A comparison of the techniques of direct pars interarticularis repairs for spondylolysis and low-grade spondylolisthesis: a meta-analysis

Nasser Mohammed, MD, MCh, Devi Prasad Patra, MD, MCh, Vinayak Narayan, MD, MCh, Amey R. Savardekar, MCh, Rimal Hanif Dossani, MD, Papireddy Bollam, MD, MSCh, Shyamal Bir, MD, PhD, and Anil Nanda, MD, MPH

Department of Neurosurgery, LSU-HSC, Shreveport, Louisiana

OBJECTIVE Spondylolysis with or without spondylolisthesis that does not respond to conservative management has an excellent outcome with direct pars interarticularis repair. Direct repair preserves the segmental spinal motion. A number of operative techniques for direct repair are practiced; however, the procedure of choice is not clearly defined. The present study aims to clarify the advantages and disadvantages of the different operative techniques and their outcomes.

METHODS A meta-analysis was conducted in accordance with the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines. The following databases were searched: PubMed, Cochrane Library, Web of Science, and CINAHL (*Cumulative Index to Nursing and Allied Health Literature*). Studies of patients with spondylolysis with or without low-grade spondylolisthesis who underwent direct repair were included. The patients were divided into 4 groups based on the operative technique used: the Buck repair group, Scott repair group, Morscher repair group, and pedicle screw–based repair group. The pooled data were analyzed using the DerSimonian and Laird random-effects model. Tests for bias and heterogeneity were performed. The I^2 statistic was calculated, and the results were analyzed. Statistical analysis was performed using StatsDirect version 2.

RESULTS Forty-six studies consisting of 900 patients were included in the study. The majority of the patients were in their 2nd decade of life. The Buck group included 19 studies with 305 patients; the Scott group had 8 studies with 162 patients. The Morscher method included 5 studies with 193 patients, and the pedicle group included 14 studies with 240 patients. The overall pooled fusion, complication, and outcome rates were calculated. The pooled rates for fusion for the Buck, Scott, Morscher, and pedicle screw groups were 83.53%, 81.57%, 77.72%, and 90.21%, respectively. The pooled complication rates for the Buck, Scott, Morscher, and pedicle screw groups were 13.41%, 22.35%, 27.42%, and 12.8%, respectively, and the pooled positive outcome rates for the Buck, Scott, Morscher, and pedicle screw groups were 84.33%, 82.49%, 80.30%, and 80.1%, respectively. The pedicle group had the best fusion rate and lowest complication rate.

CONCLUSIONS The pedicle screw–based direct pars repair for spondylolysis and low-grade spondylolisthesis is the best choice of procedure, with the highest fusion and lowest complication rates, followed by the Buck repair. The Morscher and Scott repairs were associated with a high rate of complication and lower rates of fusion.

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KEY WORDS direct repair; Buck repair; Scott repair; Morscher repair; spondylolysis; spondylolisthesis; pedicle screw–rod system; pedicle screw–hook system

THE bipedal gait of *Homo sapiens* has an evolutionary advantage to our survival but has put a biomechanical disadvantage on the lumbar spine. Spondylolysis is defined as a defect of the pars interarticularis, either unilateral or bilateral; it is estimated to occur in

3%–7% of the adult population.³ Sport activities carry a higher risk of spondylolysis with repetitive axial loading and hyperextension. The incidence of spondylolysis has been reported to be as high as 55% in fast bowlers.¹⁴ The repeated stresses that fall on the pars in highly demanding

ABBREVIATIONS BMP = bone morphogenetic protein.

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sports, such as weight lifting, cricket, soccer, and gymnastics, result in stress fractures. In most cases, spondylolysis and low-grade spondylolisthesis remain asymptomatic.³ However, in some cases, the pain can become disabling, prevent the patient from working, and progress to spondylolisthesis. Conservative management is the gold standard as the initial treatment of spondylolysis. Surgical treatment is advised in patients who have disabling symptoms despite conservative management or when there is a progression to spondylolisthesis.⁴⁰ Intersegmental fusion would unnecessarily lead to stiffness of the spine and adjacent-segment disease and degeneration, especially in young patients.⁴⁴ Therefore, there is much interest in direct repair of the pars interarticularis. Direct repair focuses on repair of the pars without causing motion restriction in the adjacent segments. The aim is to preserve spinal segmental motion and restore normal anatomy. There are many types of direct repair, with differing biomechanical properties. However, there is a lack of clarity regarding the surgical procedure of choice. The purpose of this study was to perform a systematic review and investigate differences in the fusion rate, complications, and outcomes between the following 4 types of direct pars repair: Buck repair,⁶ Scott repair,²⁹ Morscher repair,²⁸ and pedicle screw-based repair.

Methods

We performed a systematic review to identify the fusion rate, complication rate, and rate of positive outcome in the different techniques of direct pars interarticularis repair. A detailed protocol about the literature search, inclusion/exclusion criteria, selection of cases, and statistical methodology was developed. The PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines were followed (Fig. 1A). Two investigators (N.M. and V.N.) performed the literature search. To minimize selection bias, 2 reviewers (A.R.S. and D.P.P.) reviewed the articles independently. In case of doubt, a mutual consensus was reached after discussion.

Literature Search Strategy

A computerized Web search was performed of the titles and abstracts from January 1960 to June 2017 in the PubMed, Cochrane Library, Web of Science, and CINAHL (*Cumulative Index to Nursing and Allied Health Literature*) databases. A combination of key word searches were made to build a search strategy; non-English-language literature was also searched. Three non-English-language articles were reviewed after translation. An independent Web search was performed with the key words to include any unpublished literature. Key words that were used to build the search directory were “spondylolysis,” “spondylolisthesis,” “pars interarticularis,” “direct repair,” “Buck’s fusion,” “Scott’s repair,” and “Morscher’s repair.” Additional search terms used were “repair,” “surgery,” “fusion,” and “complications.”

Bias Assessment

Two investigators independently reviewed all articles to eliminate selection bias. A meta-analysis of proportions

was performed. The present study includes only observational studies, and bias would be expected. All included studies were retrospective observational studies; no randomized controlled trials were found. For each subsection of the meta-analysis, bias indicator tests, specifically the Begg-Mazumdar and Egger tests, were performed. Funnel plots were created to check the heterogeneity of the studies (Fig. 1B). The Q statistic and I^2 were calculated to assess heterogeneity. The I^2 values in the Buck repair group and the pedicle repair group were low. The I^2 values in the Scott repair group and Morscher repair group were high, suggesting increased heterogeneity. The Begg-Mazumdar test showed low power in the Scott repair group and Morscher repair group.

Inclusion and Exclusion Criteria

Studies of patients who had spondylolysis with or without low-grade spondylolisthesis and who underwent surgery for direct pars interarticularis repair were selected from the literature and included in this meta-analysis. Age was not considered a criterion for inclusion in the study. Single case reports and small case series with fewer than 5 cases were excluded. Only direct repairs were selected. Patients who underwent fusion with adjacent segments or whose procedures involved facet joint fusion were excluded. Symptomatic spondylolysis not responding to conservative management and low-grade spondylolisthesis (Meyerding classification²⁷ grades I and II) only were considered.

Patients with associated pathologies, such as spinal canal stenosis, disc degeneration, and radiculopathy, were excluded. Patients with both sporting and nonsporting backgrounds were included.

Statistical Analysis

Statistical analysis was done using StatsDirect statistical software (version 2.7.9, StatsDirect Ltd.). Due to the inherent heterogeneity of observational studies, the random-effects model was used for the meta-analysis. The meta-analysis of proportions was carried out, along with the test for heterogeneity, and the I^2 value and Q statistic were evaluated. The DerSimonian and Laird model was used to calculate the pooled effect. Forest plots were charted for each group, analyzing the pooled fusion rate, complication rate, and outcome. For each subsection of the meta-analysis, bias assessment was done using the Begg-Mazumdar and Egger tests. Funnel plots were generated for each subset of the meta-analysis. The I^2 value ranged from 0% to as high as 82% in the various groups of meta-analysis, suggesting a wide variation and heterogeneity across the included studies.

Results

Forty-six studies reporting on 900 patients who matched the inclusion criterion were selected for analysis (Table 1). The mean age ranged from 12 to 38 years. The average age was younger than 20 years in 25 studies. In only 4 studies was the average age older than 30 years; the majority of patients were in their 2nd decade of life. The percentage of males was higher in the majority of the studies. Nine studies included patients exclusively from a

FIG. 1. A: PRISMA protocol showing the selection of cases. **B:** Funnel plot for the pedicle group showing asymmetrical distribution indicating presence of bias.

sporting background. Preoperative evaluation was done by examining flexion and extension radiographs, CT scans, MR images, and, in some studies, SPECT scans. Five studies included patients who were from sport and nonsport backgrounds. In 4 series, the authors used a minimally invasive approach for the Buck repair.^{10,12,21,51} Three studies used bone morphogenetic protein (BMP) to aid the fusion. Eight studies used pedicle screws with laminar hooks, and 4 studies used pedicle screws with a wiring technique. The proportion of patients with low-grade spondylolisthesis ranged from 5.26%³³ to 100%^{7,30,47} in the included studies. While most studies included cases of low-grade spondylolisthesis, the exact proportion of cases was mentioned in only 16 studies.

Based on the surgical techniques used to repair the pars, the studies were grouped broadly into 4 categories. Buck's technique of repair was used in the first group. In this technique, a screw is passed across the pars defect. In this group, 19 studies with 305 patients were included. The Scott wiring technique was used in the second group. In this technique, a wire is wound around the transverse process and spinous process to stabilize the pars defect. Eight studies with 162 patients were included in this group. The Morscher method was used in 5 studies with 193 patients. The fourth group included 14 studies accounting for 240 patients who underwent pedicle screw-based repair. The purpose of this study was to investigate differences in the fusion rate, complications, and positive outcomes between the 4 broad categories of the pars repair. There were no prospective randomized studies addressing this issue. The fusion rate, complication rate, and positive outcome rate were compared between the groups (Table 2).

Fusion Rate

Fusion was assessed on radiographs in the majority of studies; CT scans were used in 9 studies.^{7,9,10,12,17,18,21,31,34} Ivanic et al.¹⁸ evaluated CT scans only in cases of doubtful fusion. The remaining studies did not mention the method used for assessing fusion. The pooled rates for fusion

for the Buck, Scott, Morscher, and pedicle screw groups were 83.53%, 81.57%, 77.72%, and 90.21%, respectively. The pooled fusion rates were highest for pedicle screw-based repairs and lowest for the Morscher method. The Buck method had the second highest fusion rate after the pedicle screw systems (Fig. 2).

Complication Rate

The complications of the different procedures were specified in most studies; 8 studies lacked specification. Both immediate and late complications were included in the analysis. The pooled complication rates for the Buck, Scott, Morscher, and pedicle screw groups were 13.41%, 22.35%, 27.42%, and 12.8%, respectively. The complications were lowest for the pedicle screw-based repairs, followed by the Buck repair. The highest complication rates were observed in the Morscher method.

While some complications, such as superficial wound infections, were common to all 4 groups, some were specific to the type of repair used. Root irritation was more often observed in the Buck group, followed by the Morscher group, than in the other 2 groups. Wire breakage was the prominent complication for the Scott repair and resulted in nonunion. Transverse process fracture and wire protrusions were specific to the Scott group. The Morscher method was associated with a high incidence of nonunion and implant loosening. The pedicle screw-based group had the least incidence of superficial wound infection, nonunion, and implant loosening or pullout (Fig. 3).

Outcome Analysis

In most of the studies, the outcome was measured using nonstandardized scales, such as the Henderson criteria, Macnab criteria, modified Macnab criteria, and Odom criteria. Only 5 studies reported outcomes on standardized scales, such as the Oswestry Disability Index or the Japanese Orthopaedic Association scale. For analyzing the outcome measures in the present study, cases in which

TABLE 1. Characteristics of the studies included in the meta-analysis

Authors & Year	No. of Pts	Age in Yrs*	M/F Sex	Sport	Associated w/ Listerhesis		FU in Most	Fusion in %	Complications (%)	Favorable Outcome in %	Surgical Technique
					in %	in %					
Hardcastle et al., 1992	10	20.9 (15–25)	10/0	Cricket	10	17.9 (6–47)	100	2	2 superficial wound infections (20)	90	Buck repair
Ranawat et al., 2003	10	21.7	10/0	Cricket	27.7	68 (22–120)	NS	NS	Intraop drill break (10)	100	Buck repair
Debnath et al., 2003	19	20.2 (15–34)	15/7	Variety	NS	7	NS	NS	NS	94.73	Buck repair
Buck, 1970	16	NS	NS	Mixed	NS	NS	93.75	1	1 root irritation, 1 nonunion due to screw loosening (12.5)	81	Buck repair
Bonnicci et al., 1991	24	31 (13–55)	15/9	Mixed	NS	(13–144)	79.16	1	1 postop sciatica, 5 screw loosening, 1 screw breakage (29.16)	91.66	Buck repair
Shin et al., 2012	15	32 (26–42)	NS	NS	NS	28 (24–36)	93.3	NS	NS	68.29	Buck repair
Rajasekaran et al., 2011	9	24 (15–31)	6/3	Nonsport	22.2	45 (9–108)	100	NS	NS	78	Buck repair
Suh et al., 1991	10	30 (19–40)	9/1	Nonsport	NS	8.5 (5–17)	100	NS	NS	60	Buck repair
Snyder et al., 2014	16	16	NS	Nonsport	NS	13.19 (12–24)	89.6	2	2 superficial infections, 1 pseudarthrosis, 1 radiculopathy w/ screw revision (25)	94	Buck repair w/ BMP
Karatas et al., 2016	9	15 (13–17)	5/4	Sport	11	21	100	None	None	88.8	MIS Buck repair
Kim et al., 2012	25	21.2	NS	NS	NS	61.2	72	2	2 screw breakages/nonunions (8)	84	Buck repair
Ghobrial et al., 2017	9	17.7 (14–20)	6/3	Sport	NS	30.8 (2–59)	66.7	1	1 guidewire malposition (11)	100	MIS Buck repair w/ BMP
Gillis et al., 2015	8	16–23	NS	Sport	NS	12–54	75	1	1 screw revision, 2 nonunions (37.5)	75	MIS Buck repair
Pedersen & Hagen, 1988	18	20 (14–38)	6/12	NS	NS	41 (24–72)	83.3	NS	NS	83	Buck repair
Zhu et al., 2015	11	28.4 (19–47)	7/4	NS	NS	15.7 (10–23)	63.63	3	3 donor site pain (27.27)	90.90	Buck repair w/ navigation & microendoscopic technique
de Bodman et al., 2014	20	13.7 (7–19)	18/17	NS	100	112 (24–288)	91.4	3	3 nonunions (15)	83.33	Buck repair
Giudici et al., 2011	7	18 (10–26)	NS	NS	NS	78 (24–180)	42.85	None	None	28	Buck repair
Menga et al., 2014	31	16 (10–37)	14/17	Mixed	NS	60 (24–135)	93.54	2	2 screw breakages, 1 superficial infection (9.67)	90	Buck repair
Ohmori et al., 1992	38	29.3 (13–46)	25/6	NS	5.26	32.5 (18–54)	64.51	2	2 broken screws (25)	92.10	Buck repair
Nozawa et al., 2003	20	23.7 (12–37)	14/6	Athletes	NS	23.7 (12–37)	100	1	1 wire pullout, 2 wire breakages (15)	90	Scott wiring
Johnson & Thompson, 1992	22	15.5	15/7	NS	82	48	90.90	2	2 nonunions, 2 superficial wound infections, 2 wire ruptures, 3 persistent pain (40.97)	90.9	Scott wiring
Schlenzka et al., 2006	25	18.2	9/16	NS	NS	117.6 (132–192)	43	2	2 root irritations, 1 infection, 1 pseudarthrosis (16)	64	Scott wiring
Askar et al., 2003	14	17.4 (13–24)	6/8	NS	35.71	10.9 (8–15)	100	2	2 persistent pain (14.28)	85.72	Scott wiring
Bradford & Iza, 1985	22	24 (14–41)	NS	NS	NS	12 (12–45)	86.36	3	3 nonunions, 1 wire protrusion, 3 wire breakages (29.16)	80	Scott wiring
Hioki et al., 2012	44	24.2 ± 5.4	33/11	Athletes	NS	85 ± 17	67.4	1	1 transverse process fracture, 4 wire breakages (11.36)	93.18	Scott wiring

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TABLE 1. Characteristics of the studies included in the meta-analysis

Authors & Year	No. of Pts	Age in Yrs*	M/F Sex	Sport	Associated w/ Listhesis in %	FU in Most†	Fusion in %	Complications (%)	Favorable Outcome in %	Surgical Technique
Ogawa et al., 2007	7	26.7 (19–37)	5/2	NS	NS	51.0	57.14	3 wire breakages (42.85)	85.21	Scott wiring
Giudici et al., 2011	8	18 (10–26)	5/3	NS	100	78 (24–180)	87.5	1 wire breakage (12.5)	62.5	Scott wiring
Sales de Gauzy et al., 2000	14	12 (7–15)	6/8	NS	NS	33 (16–66)	85.71	8 screw loosening (57.14)	92.85	Morscher method
Hefli et al., 1992	33	NA	NS	NS	NS	42.0	79	NS	79	Morscher method
Ivanic et al., 2003	113	16.9 (7.5–39)	78/35	NS	95	130.9 (12–186)	85.21	15 pseudarthroses, 7 implant loosening, 6 wound sloughings, 1 radicular pain due to screw (25.66)	93	Morscher method (11-yr FU)
Winter & Jani, 1989	16	9–16	NS	NS	NS	NA	50	NS	80	Morscher hook system
Pavlovic, 1994	17	19 (14–31)	11/6	Nonsport	29.41	43.2 (24–64)	82.35	1 root irritation due to screw	82.35	Morscher method
Noggle et al., 2008	5	15.8 (15–17)	4/1	Nonsport	100	7.2 (6–9)	100	1 superficial wound breakdown (20)	100	Minimally invasive PS w/ rod/hook
Songer & Rovin, 1998	7	20.5 (12–32)	NS	Mixed	100	25.5 (19–37)	100	2 persistent pain, 1 cable breakage (14)	71	PS w/ cable
Kakiuchi, 1997	16	32.4 (12–60)	NS	NS	NS	25.2 (24–28)	100	NS	81.25	PS rod w/ hook
Debusscher & Trousel, 2007	23	34 (16–52)	15/8	Nonsport	52.17	59 (6–113)	91	2 nonunions	87	PS w/ hook
Altat et al., 2011	20	13.9 (9–21)	12/8	Nonsport	45	4 (2.3–7.3)	80	4 nonunions	90	PS w/ rod
Shin et al., 2012	23	38 (24–48)	NS	Nonsport	NS	37 (30–52)	78.3	1 screw misplacement, 1 root irritation (8.69)	82.60	PS w/ hook
Karatas et al., 2016	7	15.8 ± 1.1 (SD)	5/2	Sport	14.28	24	100	1 sensory deficit, 2 wound infections (42.85)	85.71	PS w/ rod & hook, BMP used
Roca et al., 2005	19	20.5 (13–29)	NS	NS	NS	30 (24–48)	68.42	NS	78.94	PS hook
Koptan et al., 2011	10	16 (14–19)	3/7	Mixed	NS	54 (24–154)	90	1 donor site pain, 1 superficial infection (20)	80	PS w/ rod & cable in scoliotic patients
Pai et al., 2008	14	23 (16–56)	12/2	Nonsport	21.42	76.2 (48–120)	50	7 nonunions (50)	64.28	PS w/ cable (van Dam modification)
Pu et al., 2014	32	22 (19–32)	NS	NS	NS	14 (12–24)	100	None	NS	PS w/ rod
Zhou et al., 2013	22	18.4 (12–26)	19/3	NS	NS	25 (12–45)	100	1 donor site pain (4.5)	75.55	PS w/ lamina hook
Giudici et al., 2011	37	18 (10–26)†	NS	NS	NS	78 (24–180)	97.29	3 wire breakages/loosening (8.15)	83.8	PS w/ wiring
Lundin et al., 2003	5	16 (15–18)	1/4	NS	40	30–78	100	None	60	PS w/ hook

FU = follow-up; MIS = minimally invasive; NS = not specified; PS = pedicle screw; Pts = patients.

* Age is presented as mean (range) unless otherwise indicated.

† Values are given as median (range).

TABLE 2. Pooled fusion, complication, and favorable outcome rates in 4 groups of direct pars interarticularis repairs

Technique	No. of Pts	No. of Studies	Pooled Fusion Rate (95% CI)	Pooled Complication Rate (95% CI)	Pooled Positive Outcome Rate (95% CI)
Buck repair	305	19	83.53% (76–89%)	13.41% (8–18%)	84.33% (78–89%)
Scott repair	162	8	81.57% (65–93%)	22.35% (14–31%)	82.49% (73–89%)
Morscher repair	193	5	77.72% (66–86%)	27.42% (8–51%)	80.30% (80–88%)
PS-based repair	240	14	90.21% (82–96%)	12.8% (6–21%)	80.1% (74–85%)

A. Buck's Repair: Pooled fusion rate 84% **B. Scott's Repair: Pooled fusion rate 82%** **C. Morscher's Repair: Pooled fusion rate 78%** **D. Pedicle Repair: Pooled fusion rate 90%**

FIG. 2. Pooled proportional meta-analysis of the fusion rate. **A:** The Buck repair showed a pooled fusion rate of 84%. $I^2 = 54.9\%$. Random effects: pooled proportion = 0.835393 (95% CI 0.763996–0.896067). Begg-Mazumdar: Kendall's tau = -0.477612 , $p = 0.0092$. Egger: bias = -3.086419 (95% CI = -5.234691 to -0.938148), $p = 0.0079$. **B:** The Scott repair showed a pooled fusion rate of 82%. $I^2 = 82\%$. Random effects: pooled proportion = 0.815706 (95% CI 0.65304–0.935116). Begg-Mazumdar: Kendall's tau = -0.571429 , $p = 0.0312$ (low power). Egger: bias = -4.067637 (95% CI -8.329782 to 0.194509), $p = 0.0582$. **C:** The Morscher repair showed a pooled fusion rate of 78%. $I^2 = 53.9\%$. Random effects: pooled proportion = 0.777205 (95% CI 0.668954–0.869173). Begg-Mazumdar: Kendall's tau = -0.4 , $p = 0.2333$ (low power). Egger: bias = -1.596565 (95% CI -5.142773 to 1.949642), $p = 0.2473$. **D:** The pedicle screw repair showed a pooled fusion rate of 90%. $I^2 = 68.9\%$. Random effects: pooled proportion = 0.902137 (95% CI 0.822408–0.960009). Begg-Mazumdar: Kendall's tau = -0.438202 , $p = 0.0364$. Egger: bias = -1.719656 (95% CI -3.084794 to -0.354518), $p = 0.0178$.

FIG. 3. Pooled proportional meta-analysis of the complication rates. **A:** The Buck repair showed a pooled complication rate of 13%. $I^2 = 31.5\%$. Random effects: pooled proportion = 0.134178 (95% CI 0.086908–0.189836). Begg-Mazumdar: Kendall's tau = 0.52381, $p = 0.0059$. Egger: bias = 1.930049 (95% CI 0.771404–3.088694), $p = 0.0032$. **B:** The Scott repair showed a pooled complication rate of 22%. $I^2 = 37.1\%$. Random effects: pooled proportion = 0.223571 (95% CI 0.146507–0.311594). Begg-Mazumdar: Kendall's tau = 0.285714, $p = 0.3988$ (low power). Egger: bias = 2.184051 (95% CI –0.309288 to 4.677389), $p = 0.0758$. **C:** The Morscher repair showed a pooled complication rate of 27%. $I^2 = 80.2$. Random effects: pooled proportion = 0.274245 (95% CI 0.088969–0.514053). **D:** The pedicle screw repair showed a pooled fusion complication rate of 13%. $I^2 = 67.6$. Random effects: pooled proportion = 0.128798 (95% CI 0.062435–0.214551). Begg-Mazumdar: Kendall's tau = 0.662921, $p = 0.0014$. Egger: bias = 2.305739 (95% CI 1.29242 to 3.319058), $p = 0.0003$.

the patient improved completely without any symptoms of pain and returned to work were considered as positive outcomes. A postoperative Oswestry Disability Index score less than 20 was considered a positive outcome. The excellent and good outcomes in the Henderson, Odom, and Macnab criteria were considered as positive outcomes. Patients who had persisting pain or who were unable to return to work due to pain were considered to have had a negative outcome. The pooled positive outcome rates for the Buck, Scott, Morscher, and pedicle screw groups were 84.33%, 82.49%, 80.30%, and 80.1%, respectively. The favorable outcome rates were lowest for the pedicle screw

and the Morscher groups. The best outcomes were seen with the Buck repair. The favorable outcome rate for the minimally invasive Buck repair was better than that for the open Buck repair (Fig. 4).

Discussion

Direct repair surgeries have gradually evolved from 1968 to the present day use of minimally invasive approaches. Direct repair of the pars interarticularis was first reported by Kimura²³ in 1968 by using bone graft without the use of internal fixation. After this, Scott in 1986 report-

FIG. 4. Pooled proportional meta-analysis of the positive outcome rate. **A:** The Buck repair showed a pooled outcome rate of 84%. $I^2 = 36\%$. Random effects: pooled proportion = 0.843324 (95% CI 0.788331–0.891384). Begg-Mazumdar: Kendall's tau = -0.625731 , $p < 0.0001$. Egger: bias = -2.559973 (95% CI -3.908265 to -1.211681), $p = 0.0009$. **B:** The Scott repair showed a pooled outcome rate of 82%. $I^2 = 42.1\%$. Random effects: pooled proportion = 0.824903 (95% CI 0.739211–0.896526). Begg-Mazumdar: Kendall's tau = -0.571429 , $p = 0.0312$ (low power). Egger: bias = -2.089109 (95% CI -4.044024 to -0.134194), $p = 0.0399$. **C:** The Morscher repair showed a pooled outcome rate of 80%. $I^2 = 51.7\%$. Random effects: pooled proportion = 0.803549 (95% CI 0.701775–0.88835). Begg-Mazumdar: Kendall's tau = -0.6 , $p = 0.0833$ (low power). Egger: bias = -1.438749 (95% CI -5.109707 to 2.232209), $p = 0.3008$. **D:** The pedicle screw repair showed a pooled outcome rate of 80%. $I^2 = 0\%$. Random effects: pooled proportion = 0.801237 (95% CI 0.745298–0.851789). Begg-Mazumdar: Kendall's tau = -0.358974 , $p = 0.0763$. Egger: bias = -1.138245 (95% CI -2.579258 to 0.302767), $p = 0.11$.

ed the use of a wiring method. In 1970, Buck published his series of direct repairs using a lag screw across the defect in a cohort of fast bowlers.⁶ Morscher et al.,²⁸ in 1984, reported their method as being especially suited to cases of dysplastic lamina where a Buck repair was not possible. Methods based on pedicle screw insertion and minimally invasive methods are relatively recent (Fig. 5).

A total of 46 studies with 900 patients were finally considered for the study (Fig. 1A).

Buck Repair

In the Buck method, a single lag screw is passed from the inferior edge of the lamina across the defect after plac-

ing the autologous graft into the defect. Biomechanical testing in cadaver spines of the intralaminar screw construct has shown good stability of the spondylotic defect in comparison with the other methods.²⁸ The complications of this repair are mainly due to screw loosening or misplacement.¹ Of the 19 studies that used this form of repair, fusion rates ranged from 42.85%¹³ to 100%.^{15,21,38,48} The pooled fusion rate was 83.53%. The series by Giudici et al.¹³ reported the lowest fusion rate. The authors opined that accurate screw placement was the main technical difficulty to achieve a good purchase and compression at the site of defect. It was also noted that in some cases, the screw itself occupied much of the space of the defect in the region of the isthmus, which may prevent bony contact

FIG. 5. Schematic diagram showing the different types of direct repairs. **A:** Buck repair. The screw is passed from the lower edge of the lamina across the defect. **B:** Scott repair. The wire is encircled around the transverse process and spinous process. **C:** Morscher repair. Pedicle screw with laminar hooks. **D:** Pedicle screw with a U-shaped rod. Copyright Anil Nanda. Published with permission.

with the graft.¹³ Screw loosening and screw breakage were the most common complications noted in our study. The complication rate ranged from 0%²¹ to 37.5%.¹² The positive outcome ranged from 28%¹³ to 100%.³⁹

Scott Repair

The Scott repair involves a wire that is encircled around the transverse process and spinous process. The procedure is technically less demanding than the other methods of pars repair. However, it requires a wider exposure and muscle dissection, resulting in greater blood loss.¹ Vascular and nerve root injury can occur when the wire is being encircled across the transverse process, and winding the wire around the transverse process of L-5 might be difficult in cases in which it is close to the sacrum.¹ In our analysis, the main problem noted in most series employing the Scott method was wire breakage.^{2,5,13,17,19,31,32,43} There were 14 such instances reported. The fusion rates ranged from 43%⁴³ to 100%,^{2,31} and the overall pooled favorable outcome of the Scott repair was 82.49%.

Morscher Repair

In the Morscher method, the screw is inserted in the base of the superior articular process. The screw is attached to a laminar hook to achieve approximation of the pars defect. Our analysis showed a high pooled complication rate with the use of this technique (27.42%). In the series by Sales de Gauzy et al.,⁴² there were 8 cases of screw loosening. Ivanic et al.¹⁸ reported a large series of Morscher repairs (113 patients) with a long follow-up period. The series by Winter and Jani⁴⁹ reported a fusion rate of only 50%. In the same series, 7 cases of screw loosening were documented. The Morscher repair was associated with the lowest fusion rate and highest complication rate in our study. The small screw purchase in the base of the superior articular

process could be responsible for many instances of screw pullout and consequent nonfusion.

Pedicle Screw–Based Repairs

Pedicle screw–based repairs were first reported by Songer and Rovin in 1988.⁴⁷ In this method, the authors used a pedicle screw to anchor a cable that approximated the pars defect. Other pedicle screw–based methods include using a pedicle screw with laminar hook fixation³⁰ and using a pedicle screw with a curved rod running under the spinous process to stabilize the pars defect.^{1,11} In all of these techniques, the common anchor is the pedicle screw. The pedicle screw provides strong support with a low incidence of screw pullout due to larger bony purchase. Pedicle screw insertion has become an increasingly familiar procedure among surgeons and allows for minimally invasive approaches as well. Analysis of this group showed excellent fusion rates; fusion rates of 100% were noted in several studies.^{20,21,25,30,37,47,50} The pooled fusion rate was 90.21%. The pedicle screw group had the lowest pooled complication rate of 12.8%. The common complication associated with pedicle screw–based methods involved wire/cable breakage in screw–wire constructs. The pedicle screw–based techniques are associated with the most favorable fusion and lowest complication rates in comparison with the other groups.

Four studies employing the minimally invasive Buck repair with 37 patients were also analyzed.^{10,12,21,51} The minimally invasive series had low complication rates and excellent outcomes. BMP was used to aid fusion in 3 studies.^{10,21,46} All of these studies reported good fusion rates.

Analysis of the data from this study has shown that in patients with spondylolysis and low-grade spondylolisthesis in whom conservative treatment has failed, surgical management substantially improves the outcome and return to activity. Among all studied groups, pedicle screw–based repairs have the best fusion rates and lowest complication rates. Based on this finding, we conclude that the pedicle screw–based repairs are recommended as the repair of choice, followed by the Buck repair. Neither the Scott repair nor the Morscher repair is recommended as the first choice of repair of the pars defect. Patient selection is important in the management of direct repairs. The ideal candidate should have no significant disc degeneration, be young, and have a low-grade spondylolisthesis. Direct repairs are especially suited for young athletes and have shown excellent outcomes.

Justification for Our Analysis

There are a number of surgical procedures that address direct pars repair with different modifications. Moreover, newer, minimally invasive techniques have been introduced. Because of the large variety of different procedures for direct repair, the procedure of choice becomes unclear. To date, there have been systematic reviews that have addressed this issue, but no meta-analysis has been carried out. However, this study attempts to statistically define the differences in types of direct repairs in reference to the rates of fusion, complications, and outcomes. We were unable to find any randomized controlled trials that addressed this issue.

Limitations of the Study

There are a number of limitations of the present study. There were no randomized controlled trials available comparing the different groups. The statistical power of a meta-analysis is highest when randomized controlled trials are included. The present study is a meta-analysis of observational studies. There is a lack of control groups, which can introduce bias. In clinical scenarios, it is not always possible to conduct a meta-analysis. The information in the existing literature, however, cannot be disregarded, and best attempts need to be made to analyze the available data, with an understanding of the included bias that may influence the overall results. The assessment of outcome measures was not standardized in most of the studies. This may introduce discrepancy in the overall assessment of outcome in the study groups. In this study, we combined studies of patients involved in sport activities and those who were not involved in sports into a single analysis. These 2 groups are heterogeneous subsets with different risk factors, and the criteria for assessment of fusion are not well defined in the studies. In some studies, radiography was used, while in others CT scanning was performed. The assessment of fusion using radiographs is less sensitive than that using CT scans, and cases of nonfusion can be potentially missed and judged as fused.

Conclusions

Pedicle screw-based direct repairs for spondylosis and low-grade spondylolisthesis are the best choice of procedure, with the highest fusion rate and lowest complication rate, followed by the Buck repair. The Morscher repair and Scott repair had high rates of complications and lower fusion rates.

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Disclosures

The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

Author Contributions

Conception and design: Nanda, Mohammed. Acquisition of data: Mohammed, Narayan. Analysis and interpretation of data: Nanda, Mohammed, Patra, Narayan. Drafting the article: Nanda, Mohammed, Patra. Critically revising the article: Nanda, Mohammed, Patra. Reviewed submitted version of manuscript: Nanda, Mohammed, Patra. Approved the final version of the manuscript on behalf of all authors: Nanda. Statistical analysis: Mohammed. Administrative/technical/material support: Nanda, Mohammed, Patra, Savardekar, Dossani, Bollam. Study supervision: Nanda, Mohammed, Savardekar, Bollam, Bir.

Correspondence

Anil Nanda: LSU-HSC, Shreveport, Louisiana. ananda@lsuhsc.edu.