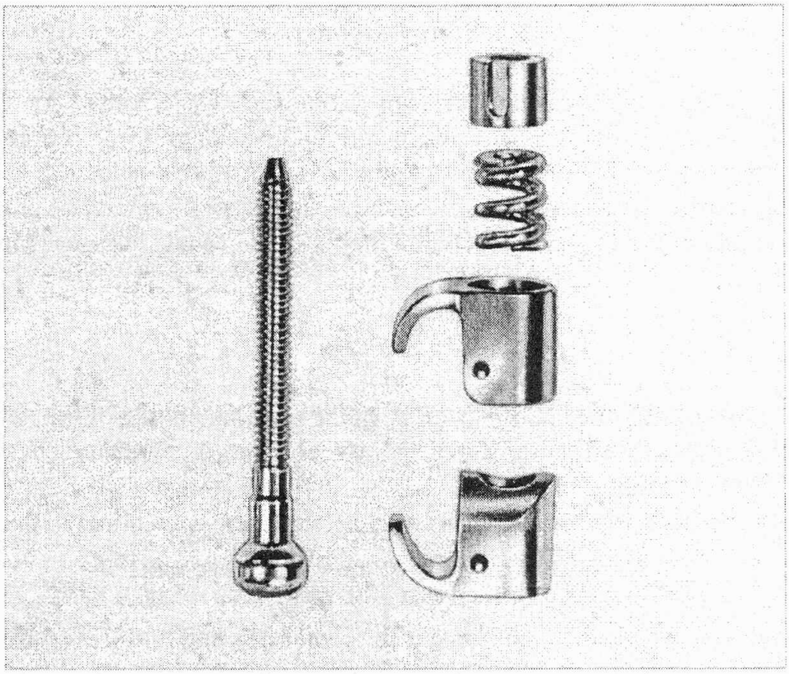

Fig. 3. The Martin system of stabilization

2.2. Measurement of displacement

In our experiment, we have measured linear displacement and the rotation angle under eccentric strain conditions. Force was applied at the end of a lever (of a constant length) connected with a jointing sleeve holding the upper side of the specimen 3 cm from the middle of the body of the vertebra C2. Different directions of the applied force caused squeezing and bending of the specimen (the bending moment). Similar experiment conditions have been used by other authors [5].

Initially the specimen was under 20 N force, which was gradually increased up to 100 N (in 20 N steps). The measured values of the bending moments were respectively 1.2, 1.8, 2.4 Nm.

Due to a lever with axial rotary movement, force could be applied in three different positions. We have measured extension and flexion (the sagittal plane) and lateral bending (the frontal plane), with constant cross-head displacement rate of 10 mm/min. A rigid rod with knobs was placed 0.5 cm below the superior surface of the vertebrae C6. The dislocations under strain were measured with 0.01 mm accuracy in a horizontal plane, by means of inductive sensors with resting devices connected with the knobs.

The value rotation angle was calculated from formula $\alpha = \arcsin(y_1 - y_2)/1$ according to three measuring devices.

2.3. Statistical analysis

Statistical analysis was carried out using a Statistica for Windows by StatSoft. In each group, mean value, standard deviation and standard error were measured. A *t*-student test was used to analyze the results of both methods at 1.8 Nm bending moment, which seemed to be the most representative (it has been found that higher moment causes instability of the connection between the test machine and the specimen).

3. Results

We have measured linear displacement and the rotation angle of the vertebrae C6 under loading applied in three different points which have simulated flexion, extension, and lateral bending.

3.1. Measurements of linear displacement

Measurements of linear displacement in frontal and sagittal planes are shown in table 1. Measurements of the intact cervical spine under axial posterior loading (extension) showed an increase of displacement from 1.11 mm to 3.18 mm under a moment of 1.2 Nm to 2.4 Nm, respectively. Specimens with both systems of stabilization had comparable rigidity and were less stable than intact specimens. The wire-stabilization method proved to be better at the lowest and the highest moments (1.2 and 2.4 Nm gave 1.4 and 2.9 mm displacement, respectively, in comparison to 1.53 mm and 3.41 mm in specimens with the Martin system stabilization).

Table 1. Average linear displacement (mm) and standard deviation during extension, flexion and lateral bending of specimens under different force applied

Moment (Nm)		1.2 Nm	1.8 Nm	2.4 Nm
Extension	A	1.11 ±0.66	2.20 ±1.20	3.18 ±1.61
	B	1.53 ±0.66	2.03 ±0.84	3.41 ±1.39
	C	1. 40 ±0.84	2.73 ±1.24	2.94 ±1.71
Flexion	A	1.41 ±1.17	2.56 ±1.57	3.52 ±1.66
	B	1.39 ±0.79	2.39 ±1.21	3.27 ±1.64
	C	1.16 ±1.23	1.97 ±1.81	1.91 ±1.01
Lateral bending	A	1.41 ±0.83	2.30 ±0.87	3.46 ±1.66
	B	1.27 ±0.97	2.39 ±1.91	2.40 ±0.93
	C	1.18 ±0.93	1.97 ±1.11	1.96 ±0.90

A – intact specimen.
B – Martin system stabilization.
C – Ramadier–Bombart system stabilization.

During flexion our results are slightly different. The intact specimen under strain showed worse results than the specimens subjected to both methods of stabilization. The wire method again provided better rigidity; we measured 1.16 mm–1.91 mm displacement in comparison to 1.39 mm–3.27 mm in the specimens with the Martin system and 1.41 mm–3.52 mm in the intact spine.

The intact spine during lateral bending (frontal plane) showed linear displacement from 1.41 mm to 3.46 mm. Those results were inferior to both systems of stabilization. Again wire stabilization seemed to provide a slightly better rigidity.

3.2. Measurement of rotation angles

Measurements of rotation angles are shown in table 2. The intact spine and spines subjected to both methods of stabilization showed similar angles of rotation under loading during extension. We noticed the opposite situation during flexion measurements. Then, wire stabilization proved to be better. During lateral bending both methods of stabilization were able to ensure better rigidity of the specimen: 2.71° and 3.39° in the Martin system and wire method, respectively, in comparison to 5.62° during the measurement of the intact spine. At a moment of 1.8 Nm, the Martin system gave better rigidity of the specimen, but without statistical significance (table 3).

Table 2. Average rotation angle (degree) and standard variation during extension, flexion and lateral bending of specimens under different forces applied

Moment (Nm)		1.2 Nm	1.8 Nm	2.4 Nm
Extension	A	0.25° ±0.35	0.65° ±0.76	1.17° ±1.18
	B	0.13° ±0.13	0.52° ±0.65	1.76° ±2.71
	C	0.37° ±0.27	1.03° ±0.74	1.46° ±0.81
Flexion	A	0.78° ±0.67	1.27° ±1.23	1.65° ±1.74
	B	0.44° ±0.41	1.67° ±2.21	2.07° ±2.39
	C	0.39° ±0.29	0.82° ±0.59	1.22 ±1.12
Lateral bending	A	2.33° ±2.19	3.69° ±2.13	5.62° ±3.53
	B	1.58° ±1.78	3.18° ±3.86	2.71° ±1.52
	C	1.95° ±1.80	3.20° ±2.15	3.39° ±2.59

A – intact specimen.
B – Martin system stabilization.
C – Ramadier–Bombart system stabilization.

Table 3. Results of the *t*-student analysis

Stabilization system/loading	Average	Standard deviation	*t*-value	*p*-test probability
Linear displacement				
M, E	2.03	0.84	–2.328	0.067
R–B, E	2.73	1.24		
M, F	2.39	1.21	0.474	0.655
R–B, F	1.97	1.81		
M, LB	2.39	1.91	1.139	0.318
R–B, LB	1.89	1.11		
Rotation angle				
M E	0.52	0.65	–1.004	0.361
R–B, E	1.03	0.74		
M, F	1.67	2.21	0.95	0.386
R–B, F	0.82	0.59		
M, LB	3.18	3.86	0.075	0.944
R–B, LB	3.20	2.15		

M – Martin system of stabilization.
R–B – Romadier–Bombart stabilization.
E – extension.
F – flexion.
LB – lateral bending.

3.4. Comments

The measurements of linear displacement and angles of rotation presented in table 1 and table 2 show a tendency to increase with the loading applied. Those results are comparable to the results of tests performed on different sections of the spine with destabilized specimens [12].

Displacements under loading, which *in vivo* would cause flexion or extension of the cervical spine, were comparable. They differ due to the mode of loading.

The specimens with wire stabilization showed under load less linear displacement than the specimens with the Martin stabilization under the same conditions, especially at a moment of 2.4 Nm. During bending in the sagittal plane, the specimens subjected to both methods of stabilization showed smaller displacement compared to the intact specimen. We observed the best biomechanical effect at wire stabilization during the lateral bending.

Rotation angles in flexion and extension are small (0.25°–2.07°), and become large only during lateral bending (1.58°–5.62°).

Based on our experiment we have found that after injuring the tested cervical spine (in a manner comparable to physiological injury at the C5–C6 level) and stabilizing it by means of the methods mentioned earlier, a wiring method led to better stabilization in the sagittal and frontal planes but without statistically significant differences in measurements (table 3).

Injured specimens subjected to both methods of stabilization showed small displacement, very similar to that of the intact specimen. We should point out that both methods of stabilization used in this experiment give sufficient and comparable stabilization according to the biomechanical and clinical standards given by BĘDZIŃSKI and PEZOWICZ [1]. Taking account of both surgical approach and technical difficulty of the Romadier–Bombart method, the authors prefer the Martin system in clinical practice. A wire under the arch increases the risk of disrupting blood vessels and meninges and may cause leakage of cerebral fluid [4]. Fixing hooks on vertebral arches is safer and results in fewer complications. In clinical practice, we suggest the use of titanium implants, which help to carry out later evaluation of the spinal canal with magnetic resonance in the case the neurological deficit fails to regress and in the case of secondary frontal approach surgery.

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