

## [ Sports Physical Therapy ]



# Nonoperative Treatment in Lumbar Spondylolysis and Spondylolisthesis: A Systematic Review

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**Context:** Both spondylolysis and spondylolisthesis can be diagnosed across the life span of sports-participating individuals. Determining which treatments are effective for these conditions is imperative to the rehabilitation professional.

**Data Sources:** A computer-assisted literature search was completed in MEDLINE, CINAHL, and EMBASE databases (1966-April 2012) utilizing keywords related to nonoperative treatment of spondylolysis and/or spondylolisthesis. Reference lists were also searched to find all relevant articles that fit our inclusion criteria: English language, human, lumbar pain with diagnosed spondylolysis and/or spondylolisthesis, inclusion of at least 1 nonoperative treatment method, and use of a comparative study design.

**Data Extraction:** Data were independently extracted from the selected studies by 2 authors and cross-referenced. Any disagreement on relevant data was discussed and resolved by a third author.

**Results:** Ten studies meeting the criteria were rated for quality using the GRADE scale. Four studies found surgical intervention more successful than nonoperative treatment for treating pain and functional limitation. One study found no difference between surgery and nonoperative treatment with regard to future low back pain. Improvement was found in bracing, bracing and exercises emphasizing lumbar extension, range of motion and strengthening exercises focusing on lumbar flexion, and strengthening specific abdominal and lumbar muscles.

**Conclusion:** No consensus can be reached on the role of nonoperative versus surgical care because of limited investigation and heterogeneity of studies reported. Studies of nonoperative care options suffered from lack of blinding assessors and control groups and decreased patient compliance with exercise programs.

**Keywords:** spondylolysis; spondylolisthesis; nonoperative treatment

Instability of the lumbar spine is one of multiple pathologic causes of low back pain (LBP).<sup>19,20</sup> It can be defined as a loss of motion stiffness such that forces applied to a given segment produce greater displacement than would occur normally.<sup>22</sup> Spondylolysis and spondylolisthesis can cause LBP because of instability. Spondylolysis is a bony defect, possibly a stress fracture, of one or both pars interarticularis and most commonly occurs in the lower lumbar spine (Figure 1).<sup>3</sup> Prevalence of spondylolysis ranges from approximately 6% to 11.5% in the general population<sup>9</sup> and approximately 7% to 8% in elite athletes; this percentage is grossly underreported.<sup>12,26,27</sup> Nearly 50% of LBP cases in adolescent athletes have been attributed to spondylolysis.<sup>21</sup>

Repetitive microtrauma leading to spondylolysis has been attributed to lumbar hyperextension combined with rotation and loading.<sup>11,26,27</sup> These injuries occur in dancers, gymnasts, figure skaters, weight lifters, and football players<sup>26,27</sup>; active spondylolysis has been reported in almost every sport.<sup>11</sup>

Spondylolisthesis is displacement of a vertebra due to a defect in the pars (Figure 2).<sup>14</sup> Spondylolysis is a precipitating factor and can be classified as isthmic, dysplastic, degenerative, traumatic, and pathologic.<sup>7,31,32</sup> Spondylolisthesis severity can be graded I through IV. Grade I is displacement of 0% to 25%; grade II, 26% to 50%; and grade III, up to 75%. Displacement of 75% to 100% is grade IV.<sup>16</sup>

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Figure 1. Sagittal fat-saturated T2-weighted image showing a defect of the right pars interarticularis at L4. Adjacent high signal in the marrow and soft tissues on the image reflects acute or subacute fracture.

Etiologic factors,<sup>6</sup> degree of slippage,<sup>16</sup> and pathology type<sup>7,31,32</sup> reflect the heterogeneous nature of both spondylolysis and spondylolisthesis. Computed tomography, single-photon computed tomography, and magnetic resonance imaging techniques assist in the accurate diagnosis of spondylolysis and spondylolisthesis. Guidelines for these conditions remain elusive.<sup>11,26,27</sup>

Development of guidelines requires a systematic review of the current level of evidence. Consequently, the purpose of this review is to systematically review nonoperative methods of intervention as related to spondylolysis and spondylolisthesis.

## METHODS

### Data Sources

An electronic literature search of MEDLINE, CINAHL, and EMBASE databases was performed for articles published between 1966 and April 2012. The MESH search terms for MEDLINE included: (*spondylolysis OR spondylolisthesis*) AND (*lumbar vertebrae OR lumbar spine*) AND (*physical therapy OR rehabilitation OR stabilization OR strengthening OR motor control OR massage OR joint mobilization OR joint manipulation OR manual therapy OR stretching OR conservative treatment OR therapy OR athletic OR training OR bracing*), limited to the English language and human subjects.

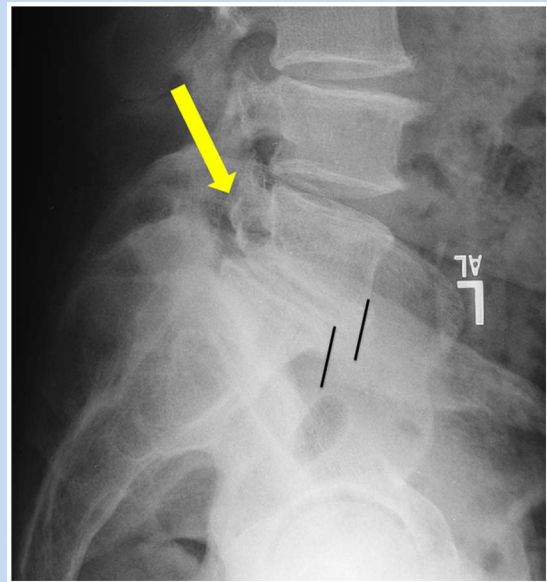


Figure 2. Radiograph of fracture of pars interarticularis (yellow arrow) with grade II spondylolisthesis demonstrating slippage (black lines).

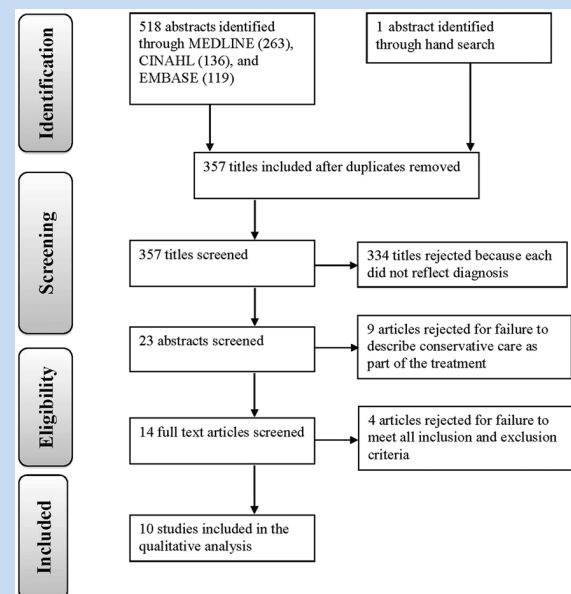


Figure 3. Flow diagram of study.

The reference lists were also checked to retrieve relevant publications. Gray literature (textbooks, abstracts presented at conferences, web information, etc) was also hand searched.

### Study Selection

Full-text articles were retrieved if the abstract provided insufficient information to establish eligibility or if the

article had passed the first eligibility screening. All articles examining nonoperative treatment of spondylolysis and/or spondylolisthesis were eligible if they met all of the following criteria: (1) patients presenting with lumbar spine pain with primary diagnosis of spondylolysis and/or spondylolisthesis; (2) cohort, case control, and/or cross-sectional design; (3) inclusion of at least 1 nonoperative therapy for spondylolysis/lithesis (relevant to physical therapy or athletic training); and (4) article was in English.

An article was excluded if (1) other pathologies were present, (2) nonoperative treatment was omitted, and (3) subjects were infants or toddlers. Criteria were independently applied by 2 reviewers (MG, JS). A third author (MR) was consulted to resolve disagreements. This screening resulted in 10 full-text articles for data extraction (Table 1 and Figure 3).

### Data Extraction

Data on the study population, description, intervention, outcome measures, and results were independently extracted and cross-referenced (Tables 1-5; see appendix, available at <http://sph.sagepub.com/content/suppl>).

## RESULTS

The systematic search through MEDLINE, CINAHL, and EMBASE yielded 10 eligible studies for data extraction. Of these 10 studies, 5 were randomized controlled trials,<sup>4,18,25,29,30</sup> 1 was a prospective randomized study,<sup>17</sup> and 4 were comparative studies without randomization or a control group.<sup>1,5,23,24</sup> One study compared the use of brace treatment with activity restriction,<sup>1</sup> 5 studies compared nonoperative care to surgical interventions,<sup>4,17,23,29,30</sup> and 3 studies compared exercise protocols.<sup>5,18,24</sup> One remaining study compared a combination of bracing and specific exercise protocol with a placebo control group.<sup>25</sup>

One study included a combination of patients with spondylolysis and spondylolisthesis,<sup>18</sup> 1 only spondylolysis,<sup>1</sup> while the remaining 8 used spondylolisthesis.<sup>4,5,17,23-25,29,30</sup>

The age of subjects in the studies varied widely: 2 had a mean subject age in the teens (13 and 13.8 years).<sup>1,23</sup> Four had mean ages in the 30s or 40s.<sup>17,18,24,25</sup> One study did not report the age of the subjects.<sup>5</sup> The 3 remaining studies had a mean age in the 60s.<sup>4,29,30</sup>

The 5 studies comparing nonoperative care to surgical interventions found nonoperative care was not as favorable as surgery. Grade of pathology was only reported in 2 of the 5 studies comparing nonoperative and surgical care (Table 2). These studies reported improvement in various pain ratings with fusions or laminectomies compared with strength and postural training,<sup>17</sup> patients with diabetes receiving lumbar fusions or decompressions versus nondescript "conservative care,"<sup>34</sup> and patients undergoing decompressive laminectomy versus patients treated with physical therapy.<sup>29,30</sup>

Two studies used the same patient population to compare flexion exercises and extension exercises.<sup>5,24</sup> Both found

significant improvement in pain, return to work, and self-rated recovery in the flexion-based group.<sup>5,24</sup> Another study compared lumbar stabilization exercises to general exercise and found significant improvement in functional score and pain rating in the stabilization group.<sup>18</sup>

When bracing was combined with flexion or extension exercises and a placebo group, extension exercises and bracing showed significant improvements in pain ratings compared with the flexion group and placebo.<sup>25</sup> A study comparing immediate bracing versus initial activity modification found improved healing of pars interarticularis defects on SPECT imaging in patients braced immediately compared with those treated with activity modification.<sup>1</sup>

Four studies found surgical intervention more successful than nonoperative treatment for treating pain and functional limitation.<sup>4,17,29,30</sup> One found no difference between surgery and nonoperative treatment in regard to vertebral slip, damage to the L4-L5 disk, and low back pain.<sup>23</sup> Of the studies comparing nonoperative treatments, improvement was found in bracing,<sup>1</sup> bracing and exercises emphasizing lumbar extension,<sup>25</sup> range of motion and strengthening exercises focusing on lumbar flexion,<sup>5,24</sup> and strengthening specific abdominal and lumbar muscles.<sup>18</sup>

## DISCUSSION

A previous review examined exercise interventions in these 2 conditions,<sup>15</sup> while this review included bracing, activity restriction, and surgical procedures. This review suggests surgical intervention is more effective than nonoperative treatments for pain and functional limitation in patients with spondylolisthesis when directly compared with each other. Studies that did compare the various nonoperative treatments revealed a variety of conclusions, ranging from no improvement with lumbar flexion exercises and bracing<sup>25</sup> to significant improvement with lumbar flexion exercises<sup>5</sup> and significant improvement with specific muscle strengthening exercise.<sup>18</sup>

Previous studies supported the use of various braces with children and adolescents involved in sport. Case series by Sys et al<sup>28</sup> and Iwamoto et al<sup>8</sup> each found a high percentage of return to sport (89.3% and 87.5%, respectively) with nonoperative treatment and bracing.

Repetitive extension and hyperextension, along with rotation, are risk factors for developing and aggravating spondylolysis and spondylolisthesis.<sup>11,26,27</sup> The highest levels of stress on the pars interarticularis were found with lumbar extension and rotation.<sup>2</sup> Some patients have greater improvement with extension.<sup>25</sup> Older subjects may have had simultaneous disk pathologies that responded positively to repetitive extension exercises and bracing.

The deep multifidi exert compressive forces as well as aid in control of spinal motion at the segmental level.<sup>10</sup> Therefore, specific strengthening of these stabilizing muscles could be beneficial in an instability condition like spondylolysis or

Table 1. Description of included studies

Eligible Studies	Study Design	Patients/Demographics Age in Years (Mean $\pm$ SD or Range)	Training Type and Duration
<b>Bracing</b>			
Anderson et al <sup>1</sup>	Comparative study	34 children/adolescents (32/34 involved in sports, most frequently basketball, football, gymnastics, baseball), age 5-17 (10 F, 24 M)	Bracing (6.2 months or 8.1 months)
<b>Bracing and PT</b>			
Spratt et al <sup>25</sup>	RCT	56 adults, age 39.9 $\pm$ 11 (26 F); 33.8 $\pm$ 8 (10 M)	Bracing and directional PT (1 month)
Seitsalo et al <sup>23</sup>	Comparative Study	227 children/adolescents, age 8-19 (113 F, 114 M)	PT/bracing versus surgery (duration not specified)
Weinstein et al <sup>29</sup>	RCT	601 adults, age 66.0 $\pm$ 10.0 (randomized, 200 F, 101 M), 66.1 $\pm$ 10.6 (observational, 212 F, 188 M)	PT/bracing/NSAIDs versus surgery (duration not specified)
Weinstein et al <sup>30</sup>	RCT	601 adults, age 66.0 $\pm$ 10.0 (randomized, 200 F, 101 M), 66.1 $\pm$ 10.6 (observational, 212 F, 188 M)	PT/bracing/NSAIDs versus surgery (duration not specified)
Freedman et al <sup>4</sup>	RCT	70 adults with diabetes, age 67.3 $\pm$ 9.1 (25 F, 45 M)	PT/NSAIDs versus surgery (duration not specified)
<b>Specific exercise</b>			
Moller and Hedlund <sup>17</sup>	Prospective randomized study	111 adults, age 39-55 (54 F, 57 M)	Strength and postural training versus surgery (training 3 $\times$ /wk for first 6 months, 2 $\times$ /wk for following 6 months)
O'Sullivan et al <sup>18</sup>	RCT	42 adults, age 29.9 $\pm$ 9 (exercise), 33 $\pm$ 10 (control) (21 F, 21 M)	Deep abdominal/lumbar multifidi training versus weekly general exercise (10 weeks)
Gramse et al <sup>15</sup>	Comparative study	47 adults (age and sex not reported)	Flexion exercises versus flexion and extension exercises (duration not reported)
Sinaki et al <sup>24</sup>	Comparative study	44 adults, age 44.5 $\pm$ 14.5 (flexion only), 44.3 $\pm$ 15.7 (flexion + extension) (26 F, 18 M)	Flexion exercises versus flexion and extension exercises (duration not reported)

SD, standard deviation; F, female patients; M, male patients; PT, physical therapy; wk, week; NSAIDs, nonsteroidal anti-inflammatories; RCT, randomized controlled trial.

spondylolisthesis. However, muscle activity can be constrained with trunk strength training utilizing functional tasks.<sup>13</sup>

Nine of the 10 articles in this review described chronic spondylolysis and/or spondylolisthesis conditions.<sup>4,5,17,18,23-25,29,30</sup> One study of the acute condition found that bracing was

effective.<sup>1</sup> Positive results with nonoperative treatments were seen within lower grade slippage (grades 0, 1, 2).<sup>18,24</sup>

Only 4 of 9 studies describing interventions for spondylolisthesis reported the degree of slippage, 1 study showed significant improvement with surgery over

Table 2. Injury and diagnostic demographics

Article	Method of Imaging for Diagnosis	Chronic/ Acute Injury	Grade of Spondylolisthesis	Spondylolisthesis Surgical Interventions (% Patients)
Anderson et al <sup>1</sup>	SPECT	Acute	N/A (only spondylolysis)	N/A
Freedman et al <sup>4</sup>	Not described	Chronic	Not reported	Decompression: 2.5 Noninstrumented fusion: 15 Instrumented fusion: 82.5
Gramse et al <sup>5</sup>	Roentgenography	Chronic	Not reported	N/A
Moller and Hedlund <sup>17</sup>	Radiograph	Chronic	Percentage patients with Grade 1 slip: 60 Grade 2 slip: 38 Grade 3 slip: 2	Posterolateral fusion with transpedicular fixation: 48 Posterolateral fusion without instrumentation: 52
O'Sullivan et al <sup>18</sup>	Oblique and lateral radiographs, CT scan	Chronic	Percentage patients with Grade 0 slip (spondylolysis): 42 Grade 1 slip: 47.5 Grade 2 slip: 11.5	N/A
Seitsalo et al <sup>23</sup>	Lateral radiograph	Chronic	Average percentage slip in Nonoperative group: 21.8 (grade 1) Operative group: 45.2 (grade 2)	Posterior fusion: 60 Posterolateral fusion: 38 Anterior fusion: 2
Sinaki et al <sup>24</sup>	Roentgenography	Chronic	Percentage patients with Grade 1 slip in flexion exercise group: 92.3 Grade 1 slip in extension exercise group: 77.7	N/A
Spratt et al <sup>25</sup>	Flexion and extension films	Chronic	Not reported	N/A
Weinstein et al <sup>29</sup>	Radiograph	Chronic	Not reported	Decompression: 5 Fusion without instrumentation: 21 Fusion with instrumentation: 74
Weinstein et al <sup>30</sup>	Radiograph	Chronic	Not reported	In spondylolisthesis patients: Decompression: 5 Fusion without instrumentation: 21 Fusion with instrumentation: 74

nonoperative care (98% of patients had grade 1 or 2 slips),<sup>17</sup> 1 study showed no significant difference between surgery and nonoperative care (average slip in nonoperative group was 21.8%, in the surgery group, 45.2%),<sup>23</sup> and 2 studies found

improvement with specific exercise compared with different exercise (100% of patients had a grade 2 or less slippage in one study, 92.3% and 77.7% of patients in the 2 exercise groups had a grade 1 slippage in the other study).<sup>18,24</sup>

Table 3. Bracing versus activity restriction: interventions, outcomes, and results

Study	Intervention	Outcome	Reported Results	Standardized Mean Difference
Anderson et al <sup>1</sup>	Bracing: Thoracolumbosacral brace (immediate bracing) Restricted: Activity restriction for 3 or more months, then braced (delayed bracing)	Quantitative SPECT imaging	Patients treated with activity restrictions and having symptoms >3 months before bracing had less improvement in defect healing as seen in SPECT imaging versus those braced before 3 months ( $P < 0.05$ )	Bracing: SPECT ratio decrease of 16% Restricted: SPECT ratio decrease of 8%

SPECT, single-photon emission computed tomography.

Table 4. Bracing and direction-based PT versus placebo control

Study	Intervention	Outcome	Reported Results	Standardized Mean Difference
Spratt et al <sup>25</sup>	FT: braced to avoid lumbar extension and taught flexion exercises and to avoid lordotic posture ET: braced to maintain lordotic posture, taught extension exercises, and taught importance of maintaining lordotic posture PC: Given abdominal wrap with no movement limitation, no information regarding flexion or extension, advised walking only if exercise was requested	Pain VAS	Significant improvement in pain VAS with ET compared with FT or PC at 1-month follow-up ( $P < 0.004$ )	VAS outcome measure FT: $5.84 \pm 1.53$ (initial); $5.97 \pm 1.49$ (1 month) ET: $5.6 \pm 1.28$ (initial); $6.85 \pm 1.50$ (1 month) PC: $5.84 \pm 1.53$ (initial); $5.97 \pm 1.49$ (1 month)

VAS, visual analog scale; FT, flexion treatment; ET, extension treatment; PC, placebo control.

## CONCLUSION

No consensus can be reached on the role of nonoperative versus surgical care because of limited investigation and heterogeneity of studies reported. Current studies investigating both nonoperative and surgical outcomes for individuals with

spondylolysis/spondylolisthesis are generally poorly defined and suffer from bias, lack of control groups, and blinding of assessors. Poor patient compliance was noted with many of the exercise programs. Many studies lacked uniform reporting of the spondylolisthesis grade, making it difficult to compare patient populations.

Table 5. Exercise interventions

Study	Intervention	Outcome	Reported Results	Standardized Mean Difference
O'Sullivan et al <sup>18</sup>	EG: Specific training of deep abdominals and lumbar multifidi CG: Regular weekly general exercise	McGill pain questionnaire ODI Lumbar spine/hip sagittal ROM EMG of IO/rectus abdominis	EG: Significant decrease in pain intensity ( $P < 0.0001$ ), ODI ( $P < 0.0001$ ), pre- versus postintervention CG: No significant change in pain intensity, ODI	Pain intensity EG: $59 \pm 24$ (initial); $19 \pm 21$ (final) CG: $53 \pm 25$ (initial); $48 \pm 23$ (final) ODI: EG: $29 \pm 15$ (initial); $15 \pm 17$ (final) CG: $26 \pm 16$ (initial); $25 \pm 18$ (final)
Gramse et al <sup>5</sup>	Flexion: Flexion back strengthening exercises Extension: Extension back strengthening exercises Both received education regarding posture, lifting, use of heat	Self-rated pain levels, return to work, self-rated recovery status	At least 3-month follow-up: flexion group had significantly less pain rated as "moderate or severe" versus extension group ( $P < 0.01$ ); flexion group had smaller percentage of patients in limited work or unable to work versus extension group ( $P < 0.02$ ); flexion group had higher percentage of self-rated recovery versus extension group ( $P < 0.001$ )	Flexion group: Moderate/severe pain rating: 27% at 3-month follow-up Limited/unable to work: 32% at 3-month follow-up Self-rated recovery: 61% "recovered" at 3-month follow-up Extension group: Moderate/severe pain rating: 67% at 3-month follow-up Limited/unable to work: 61% at 3-month follow-up Self-rated recovery: 6% "recovered" at 3-month follow-up
Sinaki et al <sup>24</sup>	Flexion: Flexion back strengthening exercises Extension: Extension back strengthening exercises Both received education regarding posture, lifting, use of heat	Self-rated pain levels, return to work, self-rated recovery status	Fewer patients treated with flexion rated pain as moderate or severe at 3-year follow-up versus extension group ( $P < 0.01$ ); flexion group had smaller percentage of patients in limited or unable to work versus extension group ( $P < 0.05$ ); flexion group had higher percentage of self-rated recovery versus extension group ( $P < 0.01$ )	Flexion group: Moderate/severe pain rating: 19% at 3 years Limited/unable to work: 24% at 3 years Recovery: 58% at 3 months, 62% at 3 years Extension group: Moderate/severe pain rating: 67% at 3 years Limited/unable to work: 61% at 3 years Recovery: 0% at 3 years

SD, standard deviation; EG, exercise group; CG, control group; ODI, Oswestry Disability Index; EMG, electromyography; IO, internal oblique; ROM, range of motion.



## Clinical Recommendations

### SORT: Strength of Recommendation Taxonomy

**A:** consistent, good-quality patient-oriented evidence

**B:** inconsistent or limited-quality patient-oriented evidence

**C:** consensus, disease-oriented evidence, usual practice, expert opinion, or case series

Clinical Recommendation	SORT Evidence Rating
Surgical treatment improves pain and functional limitation versus nonoperative treatment for diabetic or nondiabetic patients with spondylolisthesis, but no difference in amount of vertebral slip in the L4/5 disk. <sup>4,17,23,29,30</sup>	<b>B</b>
Thoracolumbar bracing improved healing of pars interarticularis defects over restricted activity for children/adolescents with spondylolysis. <sup>1</sup>	<b>C</b>
Bracing and lumbar extension exercise improves pain over bracing and lumbar flexion for patients with spondylolisthesis. <sup>25</sup>	<b>C</b>
Exercises focusing on lumbar flexion improve pain, self-reported recovery, and return to work versus exercises focusing on lumbar extension in patients with spondylolisthesis. <sup>5,24</sup>	<b>C</b>
Strengthening specific abdominal/stabilizing musculature improves pain and functional limitation general exercise. <sup>18</sup>	<b>B</b>

## REFERENCES

- Anderson K, Sarwark JF, Conway JJ, Logue ES, Schafer MF. Quantitative assessment with SPECT imaging of stress injuries of the pars interarticularis and response to bracing. *J Pediatr Orthop*. 2000;20:28-33.
- Chosa E, Totoribe K, Tajima N. A biomechanical study of lumbar spondylolysis based on a three-dimensional finite element method. *J Orthop Res*. 2004;22:158-163.
- Cyron BM, Hutton WC, Troup JD. Spondylolytic fractures. *J Bone Joint Surg Br*. 1976;58-B:462-466.
- Freedman MK, Hilibrand AS, Blood EA, et al. The impact of diabetes on the outcomes of surgical and nonsurgical treatment of patients in the spine patient outcomes research trial. *Spine (Phila Pa 1976)*. 2011;36:290-307.
- Gramse RR, Sinaki M, Ilstrup DM. Lumbar spondylolisthesis: a rational approach to conservative treatment. *Mayo Clin Proc*. 1980;55:681-686.
- Hensinger RN. Spondylolysis and spondylolisthesis in children and adolescents. *J Bone Joint Surg Am*. 1989;71:1098-1107.
- Herman MJ, Pizzutillo PD. Spondylolysis and spondylolisthesis in the child and adolescent: a new classification. *Clin Orthop Relat Res*. 2005;(434):46-54.
- Iwamoto J, Sato Y, Takeda T, Matsumoto H. Return to sports activity by athletes after treatment of spondylolysis. *World J Orthop*. 2010;1:26-30.
- Kalichman L, Kim DH, Li L, Guermazi A, Berkin V, Hunter DJ. Spondylolysis and spondylolisthesis: prevalence and association with low back pain in the adult community-based population. *Spine (Phila Pa 1976)*. 2009;34:199-205.
- MacDonald DA, Moseley GL, Hodges PW. The lumbar multifidus: does the evidence support clinical beliefs? *Man Ther*. 2006;11:254-263.
- Masci L, Pike J, Malara F, Phillips B, Bennell K, Brukner P. Use of the one-legged hyperextension test and magnetic resonance imaging in the diagnosis of active spondylolysis. *Br J Sports Med*. 2006;40:940-946.
- McCleary MD, Congeni JA. Current concepts in the diagnosis and treatment of spondylolysis in young athletes. *Curr Sports Med Rep*. 2007;6:62-66.
- McGill SM, Karpowicz A, Fenwick CM, Brown SH. Exercises for the torso performed in a standing posture: spine and hip motion and motor patterns and spine load. *J Strength Cond Res*. 2009;23:455-464.
- McGregor AH, Anderton L, Gedroyc WM, Johnson J, Hughes SP. The use of interventional open MRI to assess the kinematics of the lumbar spine in patients with spondylolisthesis. *Spine (Phila Pa 1976)*. 2002;27:1582-1586.
- McNeely ML, Torrance G, Magee DJ. A systematic review of physiotherapy for spondylolysis and spondylolisthesis. *Man Ther*. 2003;8:80-91.
- Meyerding HW. Spondylolisthesis. *Surg Gynecol Obstet*. 1932;54:371-377.
- Moller H, Hedlund R. Surgery versus conservative management in adult isthmic spondylolisthesis—a prospective randomized study: part 1. *Spine (Phila Pa 1976)*. 2000;25:1711-1715.
- O'Sullivan PB, Phytty GD, Twomey LT, Allison GT. Evaluation of specific stabilizing exercise in the treatment of chronic low back pain with radiologic diagnosis of spondylolysis or spondylolisthesis. *Spine (Phila Pa 1976)*. 1997;22:2959-2967.
- Panjabi MM. The stabilizing system of the spine. Part I. Function, dysfunction, adaptation, and enhancement. *J Spinal Disord*. 1992;5:383-389.
- Panjabi MM. The stabilizing system of the spine. Part II. Neutral zone and instability hypothesis. *J Spinal Disord*. 1992;5:390-396.
- Patel DR, Nelson TL. Sports injuries in adolescents. *Med Clin North Am*. 2000;84:983-1007.
- Pope MH, Panjabi M. Biomechanical definitions of spinal instability. *Spine (Phila Pa 1976)*. 1985;10:255-256.
- Seitsalo S, Schlenzka D, Poussa M, Osterman K. Disc degeneration in young patients with isthmic spondylolisthesis treated operatively or conservatively: a long-term follow-up. *Eur Spine J*. 1997;6:393-397.
- Sinaki M, Lutness MP, Ilstrup DM, Chu CP, Gramse RR. Lumbar spondylolisthesis: retrospective comparison and three-year follow-up of two conservative treatment programs. *Arch Phys Med Rehabil*. 1989;70:594-598.
- Spratt KF, Weinstein JN, Lehmann TR, Woody J, Sayre H. Efficacy of flexion and extension treatments incorporating braces for low-back pain patients with retrodisplacement, spondylolisthesis, or normal sagittal translation. *Spine (Phila Pa 1976)*. 1993;18:1839-1849.
- Standaert CJ, Herring SA. Expert opinion and controversies in sports and musculoskeletal medicine: the diagnosis and treatment of spondylolysis in adolescent athletes. *Arch Phys Med Rehabil*. 2007;88:537-540.
- Standaert CJ, Herring SA. Spondylolysis: a critical review. *Br J Sports Med*. 2000;34:415-422.
- Sys J, Michielsen J, Bracke P, Martens M, Verstreken J. Nonoperative treatment of active spondylolysis in elite athletes with normal X-ray findings: literature review and results of conservative treatment. *Eur Spine J*. 2001;10:498-504.
- Weinstein JN, Lurie JD, Tosteson TD, et al. Surgical compared with nonoperative treatment for lumbar degenerative spondylolisthesis: four-year results in the Spine Patient Outcomes Research Trial (SPORT) randomized and observational cohorts. *J Bone Joint Surg Am*. 2009;91:1295-1304.
- Weinstein JN, Lurie JD, Tosteson TD, et al. Surgical versus nonsurgical treatment for lumbar degenerative spondylolisthesis. *N Engl J Med*. 2007;356:2257-2270.
- Wiltse LL, Newman PH, Macnab I. Classification of spondylolysis and spondylolisthesis. *Clin Orthop Relat Res*. 1976;(117):23-29.
- Wiltse LL, Winter RB. Terminology and measurement of spondylolisthesis. *J Bone Joint Surg Am*. 1983;65:768-772.