Review of Surgical and Nonsurgical Treatments for Spondylolisthesis

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Affecting nearly 20% of the adult population, spondylolisthesis is a common condition where one vertebra slides on top of another. There is controversy as to whether or not surgical methods are necessary and beneficial towards patient satisfaction and pain management. Typically, nonsurgical methods are used when spondylolisthesis is classified as grade I or II based on Meyerding's grading scale, whereas patients with grades III and IV require surgery. This is because slippage greater than 50% results in compression of spinal nerves as well as the spinal cord, causing severe sciatica. Nonsurgical methods mainly consist of physical therapy and medications to relieve pain and decrease some pressure from the spine. While both surgical and nonsurgical methods decrease pain levels, there are no studies comparing outcomes with different surgical techniques and non-surgical treatment options. The purpose of this literature review analysis was to compare multiple clinical study reports addressing the surgical and nonsurgical outcomes of patients with spondylolisthesis. Multiple age ranges were reviewed along with postoperative results for spondylolisthesis slippage, patient satisfaction, and complication rates. Among surgical procedures studied, Surgical Reduction decreased the slippage seen in spondylolisthesis with 100% patient-reported improvement while Scott's Modified Pars Repair effectively corrected spondylolisthesis with the least complication risk involved. Patients undergoing nonsurgical treatment experienced short-term positive results sometimes followed by the need to use surgical treatments due to progressive degeneration.

Keywords: Spondylolisthesis, Spine surgery, Spinal diseases, Surgical outcomes, Nonsurgical outcomes, Spondylolysis, Laminectomy, Discectomy

Introduction

The purpose of this study is to analyze results and summarize outcomes of various surgical and nonsurgical treatment interventions for spondylolisthesis. At the most, research on surgical versus nonsurgical treatment has been analyzed to generalize which category is most effective, while surgical case studies have limited their research to specific techniques. There is a lack of concise literature including the comparisons of different treatment options, both surgical and nonsurgical. This review allows for the opportunity to discover efficacy of multiple surgical and nonsurgical options.

The medical condition termed "spondylolisthesis" is defined as the slippage of a vertebra over the vertebra directly below it. Meyerding's grading scale is used to classify slippage degree in spondylolisthesis[1]. Each grade is determined by the percent to which the vertebra has slipped relative to the inferior vertebra. Grade I is less than 25% slippage, grade II is 25% to 50% slippage, grade III is 50% to 75% slippage, and grade IV is 75% to 100% slippage. Grade V, also termed spondyloptosis, is diagnosed past 100% slippage and is rarely encountered.

Degenerative disc disease one of the most common causes of spondylolisthesis in adults[2]. After discs dry out and thin, the vertebrae in proximity tend to slip and can cause nerve or spinal cord compression. This is termed "spinal stenosis", the narrowing of the spinal canal. Spondylolisthesis facilitates stenosis because the vertebral movement directly impacts the spinal cord.

Vertebral slippage can also be induced by an external injury that involves spondylolysis, a fracture in the pars interarticularis[2]. This portion of the vertebrae normally connects facet joints, effectively holding the spine together in its sagittal position. Slippage caused by spondylolysis can lead to isthmic or traumatic spondylolisthesis, both of which are caused by external injuries. Specifically, when spondylolysis is present, spondylolisthesis usually follows as part of the vertebral column that is no longer stable and in its proper position. The pain that comes with these major types of spondylolisthesis is commonly seen as sciatica or pain in the lower back itself. Patients' abilities to continue their regular activities and hobbies then become hindered and even worsen over time as spondylolisthesis progresses.

Fortunately, because pain is induced by nerve compression, simple methods of pain reduction are available in the form of nonsurgical treatment such as medication. Other forms of pain management include surgery to eliminate slippage as much as possible or decompress nerve roots.

Laminectomies, specifically, involve the removal of part or all of the lamina. This effectively changes the shape of vertebrae to allow for spinal nerve decompression[3]. Meanwhile, if

a herniated disc is present, a discectomy can be performed to remove part or all of the disc. This relieves spinal nerve pressure that was previously facilitated by improper disc positions. Another technique includes surgical reduction, which adjusts the vertebra back into its original place. With this technique, both slippage and pain can be decreased due to the decompression and realignment involved[4].

For spondylolisthesis caused by pars fracture, surgical procedures have been used successfully to fix the fracture causing the slippage. Buck's technique involves drilling part of the bone and then screwing the fracture in place for healing. Scott's technique consists of using wire in order to "stitch" the fracture. Scott's modified technique can be used with a pedicle screw for fixation[5]. All of these methods hold the vertebra in place to prevent slippage.

For severe cases, a sacral dome osteotomy can be used for decompression and reduction of the spine. This is done by an initial partway removal of the sacrum to then allow space for the reduction of the vertebra itself. Sacral dome osteotomies decrease slippage while allowing for decompression at a greater degree compared to reduction by itself[6]. Additionally, high-grade spondylolisthesis can be treated by a combination of techniques as seen in Bohlman's method. Two types of decompression and fusion are used to ensure surgical effectiveness. These decompression methods, which typically involve laminectomies and discectomies, are administered in both the spinal canal area as well as the intervertebral foramen where spinal nerves start to exit spine. To prevent future spondylolisthesis development, interbody fusion and posterior fusion are performed. Interbody fusion involves the use of bone graft for stabilization between slipped and healthy vertebrae, while posterior fusion generally involves placement of bone graft along the back of the spine. With Bohlman's method, both current and future concerns for spondylolisthesis are addressed, although the procedure itself is more complex when compared to other surgeries[7].

Common nonsurgical treatments for symptomatic spondylolisthesis typically include a combination of pain management and physical therapy, while restriction of offending activities with a brace is used when there is a fractured pars interarticularis. Medical management includes corticosteroid injections or prescription pain medication. Personalized physical therapy can target strength in specific areas of the body, such as the lower back, to improve posture and decrease spinal pressure. Braces are typically used temporarily to align the spine while preventing further spinal movement so that slippage doesn't further progress[8].

Since research studies comparing outcomes of different surgical and non-surgical procedures for spondylolisthesis are uncommon, this paper seeks to summarize the efficacy of various treatment options available.

Results

Surgical procedure results were analyzed for three outcome measures: (1) reduction in slippage from pre to post-operative, (2) the subjects self-reported improvement scores and finally (3) complication rates. The sacral dome osteotomy procedure produced excellent results in terms of overall improvement, with 70% reduction in slippage, 93% of patients reporting improvement and 26.6% complication rate as shown in Figure 1. The reduction with fusion procedure also exhibited excellent results as seen with the 100% patients reporting improvement, reduced slippage by 59.9% on average but reported a 44% complication rate.

Many common surgical techniques, including fusion in situ and laminectomies, do not focus on anatomical reduction of the slippage seen in spondylolisthesis. Fusion in situ had a 4% slip reduction with 82% patients reporting improvement and 18% complication rate. Laminectomies do not correct slippage at all but 68.8% of patients undergoing this procedure reported improvement with a 13.8% complication rate. Even without anatomical reduction of the slippage, significant patient improvement scores demonstrate excellent post-operative results.

The Bohlman procedure generally lowered spondylolisthesis by one grade (25%) on average as seen in Figure 1, with 89.8% of patients reporting improvement and 37.5% of patients having some complication during or after surgery

Figure 1 also shows different outcomes reported for similar procedures. Variations of the pars repair procedure differed in complication rates, ranging from 2.7% for the Modified Scotts Pars Repair to 57% for the Bucks Pars Repair. The percentage of patients reporting improvement, ranged from a low of 28.5% for the Bucks Pars Repair to a high of 83.8% with the Modified Scotts Pars Repair procedure. The Buck's, Scott's, and Modified methods all reduced slippage by 7% on average.

Complication rates did not correlate with percentage of patient reporting improvement scores. The reduction with fusion procedure had the greatest amount of patient self-reported improvement at 100%, even with a relatively high complication rate of 44%.

In contrast, surgeries not as invasive, such as decompression methods and laminectomies, had a lower complication rate. In fact, adding surgical fusion to laminectomy procedure lowered the complication rate by 3.8% in comparison to just the laminectomy itself. There was also a 10% increase in patient satisfaction. Fusion when done by itself tends to have more complications than laminectomy with a rate of 18% versus 13%, but better self-reported improvement of 82% versus 68% for laminectomy as shown in Figure 1.

When the use of a brace was combined with conservative treatments such as the use of medication and discontinued activities, 95% of patients reported improvement as seen in Figure 2. The use of bracing with medication resulted in 78% of patients

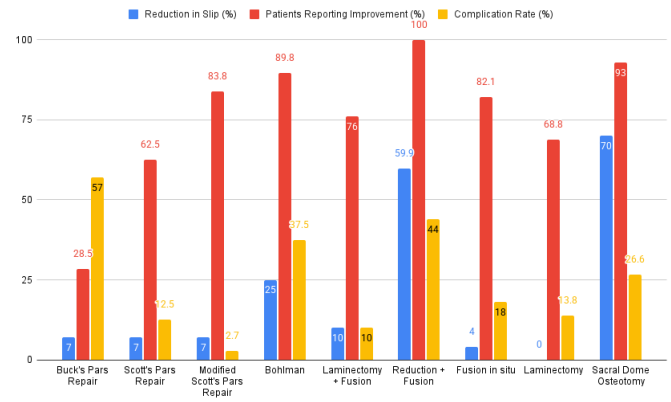

Fig. 1 A bar graph indicating the resulting average percentage values for reduction in slip, patients reporting improvement, and complication rate per type of surgical technique. The blue bars represent values for percent slip reduction, the red bars indicate values for percentage of patients reporting improvement, and the yellow bars indicate complication rate. The Y-axis displays values from 0 to 100 percent for all given dependent variables, while the X-axis represents the various surgical techniques considered in the study.

reporting improvement, while the use of bracing only without medication resulted in 36% patients reporting improvement. Essentially, adding medication to brace use increased average patient satisfaction by 42%, which was higher than brace use or physical therapy by itself. Physical therapy treatment alone had 32.2% self-reported improvement.

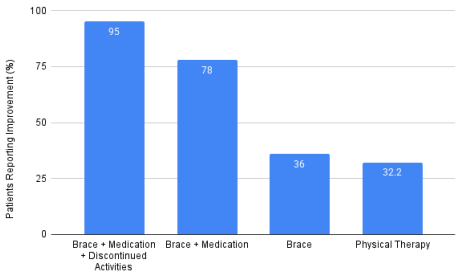

Fig. 2 A bar graph showing the average percentage of patients reporting improvement per type of nonsurgical method. The Y-axis represents percentage values from 0 to 100 based on the percentage of patients reporting improvement, while the X-axis represents the various nonsurgical methods considered in the study.

Discussion

When analyzing the various reductions in spondylolisthesis slippage, it is unsurprising that the different variations of the pars repair all had the same averages of 7% according to Figure 1. This is mainly due to the fact that patients who had very low-grade spondylolisthesis hoped to decrease the chance of developing further spondylolisthesis in the future. So, it makes sense that the pars repair, which solely focuses on the fixation of the pars interarticularis, did not have any significant effect on spondylolisthesis slippage itself at the time of operation. Instead, the method is important for addressing the fracture in the vertebrae. Pedicle screws are used in the fixation of the pars interarticularis when looking at the modified Scott's pars repair technique[5]. Improvement can be seen due to the fact that screw implementation provides greater support for the pars interarticularis. In fact, the outcome of 83.8% of patients reporting improvement according to Figure 1 is due to this extra support. Hence, spondylolisthesis is less likely to develop in the future. The usage of screws is also more reliable, therefore leading to a lower complication rate. When this pars repair technique is compared to Scott's and Buck's method, it is apparent in Figure 1 that Buck's technique exhibits a larger complication rate of 57% from the use of drilling. Though the drilling helps to stabilize fractures easier, it may not be as safe for the patient. This uncertainty leads to the lower improvement percentage of 28.5% as seen in Figure 1. Meanwhile, the Scott's repair seems appealing from its usage of cables for stabilization. But, cable usage simply isn't as strong as the method used in Modified Scott's repair[5]. This explains the contrast of Scott's repair in Figure 1 in regards to the slightly higher complication rate of 12.5% and lower improvement percentage of 62.5%. The associated study of F. Giudici et al. only included 10 patients in Scotts Repair and 7 patients Buck's repair, respectively[5]. Scott's modified repair included 45 patients due to limitations of the other operations, meaning that more certainty is given to this method in regards to the procedure and data. Overall, the modified Scott's pars repair poses a reliable way to prevent spondylolisthesis slippage. However, these findings may not be applicable to older patients. F. Giudici et al. included patients under 25 years of age when examining the various pars repair methods. Additionally, these patients had spondylolisthesis slippage under 15%. Older patients may generally have a higher grade of spondylolisthesis simply because of the condition's progressive nature. Hence, the pars repair variations may not provide the same degree of positive outcomes among different age groups.

The reduction with fusion technique is also another effective way to reduce spondylolisthesis slippage while maintaining patient satisfaction. Firstly, reduction directly targets spondylolisthesis slippage while also decompressing any nerve roots[4]. This is evident by the 59.9% average decrease in slip as evident in Figure 1. In fact, reduction with fusion had the second highest reduction in slip average compared to all the surgeries listed in this study. However, J. Štulík et al. only included patients age 13 years or younger, with grade II spondylolisthesis or higher, suggesting that the outcomes may be different if patients with less severe spondylolisthesis or different age ranges were included[4]. The decompressive method offered by surgical

reduction of vertebrae is an effective way to manage pain as indicated by the 100% patient reported improvement scores in Figure 1. It is important to note that this result was noted by multiple patient studies from the research paper of this surgical technique. Even though reduction combined with fusion is an effective treatment method for spondylolisthesis, there is added risk from the fusion aspect of the surgery. Its invasiveness, especially from harvesting bone graft, leads to increased infection rates. This contributes to the relatively high complication rate of 44% as seen in Figure 1.

Because fusion in situ involves fusion of vertebrae without any reduction, spondylolisthesis slippage decreased only 4% as shown in Figure 1. Even though this method does not effectively treat slippage, 82.1% of patients surprisingly reported improvement according to Figure 1. This is likely due to the fact that fusion prevents further slippage and pain. Fusion is also associated with less flexibility due to impairment of bone movement, but it is a decent method for treating the future development of spondylolisthesis[9,10]. The study by M. Martiniani et al. only included 6 patients for in situ fusion which reduces generalizability to a larger population[10]. Additionally, even though most patients in their study reported improvement, the patients selected for the study were under 28 years of age, thus limiting clinical relevance to older populations.

Decompression methods, which typically involve laminectomies or discectomies, are still a common practice for treating spondylolisthesis. This is emphasized by the fact that this study found 68.8% of patients reporting improvement for the laminectomy according to Figure 1. This study by J.N. Weinstein et al. incorporated older patients, with an average age of 64.7 years[3]. 78% of patients selected for the study were "very dissatisfied" with their symptoms before the procedure, therefore creating a selection bias. These patients had a lot of pain to begin with, making them more likely to observe a difference in pain. Nearly 45% of patients had hypertension and 18% had a heart problem, indicating that this study did not target younger patients and the outcomes may not be applicable to them. Nonetheless, another main advantage for this procedure is the very low complication rates. In fact, the laminectomy had the third lowest complication rate of 13.8% as can be seen in Figure 1. These methods have become less invasive over time due to the fact that smaller incisions allow for small parts of bone or discs to be removed to allow for targeted decompression of nerves[11,12]. However, it appears that for better overall outcomes, laminectomies should be paired with reduction or fusion. When laminectomies are paired with fusion, a higher patient satisfaction rate of 76% can be seen, as in Figure 1. The addition of fusion decreased slippage by 6% more on average when comparing the two surgeries in Figure 1. Decompression methods by themselves do not reduce spondylolisthesis slippage, increasing the risk for future nerve compression.

Even though the Bohlman technique consists of fusion and decompression, the surgery performed well compared to the other methods that directly treat spondylolisthesis. Surprisingly, slippage reduced by 25% on average as seen in Figure 1, which is higher than other decompression methods. However, R. A. Hart et al. included patients of all ages with only grades III and IV spondylolisthesis[7]. Slip reduction for lesser grades may have different outcomes. Patients also underwent fusion at either the L4-S1 level or the L5-S1 level, and different screws were used for fixation. Increased stabilization can lead to a decrease in movement capabilities, thereby also affecting satisfaction rates. On the other hand, because decompression is involved to some extent, pain levels decreased leading to better patient satisfaction. The relatively high complication rate of 37.5% in Figure 1, however, was a result of the fact that the Bohlman uses two types of fusion. Post-op complications of infection and failure of fusion have been described by the authors[7].

The sacral dome osteotomy technique is appealing due to the fact that it involves a combination of reduction, fusion, and decompression. As seen in Figure 1, 93% of patients that received this surgery reported improvement largely because of nerve decompression and preventative measures for future spondylolisthesis. K. Min et al. only included patients with grade IV or V spondylolisthesis, therefore the procedure's value cannot be estimated for less severe cases[6]. Another confounding factor is age of patients selected, since this study included patients younger than 29 years only. This technique significantly reduces spondylolisthesis slippage as evident by the 70% slip reduction average seen in Figure 1. The complication rate of 26.6% evident in Figure 1 can be attributed to the fact that this technique combines multiple surgical techniques, increasing the risk of iliac crest infections from bone graft as well as other conditions[6].

Nonsurgical management is very effective when multiple treatment measures are combined. The data proves that medication by itself should be associated with large amounts of improvement. This is because a 42% increase was seen in average patient satisfaction when adding medication to brace use, as seen in Figure 2. Patients who used a spinal brace without medication were much less likely to have satisfaction, as evident in Figure 2 by the 36% average. This is largely due to the fact that in M. E. Steiner et al.'s study, there was a wide selection of patients with differing severity of slippage and varied severity of symptoms[12]. Furthermore, this study included patients with a mean age of 16 years, which reduces applicability to older patients. Medication, meanwhile, directly targets pain by relieving inflammation in the affected area of the spine. This leads to medication being the most effective nonsurgical pain relief method. Just the use of medication, however, may not be the only sufficient treatment method. The satisfaction rate, according to Figure 2, further rose 17% after patients were advised to discontinue offending activities which can be attributed to better healing over time. Physical therapy by itself may not be an ideal

treatment method, as evident by the relatively low satisfaction rate of 32.2% as seen in Figure 2. Combining non-surgical treatment methods with the use of a brace should involve consulting a physical therapist for optimal results[8,12].

Surgical and nonsurgical methods can be effective in their own ways, but the decision ultimately depends on the severity of symptoms and grade of spondylolisthesis, which helps the patient and provider analyze which nonsurgical or surgical treatment is the better option.

Patients who have spondylolysis are likely to develop spondylolisthesis in the future since progression can get worse due to an unstable spine. If spondylolysis is diagnosed quickly, then spondylolisthesis can be easily prevented with the modified Scott's pars repair technique. This ultimately has an extremely low risk of complications compared to other pars repair techniques, and the method uses pedicle screws to minimize invasion while keeping the pars interarticularis together during the healing process.

Meanwhile, spondylolisthesis is most effectively treated with the use of reduction and fusion. Reduction takes pressure off of spinal nerves directly and this decompression reduces symptoms immediately. Surgical Fusion stabilizes the spine. This procedure results in the best patient reported improvement scores.

Sacral dome osteotomies should be used when patients with spondylolisthesis have spondyloptosis. Slippage may not be decreased below grade I, but most pain is managed with this surgery since nerves can be decompressed significantly. Bone can also be reshaped during the procedure, making surgical fusion much easier. When vertebrae go through spondyloptosis, this is needed to align the vertebral column again to stabilize the spine.

Nonsurgical treatments are very effective for treating spondylolisthesis pain, but only when combined with other conservative treatments. A combination of discontinuing activities, physical therapy, bracing, and medication should be used to get the most pain reduced. But surgery should be considered when spondylolisthesis slippage is past grade II. This is because pain can be harder to manage, and degeneration of the spine still continues, even with nonsurgical treatment.

Limitations for this research include a lack of literature and case studies for some surgical techniques. Newer methods, such as sacral dome osteotomies, have not been studied as much as some of the other surgical techniques. In addition, most research papers lack uniformity in measuring outcomes. Different surveys are used to measure specific pain locations, and most research papers lack data on individual patient results. Cumulative results are reported instead. Additionally, surgical technique execution is not uniform across physicians. Essentially, results can vary due to the fact that techniques may be executed differently from one surgeon to another. Different instrumentation and different methods for similar techniques can lead to different outcomes.

It is also important to note that many confounding variables were not mentioned in the studies analyzed. Comorbidities, surgeon's experience, surgical environment, and hospital can greatly influence data by introducing variability in procedural effectiveness and patient outcomes.

Research in the future should consist of multiple data points across surgery instead of mean results in order to allow for more accurate statistical analysis. Additionally, it is much easier to measure results across different surgeries if the same surveying tool is used to measure patient reported satisfaction. Currently, patient outcomes can be subjective and different questions are asked to measure pain levels. Attention should also be brought to less common surgical procedures since they can be more efficient and effective for certain specific conditions or situations.

Methods

Search Strategy

To locate different study methods, a PubMed search tool was used with specific keywords. This included "Spondylolisthesis", "Surgical", "Nonsurgical", "Complications", "Slip", "Satisfaction", and "Improvement". A filter was applied to only include research papers rather than presentations or posters. PubMed Central was then used to analyze articles in their full text.

Inclusion and Exclusion Criteria

Research papers had to be either a narrative review, a clinical study report, or a systematic literature review about spondylolisthesis treatment. This included research papers that have done studies of specific surgical techniques, or papers that have compared different types of techniques regardless of surgical or nonsurgical discussions. Patients in these studies were of all ages ranging from children to seniors with symptomatic spondylolisthesis. In addition, papers that contained any information on surgical procedures for spondylolisthesis must have been included only if they were published after the year 2000 in order to analyze most modern techniques. However, papers that included nonsurgical information on spondylolisthesis had no restrictions based on the publication date as nonsurgical methods from even the 20th century are still being used today.

Initially 51 primary articles were chosen and it was ensured that each article had its own independent variable, papers were then checked to make sure that specific dependent variables were included. For research involving surgical techniques, this meant having primary outcomes such as mean slip reduction, percent of patients reporting improvement after treatment, and the rate of complications. Nonsurgical techniques only consisted of percent of patients reporting improvement as the primary outcome. These outcomes were present at least 6 months post-intervention, except for spondylolisthesis slippage, which was measured right

after the operation. 36 articles were then excluded since they lacked the specific outcome measures needed. If the total number of patients was present along with the number of patients applied to each primary outcome in an article, then the article was included and the data could be collected from that article by calculating the specific percentage for a primary outcome.

After further exclusion, 15 research articles that included fusion techniques, reduction techniques, decompressive technique, and conservative treatments were selected. It is also important to note that some studies included multiple surgical techniques. Specifically, 3 studies included multiple surgical methods. One of the studies notably had 3 different variations of the pars repair, including Buck's, Scott's, and modified Scott's techniques. This overlap led to a total of 14 different independent variables.

Data Extraction

After ensuring that all data could be collected, data was aggregated into two separate Google Sheet documents. These documents were separated by surgical and nonsurgical treatment while including all the necessary independent variables and dependent variables to form tables.

For surgical methods, this meant including the variety of methods found: Buck's pars repair, Scott's pars repair, Scott's modified pars repair, Bohlman technique, laminectomy plus fusion, reduction plus fusion, fusion in situ, laminectomy, and sacral dome osteotomy. These identified as the independent variables, and they were placed horizontally along a table made for aggregating the data.

Meanwhile, the dependent variables, which consisted of mean slip reduction, percentage of patients reporting improvement after surgery, and complication rate, were all placed vertically along the data table.

Similarly, for nonsurgical treatments, four treatment methods or combinations were found and placed horizontally along a separate table on Google Sheets. This consisted of brace with medication and discontinued activities, brace with medication, brace, and physical therapy. The dependent variable, percentage of patients reporting improvement, was placed vertically along the table.

Each article was specifically analyzed for reduction in slippage as a percentage from pre-op to post-op. If the outcome data was not already calculated by the authors of the study as a percentage change, then the data for pre- to post-operation slip percentage from the study was used to calculate reduction in slippage for each procedure.

After data tables were properly set up, corresponding percentages were carried over from the research articles to the spreadsheet document in order to prepare for graph creation.

Synthesis Method

In regard to data analysis, two charts were made for surgical and nonsurgical comparisons. After data extraction, a chart creation tool was used on Google Sheets to visualize the various methods. One chart consisted of a bar graph where the surgical methods were placed on the X-axis and the respective percentages on the Y-axis. All dependent variables were included on the bar graph since the outcome measure of percentages remained consistent. A coloring system was used to distinctly represent the dependent variable was being measured. For nonsurgical methods, a bar graph was also created to visualize data. The following independent variables were placed along the X-axis: brace with medication and discontinued activities, brace with medication, brace, and physical therapy. On the Y-axis included the primary outcome measure, which was percentage of patients reporting improvement.

A narrative method was used to analyze the surgical and nonsurgical methods as a whole. Statistical analysis methods were not used in this study due to a lack of consistency in scoring methods throughout the studies found. Data was summarized and significance for various outcomes were derived in relation to other outcome measures. A narration of the results allowed for easier comparisons of advantages and disadvantages between various interventions.

Meanwhile, nonsurgical methods also did not require a certain type of scoring method as the only dependent variable included was the percentage of patients reporting improvement due to the use of conservative treatment. From the research articles included, independent variables consisted of physical therapy, a brace with medication and discontinued activities, a brace with medication, and a brace by itself. The various nonsurgical treatment methods were then correlated with their results based off of their article findings.

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References

1 N. V. Mohile, A. S. Kuczmarski, D. Lee *et al.*, *Spondylolysis and isthmic spondylolisthesis: A guide to diagnosis and management*, 2022.

2 P. J. Denard, K. F. Holton, J. Miller *et al.*, *Lumbar spondylolisthesis among elderly men*, 2010.

3 J. N. Weinstein, J. D. Lurie, T. D. Tosteson *et al.*, *Surgical versus nonsurgical treatment for lumbar degenerative spondylolisthesis*, 2007.

4 J. Štulík, G. Geri, M. Barna *et al.*, *High-grade high-dysplastic lumbosacral spondylolisthesis in children treated with complete reduction and single-level circumferential fusion: A prospective case series*, 2022.

5 F. Giudici, L. Minoia, M. Archetti *et al.*, *Long-term results of the direct repair of spondylolisthesis*, 2011.

6 K. Min, T. Liebscher and D. Rothenfluh, *Sacral dome resection and single-stage posterior reduction in the treatment of high-grade high dysplastic spondylolisthesis in adolescents and young adults*, 2011.

7 R. A. Hart, C. M. Domes, B. Goodwin *et al.*, *High-grade spondylolisthesis treated using a modified Bohlman technique: Results among multiple surgeons*, 2014.

8 S. Goetzinger, S. Courtney, K. Yee *et al.*, *Spondylolysis in young athletes: An overview emphasizing nonoperative management*, 2020.

9 X. Xue, X. Wei and L. Li, *Surgical versus nonsurgical treatment for high-grade spondylolisthesis in children and adolescents*, 2016.

10 M. Martiniani *et al.*, *"In Situ" Fusion or Reduction in High-Grade High Dysplastic Developmental Spondylolisthesis (HDSS)*, 2012.

11 P. Försth, G. Ólafsson, T. Carlsson *et al.*, *A randomized, controlled trial of fusion surgery for lumbar spinal stenosis*, 2016.

12 M. E. Steiner and L. J. Micheli, *Treatment of symptomatic spondylolysis and spondylolisthesis with the modified Boston brace*, 1985.