

## Elastic resistance of the spine: Why does motion preservation surgery almost fail?

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### INTRODUCTION

In April 2009 and March 2011, two earthquakes in Abruzzo and Japan destroyed 65% of the buildings in reinforced concrete. In April 2011, the results of the Chi-Quadrato DIMS research project which evaluated the effects of high magnitude earthquakes on buildings built in wood was published. Wooden buildings proved to be those with the highest resistance to the mechanical movements of an earthquake owing to the physical properties of wood, elastic resistance to load-bearing and twisting. For this reason, in May 2011, 500 houses built in wood were delivered to the homeless Abruzzo population. The overall characteristics of the vertebral column are the same as those of wood, namely elastic resistance to movement, twisting potential and elastic resistance to load bearing. These aspects reflect the three main functional characteristics of the spine: motility in all 3 spatial planes, passive and active resistance to the axial load and elastic resistance to excessive degrees of movement. In the light of this, we can assert that motility at the level of a single metamere should not be interpreted merely as movement on the 3 planes but also, and above all, as elastic resistance to dynamic stress on these 3 planes. In fact, metameric movement depends on an active motility, involving the intervertebral disc, the articular masses and the muscular structures, and a passive motility, involving the disc, ligamentous system and articular capsules<sup>[1-15]</sup>. In the light of this, the aim of motion preservation is to neutralize excessive movements while preserving the physiological biomechanical properties of the metamere involved in interrupting the progression of the degenerative process and to prevent adjacent segment disease (ASD). This procedure was firstly named "dynamic sta-

### Abstract

Single metamere motility should not be interpreted merely as a movement on the 3 planes but also, and above all, as elastic resistance to dynamic stress on these 3 planes. In the light of this consideration, the aim of motion preservation is to neutralize excessive movements while preserving the physiological biomechanical properties of the metamere involved to interrupt the progression of degenerative processes and to prevent adjacent segment disease. Despite the fact that a myriad of devices have been developed with the purpose of achieving dynamic neutralization of the spine, there are now some doubts regarding the true efficacy of these devices.

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**Key words:** Elastic resistance; Disc prosthesis; Dynamic implant; Interspinous device; Biomechanics

**Core tip:** Elastic resistance of the spinal motor unit is a biomechanical property often underestimated but crucial for the stability of the spine. The biomechanics of dynamic implants take into account only the motility of the devices and not the elastic resistance. Is it possible that this is the reason why dynamic implants almost fail?

bilization” but nowadays the term “dynamic neutralization” (intended as neutralization of excessive degrees of movement) seems to be more appropriate<sup>[16]</sup>. The numerous devices developed to achieve a dynamic neutralization of the spine have been divided into anterior (aimed at restoring or maintaining disc height and motion by total disc replacement) and posterior (aimed at restoring or maintaining articular movement or posterior tension band). These devices comprise total disc prosthesis, posterior interspinous or interlaminar systems, systems with pedicular screws and prosthesis of the facets or posterior ligaments. Despite the good intentions of dynamic neutralization, there are now some doubts regarding the efficacy of these devices.

## DISC PROSTHESIS

The aim is to restore active movement in flexion-extension, rotation and lateral bending of the damaged disc. They provide excellent restoration of movement in all 3 planes but poor elastic resistance to movement, also due to removal of the anterior longitudinal ligament (ALL)<sup>[17]</sup>. Disc prosthesis allows good movement of the metamere but with a greater range of motion (ROM) in comparison to a normal disc, especially in rotation. This causes overloading of the facet joints. This is the result of an underestimation of the properties of the disc whose principal characteristic is elastic resistance. Nowadays, the materials and design of disc prostheses are not able to completely guarantee the biomechanical characteristics of a healthy disc and the physiological role of the nucleus pulposus during segmental motion<sup>[4,5,18-22]</sup>. Moreover, the surgical technique used for disc prosthesis insertion markedly reduces the elastic resistance of the metamere involved due to the elastic properties of the disc and the tension of the ALL. Hence, the results are very good in terms of movement but poor in terms of elastic resistance; this feature causes an acceleration of the degeneration of the spinal motor unit which often ends in heterotopic ossification of the prosthesis<sup>[23-37]</sup>. Moreover, recent studies have shown that the incidence of the ASD, ASD is not influenced by the use of disc prosthesis or by the interbody cage. This feature explains the controversy regarding prevention of ASD<sup>[38-43]</sup>.

## INTERSPINOUS-INTERLAMINAR SYSTEMS

The aim is to neutralize excessive movement in flexion and extension associated with distraction of the metamere to opening of the foramina. It provides fair control of flexion-extension but no control of active movements or passive resistance in rotation and lateral bending. Moreover, the insertion of the device in distraction causes an anterior overloading of the already damaged disc with a change in the 80-20 rule of the spine loading. This biomechanical aspect accelerates and does not prevent degenerative processes of the metamere, with

the possibility of developing spondylolisthesis<sup>[44-53]</sup>. In a recent work, Ayturk *et al.*<sup>[2]</sup>, reviewing the spinal literature concerning the postoperative status of interspinous devices (ID) followed over an average of 23.0-42.9 postoperative months, revealed that ID were burdened by an 11.6%-38.0% complication rate, 4.6%-85.0% reoperation rate and a 66.7%-77.0% incidence of poor outcomes. Last but not least, the devices implanted have a very high cost. In the light of the above, with high maximal complication rates (38%), reoperation rates (85%), poor outcomes (77%) and high costs, the utilization and implantation of ID remains extremely controversial<sup>[54]</sup>. In my opinion, this sums up the real situation about ID: high costs and poor outcome.

## PEDICULAR DYNAMIC SYSTEMS

The aim is to dynamically neutralize excessive movement and prevent ASD. They provide excellent control of movement in flexion-extension and lateral bending but minimal control in axial rotation. We can say that the intended functions of a motion preservation system are maintenance of the intervertebral ROM to reduce intradiscal pressure and reduce facet joint forces<sup>[55]</sup>. In this regard, metameric movement in axial rotation plays an essential role as the biomechanical vector of force that solicits the facet joints and the disc<sup>[56]</sup>. To be able to control this movement, the implant should have physical and mechanical characteristics. Biomechanically, the maintenance of the natural intervertebral motion, which especially includes the elastic resistance to torsion, can only be achieved if the elastic modulus of the longitudinal rod is high, but to considerably reduce the intradiscal pressure, high implant stiffness is required and in order to reduce facet joint forces, a rigid connection between longitudinal rod and pedicle screw is necessary. For these reasons the intended functions of a motion preservation system must have a contradictory implant stiffness<sup>[57,58]</sup>. In fact, a dynamic system based on screws and elastic rods have to have some particular properties in order to maintain the biomechanical characteristics of the spinal motor unit, namely rigidity and flexibility that are not compatible with one other. Actually, since rigid systems guarantee rigidity and dynamic systems guarantee flexibility, the result is: (1) in the case of rigid systems, a complete loss of the ROM; (2) in the case of dynamic systems, an overload of the disc and the articular facets. Preservation of these structures relies exclusively on the control of the elastic twisting movements. Since the only way to control these forces is the rigid connection of the rods and since this connection does not preserve the physiological movement of the spinal motor unit, no dynamic pedicle system able to control such rotation movements currently exists<sup>[57-63]</sup>. The screw insertion technique via the transverse process, such as the DYNamic NEutralization SYstem (DyNeSys) system, permits a rotational axis of the metamere posterior with respect to the physiological one, generating a movement with a fulcrum of metameric rotation different to that

of the other metameres. Screw insertion *via* the articular process, such as the Flex system, modifies the rotational axis that becomes more posterior than the DyNeSys and the physiological one. Both of these systems increase overloading of the facet joints with biomechanical variations<sup>[64]</sup>; (3) normally, after distraction of the metamere, intradiscal pressure values are markedly reduced for rigid implants. The effect on intradiscal pressure is the same as in a dynamic implant; meaning that the mechanical effects of a dynamic implant on discs are similar to those of a rigid fixation device, except after distraction. In the light of this, as dynamic pedicle systems are incompatible with a distraction implanting, a dynamic implant does not necessarily reduce axial spinal loads compared to an un-instrumented spine<sup>[57,58]</sup>; (4) pedicle-screw-based dynamic implants strongly reduce posterior disc bulging during extension since the presence of a dynamic rod controls the movements in compression on the posterior elements. However, in contrast to the intact spine, based on a posterior shift of the core, insertion of such an implant increases posterior disc bulging during flexion. The reason for this is that the dynamic rods, secured by the screw in the pedicle, prevent normal displacement of the nucleus pulposus within the disc during normal movements in flexion. This implies an increased tension on the fibers of the annulus which can lead to a higher risk of a recurrence of a bulging disc<sup>[65-67]</sup>; and (5) the use of a dynamic system as a hybrid implant due to prevention of ASD has shown that there are no clinical benefits in the disc with initial degeneration<sup>[41,68,69]</sup>. This is probably attributable to the fact that the biomechanics of the hybrid system do not control the hypermobility that is at the base of the initial degeneration of the adjacent disc. So if the disc is already degenerated, the hybrid system does not seem to protect against the progression of degeneration<sup>[70]</sup>.

## TOTAL FACET REPLACEMENT

The aim is to dynamically neutralize hyper-movement of the facet joints and to restore the articular ROM. It provides excellent control of movement in flexion-extension and lateral bending and good control of movement in rotation and is indicated in cases of moderate disc degeneration, facet pain and arthrosis of the articular masses<sup>[71,72]</sup>.

## TOTAL POSTERIOR ELEMENT REPLACEMENT TOPS

This procedure allows at least 85% of the ROM in the sagittal plane and mimics the flexibility of the metamere in lateral bending. In axial rotation, it mimics the biomechanical behavior of the posterior complex<sup>[30,71,73]</sup>.

These last two devices, in my opinion, mimic the physiological motility of the posterior elements of the spinal motor unit in an attempt to restore the biomechanical characteristics of the facet joints and posterior ligamentous system.

## CONCLUSION

On the basis of this analysis, we can assert that dynamic neutralization systems seem to be very promising although long-term results are lacking for many of them. However, the certainty is that the future of vertebral stabilization will be dynamic systems instead of rigid ones. Unfortunately, to date, none of the dynamic systems used alone is capable of controlling movements on all 3 planes of motion of the functional motor unit. Moreover, motion preservation technology should take into account not only movement but also, and above all, the elastic resistance properties of the metamere involved. In the light of the above considerations, the future of dynamic neutralization will be the control of all the components of the motor unit. Only in this way will it be possible to preserve both motion and the biomechanical properties of the metamere, guaranteeing a degree of vertebral motion and elasticity as physiological as possible.

## REFERENCES

- 1 Schmidt H, Kettler A, Heuer F, Simon U, Claes L, Wilke HJ. Intradiscal pressure, shear strain, and fiber strain in the intervertebral disc under combined loading. *Spine (Phila Pa 1976)* 2007; **32**: 748-755 [PMID: 17414908]
- 2 Ayturk UM, Garcia JJ, Puttlitz CM. The micromechanical role of the annulus fibrosus components under physiological loading of the lumbar spine. *J Biomech Eng* 2010; **132**: 061007 [PMID: 20887032 DOI: 10.1115/1.4001032]
- 3 Campana S, Charpail E, de Guise JA, Rillardon L, Skalli W, Mitton D. Relationships between viscoelastic properties of lumbar intervertebral disc and degeneration grade assessed by MRI. *J Mech Behav Biomed Mater* 2011; **4**: 593-599 [PMID: 21396608 DOI: 10.1016/j.jmbbm.2011.01.007]
- 4 O'Connell GD, Sen S, Elliott DM. Human annulus fibrosus material properties from biaxial testing and constitutive modeling are altered with degeneration. *Biomech Model Mechanobiol* 2012; **11**: 493-503 [PMID: 21748426 DOI: 10.1007/s10237-011-0328-9]
- 5 Przybyla AS, Skrzypiec D, Pollintine P, Dolan P, Adams MA. Strength of the cervical spine in compression and bending. *Spine (Phila Pa 1976)* 2007; **32**: 1612-1620 [PMID: 17621208]
- 6 Shirazi-Adl A. Analysis of large compression loads on lumbar spine in flexion and in torsion using a novel wrapping element. *J Biomech* 2006; **39**: 267-275 [PMID: 16321628 DOI: 10.1016/j.jbiomech.2004.11.022]
- 7 Gillespie KA, Dickey JP. Biomechanical role of lumbar spine ligaments in flexion and extension: determination using a parallel linkage robot and a porcine model. *Spine (Phila Pa 1976)* 2004; **29**: 1208-1216 [PMID: 15167660]
- 8 Adams MA, Hutton WC, Stott JR. The resistance to flexion of the lumbar intervertebral joint. *Spine (Phila Pa 1976)* 1980; **5**: 245-253 [PMID: 7394664]
- 9 Gudavalli MR, Triano JJ. An analytical model of lumbar motion segment in flexion. *J Manipulative Physiol Ther* 1999; **22**: 201-208 [PMID: 10367755 DOI: 10.1016/S0161-4754(99)70045-X]
- 10 Solomonow M, Zhou BH, Harris M, Lu Y, Baratta RV. The ligamento-muscular stabilizing system of the spine. *Spine (Phila Pa 1976)* 1998; **23**: 2552-2562 [PMID: 9854754]
- 11 Hindle RJ, Pearcy MJ, Cross A. Mechanical function of the human lumbar interspinous and supraspinous ligaments. *J Biomed Eng* 1990; **12**: 340-344 [PMID: 2395361 DOI: 10.1016/0141-5425(90)90010-K]

- 12 **Anderson AL**, McIff TE, Asher MA, Burton DC, Glattes RC. The effect of posterior thoracic spine anatomical structures on motion segment flexion stiffness. *Spine* (Phila Pa 1976) 2009; **34**: 441-446 [PMID: 19247164 DOI: 10.1097/BRS.0b013e318198c62d]
- 13 **Sharma M**, Langrana NA, Rodriguez J. Role of ligaments and facets in lumbar spinal stability. *Spine* (Phila Pa 1976) 1995; **20**: 887-900 [PMID: 7644953]
- 14 **Busscher I**, van Dieën JH, Kingma I, van der Veen AJ, Verkerke GJ, Veldhuizen AG. Biomechanical characteristics of different regions of the human spine: an in vitro study on multilevel spinal segments. *Spine* (Phila Pa 1976) 2009; **34**: 2858-2864 [PMID: 20010393 DOI: 10.1097/BRS.0b013e3181b4c75d]
- 15 **Zander T**, Rohlmann A, Bergmann G. Analysis of simulated single ligament transection on the mechanical behaviour of a lumbar functional spinal unit. *Biomed Tech* (Berl) 2004; **49**: 27-32 [PMID: 15032495 DOI: 10.1515/BMT.2004.006]
- 16 **Ciavarro C**, Caiani EG, Brayda-Bruno M, Zerbi A, Galbusera F, Vaga S, Lamartina C. Mid-term evaluation of the effects of dynamic neutralization system on lumbar intervertebral discs using quantitative molecular MR imaging. *J Magn Reson Imaging* 2012; **35**: 1145-1151 [PMID: 22128094 DOI: 10.1002/jmri.23525]
- 17 **Chung SK**, Kim YE, Wang KC. Biomechanical effect of constraint in lumbar total disc replacement: a study with finite element analysis. *Spine* (Phila Pa 1976) 2009; **34**: 1281-1286 [PMID: 19455003 DOI: 10.1097/BRS.0b013e3181a4ec2d]
- 18 **Cortes DH**, Elliott DM. Extra-fibrillar matrix mechanics of annulus fibrosus in tension and compression. *Biomech Model Mechanobiol* 2012; **11**: 781-790 [PMID: 21964839 DOI: 10.1007/s10237-011-0351-x]
- 19 **Wagnac E**, Arnoux PJ, Garo A, El-Rich M, Aubin CE. Calibration of hyperelastic material properties of the human lumbar intervertebral disc under fast dynamic compressive loads. *J Biomech Eng* 2011; **133**: 101007 [PMID: 22070332 DOI: 10.1115/1.4005224]
- 20 **Lin CY**, Kang H, Rouleau JP, Hollister SJ, Marca FL. Stress analysis of the interface between cervical vertebrae end plates and the Bryan, Prestige LP, and ProDisc-C cervical disc prostheses: an in vivo image-based finite element study. *Spine* (Phila Pa 1976) 2009; **34**: 1554-1560 [PMID: 19564765 DOI: 10.1097/BRS.0b013e3181aa643b]
- 21 **Guy RD**, McAfee PC, Banco RJ, Bitan FD, Cappuccino A, Geisler FH, Hochschuler SH, Holt RT, Jenis LG, Majd ME, Regan JJ, Tromanhauser SG, Wong DC, Blumenthal SL. Prospective, randomized, multicenter Food and Drug Administration investigational device exemption study of lumbar total disc replacement with the CHARITE artificial disc versus lumbar fusion: five-year follow-up. *Spine J* 2009; **9**: 374-386 [PMID: 18805066 DOI: 10.1016/j.spinee.2008.08.007]
- 22 **Rundell SA**, Guerin HL, Auerbach JD, Kurtz SM. Effect of nucleus replacement device properties on lumbar spine mechanics. *Spine* (Phila Pa 1976) 2009; **34**: 2022-2032 [PMID: 19730210 DOI: 10.1097/BRS.0b013e3181af1d5a]
- 23 **Mehren C**, Suchomel P, Grochulla F, Barsa P, Sourkova P, Hradil J, Korge A, Mayer HM. Heterotopic ossification in total cervical artificial disc replacement. *Spine* (Phila Pa 1976) 2006; **31**: 2802-2806 [PMID: 17108833]
- 24 **Lee JH**, Jung TG, Kim HS, Jang JS, Lee SH. Analysis of the incidence and clinical effect of the heterotopic ossification in a single-level cervical artificial disc replacement. *Spine J* 2010; **10**: 676-682 [PMID: 20537598 DOI: 10.1016/j.spinee.2010.04.017]
- 25 **Yi S**, Kim KN, Yang MS, Yang JW, Kim H, Ha Y, Yoon do H, Shin HC. Difference in occurrence of heterotopic ossification according to prosthesis type in the cervical artificial disc replacement. *Spine* (Phila Pa 1976) 2010; **35**: 1556-1561 [PMID: 20581764 DOI: 10.1097/BRS.0b013e3181c6526b]
- 26 **Lee SE**, Chung CK, Jahng TA. Early development and progression of heterotopic ossification in cervical total disc replacement. *J Neurosurg Spine* 2012; **16**: 31-36 [PMID: 21999390 DOI: 10.3171/2011.8.SPINE11303]
- 27 **Richards O**, Choi D, Timothy J. Cervical arthroplasty: the beginning, the middle, the end? *Br J Neurosurg* 2012; **26**: 2-6 [PMID: 21815734 DOI: 10.3109/02688697.2011.595846]
- 28 **Chen J**, Wang X, Bai W, Shen X, Yuan W. Prevalence of heterotopic ossification after cervical total disc arthroplasty: a meta-analysis. *Eur Spine J* 2012; **21**: 674-680 [PMID: 22134486 DOI: 10.1007/s00586-011-2094-x]
- 29 **Park JH**, Rhim SC, Roh SW. Mid-term follow-up of clinical and radiologic outcomes in cervical total disc replacement (Mobi-C): incidence of heterotopic ossification and risk factors. *J Spinal Disord Tech* 2013; **26**: 141-145 [PMID: 22105106]
- 30 **Heuer F**, Schmidt H, Käfer W, Graf N, Wilke HJ. Posterior motion preserving implants evaluated by means of intervertebral disc bulging and annular fiber strains. *Clin Biomech* (Bristol, Avon) 2012; **27**: 218-225 [PMID: 21983522 DOI: 10.1016/j.clinbiomech.2011.09.004]
- 31 **Chung SB**, Muradov JM, Lee SH, Eoh W, Kim ES. Uncovertebral hypertrophy is a significant risk factor for the occurrence of heterotopic ossification after cervical disc replacement: survivorship analysis of Bryan disc for single-level cervical arthroplasty. *Acta Neurochir* (Wien) 2012; **154**: 1017-1022 [PMID: 22421919 DOI: 10.1007/s00701-012-1309-1]
- 32 **Wu JC**, Huang WC, Tsai TY, Fay LY, Ko CC, Tu TH, Wu CL, Cheng H. Multilevel arthroplasty for cervical spondylosis: more heterotopic ossification at 3 years of follow-up. *Spine* (Phila Pa 1976) 2012; **37**: E1251-E1259 [PMID: 22739672]
- 33 **Wu JC**, Huang WC, Tsai HW, Ko CC, Fay LY, Tu TH, Wu CL, Cheng H. Differences between 1- and 2-level cervical arthroplasty: more heterotopic ossification in 2-level disc replacement: Clinical article. *J Neurosurg Spine* 2012; **16**: 594-600 [PMID: 22443547 DOI: 10.3171/2012.2.SPINE111066]
- 34 **Brenke C**, Scharf J, Schmieder K, Barth M. High prevalence of heterotopic ossification after cervical disc arthroplasty: outcome and intraoperative findings following explantation of 22 cervical disc prostheses. *J Neurosurg Spine* 2012; **17**: 141-146 [PMID: 22657947 DOI: 10.3171/2012.4.SPINE12223]
- 35 **Wu JC**, Huang WC, Tu TH, Tsai HW, Ko CC, Wu CL, Cheng H. Differences between soft-disc herniation and spondylosis in cervical arthroplasty: CT-documented heterotopic ossification with minimum 2 years of follow-up. *J Neurosurg Spine* 2012; **16**: 163-171 [PMID: 22136390 DOI: 10.3171/2011.10.SPINE11497]
- 36 **Jin YJ**, Park SB, Kim MJ, Kim KJ, Kim HJ. An analysis of heterotopic ossification in cervical disc arthroplasty: a novel morphologic classification of an ossified mass. *Spine J* 2013; **13**: 408-420 [PMID: 23332520 DOI: 10.1016/j.spinee.2012.11.048]
- 37 **Dooris AP**, Goel VK, Grosland NM, Gilbertson LG, Wilder DG. Load-sharing between anterior and posterior elements in a lumbar motion segment implanted with an artificial disc. *Spine* (Phila Pa 1976) 2001; **26**: E122-E129 [PMID: 11246394]
- 38 **Marotta N**, Landi A, Tarantino R, Mancarella C, Ruggeri A, Delfini R. Five-year outcome of stand-alone fusion using carbon cages in cervical disc arthrosis. *Eur Spine J* 2011; **20** Suppl 1: S8-S12 [PMID: 21404034 DOI: 10.1007/s00586-011-1747-0]
- 39 **Xing D**, Ma XL, Ma JX, Wang J, Ma T, Chen Y. A meta-analysis of cervical arthroplasty compared to anterior cervical discectomy and fusion for single-level cervical disc disease. *J Clin Neurosci* 2013; **20**: 970-978 [PMID: 23375397 DOI: 10.1016/j.jocn.2012.03.046]
- 40 **Yin S**, Yu X, Zhou S, Yin Z, Qiu Y. Is cervical disc arthroplasty superior to fusion for treatment of symptomatic cervical disc disease? A meta-analysis. *Clin Orthop Relat Res* 2013; **471**: 1904-1919 [PMID: 23389804 DOI: 10.1007/s11999-013-2830-0]
- 41 **Helgeson MD**, Bevevino AJ, Hilibrand AS. Update on the evidence for adjacent segment degeneration and disease. *Spine J* 2013; **13**: 342-351 [PMID: 23420004 DOI: 10.1016/

- j.spinee.2012.12.009]
- 42 **Sasso RC**, Best NM. Cervical kinematics after fusion and bryan disc arthroplasty. *J Spinal Disord Tech* 2008; **21**: 19-22 [PMID: 18418131 DOI: 10.1097/BSD.0b013e3180500778]
- 43 **Berg S**, Tropp HT, Leivseth G. Disc height and motion patterns in the lumbar spine in patients operated with total disc replacement or fusion for discogenic back pain. Results from a randomized controlled trial. *Spine J* 2011; **11**: 991-998 [PMID: 21978518 DOI: 10.1016/j.spinee.2011.08.434]
- 44 **Floman Y**, Millgram MA, Smorgick Y, Rand N, Ashkenazi E. Failure of the Wallis interspinous implant to lower the incidence of recurrent lumbar disc herniations in patients undergoing primary disc excision. *J Spinal Disord Tech* 2007; **20**: 337-341 [PMID: 17607096 DOI: 10.1097/BSD.0b013e318030a81d]
- 45 **Sun HL**, Li CD, Liu XY, Lin JR, Yi XD, Liu H, Lu HL. [Mid-term follow-up and analysis of the failure cases of interspinous implants for degenerative lumbar diseases]. *Beijing Da Xue Xue Bao* 2011; **43**: 690-695 [PMID: 22008677]
- 46 **Verhoof OJ**, Bron JL, Wapstra FH, van Royen BJ. High failure rate of the interspinous distraction device (X-Stop) for the treatment of lumbar spinal stenosis caused by degenerative spondylolisthesis. *Eur Spine J* 2008; **17**: 188-192 [PMID: 17846801]
- 47 **Maida G**, Marcati E, Sarubbo S. Heterotopic ossification in vertebral interlaminar/interspinous instrumentation: report of a case. *Case Rep Surg* 2012; **2012**: 970642 [PMID: 22888459 DOI: 10.1155/2012/970642]
- 48 **Bowers C**, Amini A, Dailey AT, Schmidt MH. Dynamic interspinous process stabilization: review of complications associated with the X-Stop device. *Neurosurg Focus* 2010; **28**: E8 [PMID: 20568923 DOI: 10.3171/2010.3.FOCUS1047]
- 49 **Epstein NE**. X-Stop: foot drop. *Spine J* 2009; **9**: e6-e9 [PMID: 18809360 DOI: 10.1016/j.spinee.2008.08.004]
- 50 **Barbagallo GM**, Olindo G, Corbino L, Albanese V. Analysis of complications in patients treated with the X-Stop Interspinous Process Decompression System: proposal for a novel anatomic scoring system for patient selection and review of the literature. *Neurosurgery* 2009; **65**: 111-119; discussion 119-120 [PMID: 19574832 DOI: 10.1227/01.NEU.0000346254.07116.31]
- 51 **Korovessis P**, Repantis T, Zacharatos S, Zafiropoulos A. Does Wallis implant reduce adjacent segment degeneration above lumbosacral instrumented fusion? *Eur Spine J* 2009; **18**: 830-840 [PMID: 19387697 DOI: 10.1007/s00586-009-0976-y]
- 52 **Tamburrelli FC**, Proietti L, Logroscino CA. Critical analysis of lumbar interspinous devices failures: a retrospective study. *Eur Spine J* 2011; **20** Suppl 1: S27-S35 [PMID: 21404029 DOI: 10.1007/s00586-011-1763-0]
- 53 **Trautwein FT**, Lowery GL, Wharton ND, Hipp JA, Chomiak RJ. Determination of the in vivo posterior loading environment of the Coflex interlaminar-interspinous implant. *Spine J* 2010; **10**: 244-251 [PMID: 20004622 DOI: 10.1016/j.spinee.2009.10.010]
- 54 **Epstein NE**. A review of interspinous fusion devices: High complication, reoperation rates, and costs with poor outcomes. *Surg Neurol Int* 2012; **3**: 7 [PMID: 22347676 DOI: 10.4103/2152-7806.92172]
- 55 **Bowden AE**, Guerin HL, Villarraga ML, Patwardhan AG, Ochoa JA. Quality of motion considerations in numerical analysis of motion restoring implants of the spine. *Clin Biomech* (Bristol, Avon) 2008; **23**: 536-544 [PMID: 18258345 DOI: 10.1016/j.clinbiomech.2007.12.010]
- 56 **Schmidt H**, Heuer F, Claes L, Wilke HJ. The relation between the instantaneous center of rotation and facet joint forces - A finite element analysis. *Clin Biomech* (Bristol, Avon) 2008; **23**: 270-278 [PMID: 17997207 DOI: 10.1016/j.clinbiomech.2007.10.001]
- 57 **Rohlmann A**, Nabil Boustani H, Bergmann G, Zander T. Effect of a pedicle-screw-based motion preservation system on lumbar spine biomechanics: a probabilistic finite element study with subsequent sensitivity analysis. *J Biomech* 2010; **43**: 2963-2969 [PMID: 20696430 DOI: 10.1016/j.jbiomech.2010.07.018]
- 58 **Rohlmann A**, Burra NK, Zander T, Bergmann G. Comparison of the effects of bilateral posterior dynamic and rigid fixation devices on the loads in the lumbar spine: a finite element analysis. *Eur Spine J* 2007; **16**: 1223-1231 [PMID: 17206401]
- 59 **Ianuzzi A**, Kurtz SM, Kane W, Shah P, Siskey R, van Ooij A, Bindal R, Ross R, Lanman T, Büttner-Janitz K, Isaza J. In vivo deformation, surface damage, and biostability of retrieved Dynesys systems. *Spine* (Phila Pa 1976) 2010; **35**: E1310-E1316 [PMID: 20975485 DOI: 10.1097/BRS.0b013e3181d6f84f]
- 60 **Kiapour A**, Ambati D, Hoy RW, Goel VK. Effect of graded facetectomy on biomechanics of Dynesys dynamic stabilization system. *Spine* (Phila Pa 1976) 2012; **37**: E581-E589 [PMID: 22198353 DOI: 10.1097/BRS.0b013e3182463775]
- 61 **Wu JC**, Huang WC, Tsai HW, Ko CC, Wu CL, Tu TH, Cheng H. Pedicle screw loosening in dynamic stabilization: incidence, risk, and outcome in 126 patients. *Neurosurg Focus* 2011; **31**: E9 [PMID: 21961872 DOI: 10.3171/2011.7.FOCUS11125]
- 62 **Kim K**, Park WM, Kim YH, Lee S. Stress analysis in a pedicle screw fixation system with flexible rods in the lumbar spine. *Proc Inst Mech Eng H* 2010; **224**: 477-485 [PMID: 20408492]
- 63 **Kelly MP**, Mok JM, Berven S. Dynamic constructs for spinal fusion: an evidence-based review. *Orthop Clin North Am* 2010; **41**: 203-215 [PMID: 20399359 DOI: 10.1016/j.joc.2009.12.004]
- 64 **Ko CC**, Tsai HW, Huang WC, Wu JC, Chen YC, Shih YH, Chen HC, Wu CL, Cheng H. Screw loosening in the Dynesys stabilization system: radiographic evidence and effect on outcomes. *Neurosurg Focus* 2010; **28**: E10 [PMID: 20568916 DOI: 10.3171/2010.3.FOCUS1052]
- 65 **Boustani HN**, Zander T, Disch AC, Rohlmann A. Pedicle-screw-based dynamic implants may increase posterior intervertebral disc bulging during flexion. *Biomed Tech* (Berl) 2011; **56**: 327-331 [PMID: 22103650 DOI: 10.1515/BMT.2011.023]
- 66 **Rundell SA**, Auerbach JD, Balderston RA, Kurtz SM. Total disc replacement positioning affects facet contact forces and vertebral body strains. *Spine* (Phila Pa 1976) 2008; **33**: 2510-2517 [PMID: 18978591 DOI: 10.1097/BRS.0b013e318186b258]
- 67 **Bellini CM**, Galbusera F, Raimondi MT, Mineo GV, Brayda-Bruno M. Biomechanics of the lumbar spine after dynamic stabilization. *J Spinal Disord Tech* 2007; **20**: 423-429 [PMID: 17970182]
- 68 **Kumar A**, Beastall J, Hughes J, Karadimas EJ, Nicol M, Smith F, Wardlaw D. Disc changes in the bridged and adjacent segments after Dynesys dynamic stabilization system after two years. *Spine* (Phila Pa 1976) 2008; **33**: 2909-2914 [PMID: 19092623 DOI: 10.1097/BRS.0b013e31818bdca7]
- 69 **Cakir B**, Carazzo C, Schmidt R, Mattes T, Reichel H, Käfer W. Adjacent segment mobility after rigid and semi-rigid instrumentation of the lumbar spine. *Spine* (Phila Pa 1976) 2009; **34**: 1287-1291 [PMID: 19455004 DOI: 10.1097/BRS.0b013e3181a136ab]
- 70 **Putzier M**, Hoff E, Tohtz S, Gross C, Perka C, Strube P. Dynamic stabilization adjacent to single-level fusion: part II. No clinical benefit for asymptomatic, initially degenerated adjacent segments after 6 years follow-up. *Eur Spine J* 2010; **19**: 2181-2189 [PMID: 20632044 DOI: 10.1007/s00586-010-1517-4]
- 71 **Wilke HJ**, Schmidt H, Werner K, Schmölz W, Drumm J. Biomechanical evaluation of a new total posterior-element replacement system. *Spine* (Phila Pa 1976) 2006; **31**: 2790-2796; discussion 2797 [PMID: 17108830]
- 72 **Phillips FM**, Tzermiadianos MN, Voronov LI, Havey RM, Carandang G, Renner SM, Rosler DM, Ochoa JA, Patwardhan AG. Effect of the Total Facet Arthroplasty System after complete laminectomy-facetectomy on the biomechanics

of implanted and adjacent segments. *Spine J* 2009; **9**: 96-102 [PMID: 18440280 DOI: 10.1016/j.spinee.2008.01.010]

- 73 **McAfee P**, Khoo LT, Pimenta L, Capuccino A, Sengoz A, Coric D, Hes R, Conix B, Asgarzadie F, Hamzaoglu A, Mirofsky

Y, Anekstein Y. Treatment of lumbar spinal stenosis with a total posterior arthroplasty prosthesis: implant description, surgical technique, and a prospective report on 29 patients. *Neurosurg Focus* 2007; **22**: E13 [PMID: 17608334]

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