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ORIGINAL PAPER

Comparison of percutaneous endoscopic lumbar discectomy versus microendoscopic discectomy for the treatment of lumbar disc herniation: a meta-analysis

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Abstract

Purpose We conducted a systematic review and meta-analysis to compare the clinical outcomes of percutaneous endoscopic lumbar discectomy (PELD) and microendoscopic discectomy (MED) for the treatment of lumbar disc herniation (LDH), and to clarify whether PELD is more superior to MED.

Methods We performed a comprehensive search in the databases of MEDLINE, EMBASE, PubMed, Web of Science, Cochrane database, CNKI, and Wanfang Data to acquire all relevant studies up to July 2018. The searched literatures were then screened according to the strict inclusion and exclusion criteria. The critical data were extracted and analyzed utilizing Review Manager software. The pooled effects were calculated by mean difference (MD) or odds ratio (OR) with 95% confidence intervals (CI) on the basis of data attributes.

Results A total of 18 studies (2161 patients, 1093 in the PELD group and 1068 in the MED group) were included in this systematic review and meta-analysis. At last follow-up, the results revealed that no significant difference was found between PELD group and MED group with respect to ODI (MD − 0.30; 95% CI − 1.02 to 0.42; $P = 0.41$), VAS-leg pain (MD − 0.18; 95% CI − 0.45 to 0.09; $P = 0.19$), VAS-unspecified (MD − 0.00; 95% CI − 0.05 to 0.04; $P = 0.94$), excellent & good rate (OR, 1.04; 95% CI 0.68 to 1.59; $P = 0.86$), total complication rate (OR, 0.96; 95% CI 0.65 to 1.43; $P = 0.85$), dural tear rate (OR, 0.39; 95% CI 0.10 to 1.55; $P = 0.18$), and residue or recurrence rate (OR, 2.22; 95% CI 1.02 to 4.83; $P = 0.05$). When compared to MED group, the PELD group showed significantly better results with regard to shorter length of incision (MD − 1.18; 95% CI − 1.39 to − 0.97; $P < 0.00001$), less blood loss (MD − 45.17; 95% CI − 64.74 to − 25.60; $P < 0.00001$), shorter post-operative in-bed time (MD − 59.11; 95% CI − 71.19 to − 47.04; $P < 0.00001$), shorter post-operative hospital stay (MD − 3.07; 95% CI − 4.81 to − 1.33; $P < 0.00001$), shorter total hospital stay (MD − 2.29; 95% CI − 3.03 to − 1.55; $P < 0.00001$), and lower VAS-back pain at last follow-up (MD − 0.77; 95% CI − 1.31 to − 0.24; $P = 0.005$), but with significantly worse results such as more fluoroscopy (MD 7.63; 95% CI 5.25 to 10.01; $P < 0.00001$) and higher re-operation rate (OR, 2.67; 95% CI 1.07 to 6.67; $P = 0.04$). Although no significant difference was found between the two groups in terms of duration of operation (MD 6.27; 95% CI − 2.44 to 14.98; $P = 0.16$) and total hospital cost (MD − 0.69; 95% CI − 12.60 to 11.23; $P = 0.91$), further subgroup analysis revealed that the duration of operation was significantly longer in the PELD group compared with the MED group in "Years before 2016" (MD 24.97; 95% CI 7.07 to 42.87; $P = 0.006$) and "Year 2016 to 2017" (MD 6.57; 95% CI 0.58 to 12.55; $P = 0.03$) subgroups but not in the subgroup "Year 2018" (MD − 5.66; 95% CI − 18.84 to 7.53; $P = 0.40$), and that the total hospital cost was significantly more in the PELD group compared with the MED group in the subgroup "Southeast of China" (MD 6.67; 95% CI 3.23 to 10.28; $P = 0.0002$) but not in the subgroup "Midwest of China" (MD − 8.09; 95% CI − 17.99 to 1.80; $P = 0.11$).

Conclusions For the treatment of LDH, both of PELD and MED can reach excellent results and no superiority was found between the two minimally invasive procedures with regard to duration of operation, ODI, VAS-leg pain, VAS-unspecified, excellent & good rate, total complication rate, dural tear rate, and residue or recurrence rate. While PELD can achieve better

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outcomes with respect to the length of incision, blood loss, post-operative in-bed time, post-operative hospital stay, total hospital stay, and VAS-back pain at last follow-up, however, MED showed certain advantages of less fluoroscopic times and lower re-operation rate. More practice and development are needed to make up for the deficiencies of PELD. Besides, the economic factor should also be considered according to different regions before making the treatment strategies. Well-defined randomized controlled trials with large samples are needed to further confirm these results.

Keywords Minimally invasive surgery · Percutaneous endoscopic lumbar discectomy · Microendoscopic discectomy · Lumbar disc herniation · Treatment outcome

Introduction

Lumbar disc herniation (LDH), usually manifested as sciatica with low back pain (LBP), is one of the serious health problems that need to seek medical advice and brings about huge cost of medical treatment [1, 2]. To prevent or improve the dysfunction caused by further aggravation of LDH, surgical interventions should be considered when systematic conservative treatments are invalid. With the development of minimally invasive surgery, various procedures have been introduced for minimally invasive discectomy [3]. Notably, one of the classical procedures named microendoscopic discectomy (MED) has achieved stable, lasting, and encouraging clinical outcomes since it was first introduced by Smith and Foley in 1997 [4–8]. However, the destruction of spine tension band and lamina bony structure is unavoidable in MED, which may lead to post-operative lumbar instability and LBP.

In 2002, Yeung and Tsou [9] reported the procedure of percutaneous endoscopic lumbar discectomy (PELD) utilizing the yeung endoscopic spine system (YESS), which was then modified by Hoogland et al. [10] under transforaminal endoscopic spine system (TESSYS). In recent years, percutaneous endoscopic lumbar discectomy (PELD) is becoming more and more popular for the treatment of LDH. This procedure seems to be more superior to MED for the reason that it can be operated under local anaesthesia and with less invasion. Previous studies [11, 12] showed that PELD achieved excellent results regarding safety and efficacy, which was comparable to conventional microsurgical technique and MED, implying an alternative therapeutic technique for LDH. While evidence-based review with large samples is needed to clarify which procedure is more beneficial for patients with LDH, therefore, we carried out this systematic review and meta-analysis to determine the priority of PELD and MED for the treatment of LDH.

Materials and methods

Search strategy

MEDLINE, EMBASE, PubMed, Web of Science, Cochrane database, CNKI, and Wanfang databases were used for identifying relevant studies since the date of inception to July 2018. The search strategy consisted of key words and commonly used synonyms and abbreviations including "percutaneous endoscopic lumbar discectomy/PELD," "percutaneous transforaminal endoscopic discectomy/PTED," "transforaminal endoscopic lumbar discectomy/TELD," "percutaneous endoscopic transforaminal discectomy/PETD," "Yeung endoscopic spine system/YESS," "transforaminal endoscopic spine system/TESSYS," "microendoscopic discectomy/MED," and "lumbar disc herniation/LDH," with appropriate combinations of the operators "AND," "OR," and "NOT." We also evaluated the references cited in the eligible studies and relevant reviews to identify additional studies. The language of the literature was limited to English or Chinese.

Inclusion and exclusion criteria

To obtain credible evidence whether PELD is superior to MED, strict criteria were made to select the searched literatures. Studies were included if they met the following criteria: (1) contrastive study that compared PELD with MED for the treatment of LDH; (2) single-level LDH with sciatica; (3) the technique of PELD could be YESS or TESSYS; and (4) the study reported at least one desirable outcome. Studies were excluded if they met the following criteria: (1) meta-analysis, review article, case report, conference paper, degree dissertation, and data unextractable; (2) without description of specific inclusion and exclusion criteria; (3) patients with a history of spinal surgery; (4) patients with spine abnormalities such as instability, spondylolisthesis, spinal stenosis, infection, tuberculosis, tumour, and so on; (5) no specific surgical plan was introduced; (6) the same operation combined with additional operative procedures; (7) interlaminar approach was used in peld; (8) only less than 20 cases were included in at least one of the groups; (9) the follow-up time period was less than three months; (10) parameters of baseline characteristics with statistical difference; and (11) when overlap of time periods existed in dual or multiple studies reported by the same institution, the most recent one was included, while the others were excluded. Two investigators independently examined the studies selected by the search strategy for the final inclusion. Any disagreement was resolved by discussion with the other authors.

Data extraction

Two reviewers independently extracted the relevant data from the included studies. A standardized form was used to gather the desirable parameters as follows: (1) basic characteristics of the studies and populations, including author information, publication year, sourced country, study design, number of patients, age, sex, and follow-up time; (2) main peri-operative outcomes, including length of incision, duration of operation, fluoroscopy, blood loss, post-operative in-bed time, post-operative hospital stay, total hospital stay, and total hospital cost; (3) functional outcomes pre-operatively and at last follow-up, including Oswestry disability index (ODI), visual analogue score (VAS)-back pain, VAS-leg pain, and VAS-unspecified; and (4) surgical complications and outcomes at last follow-up, including excellent & good rate, total complication rate, dural tear rate, residue or recurrence rate, and re-operation rate. Particularly, we merely included excellent & good outcomes that evaluated by Macnab's criteria [13]. All of the reported complications were considered for the synthesis and analysis in total complication rate, such as dural tear, residue or recurrence, neural injury, persistent strong LBP, infection, poor wound healing, and so on. In particular, we separately analyzed the dural tear rate, neural injury, and residue or recurrence rate, which were considered significant to the prognosis. With regard to the total hospital cost, we contacted the authors to acquire the initial data for unifying the units, when necessary. Also, the time units and length units were also unified according to the data acquired. Several studies might not show the source of pain clearly, so we considered the VAS as VAS-unspecified. Any disagreement between the reviewers was resolved by discussion with other authors. Lastly, the extracted data were rechecked by the corresponding author.

Methodological quality assessment

Two reviewers independently assessed the methodological quality of included studies based on the modified Jadad quality scale [14], which has eight questions to check the quality of evidence. The questions designed are as follows: (A) Was the study described as randomized? (B) Was the method of randomization appropriate? (C) Was the study described as blinded? (D) Was the method of blinding appropriate? (E) Was there a description of withdrawals and dropouts? (F) Was there a clear description of the inclusion/exclusion criteria? (G) Was the method used to assess adverse effects described? And, (H) was the method of statistical analysis described? For each question, answer "Yes" scores 1 point and answer "No" scores 0 point. Total scores of 0–3 indicate poor to low quality and 4–8 good to excellent quality. Any disagreement was resolved by discussion with the other authors.

Data synthesis and statistical analysis

Review Manager software (RevMan version 5.3; The Cochrane Collaboration) was used for data synthesis and statistical analysis. Continuous data were calculated by mean differences (MD) with 95% confidence intervals (CIs), and dichotomous data were calculated by odd ratio (OR) with 95% CI. The chi-squared test and the degree of inconsistency (I^2) were used to evaluate heterogeneity among combined study results [15]. A value of $I^2 < 31\%$ was considered to a fine homogeneity, and the fixed-effect model was used. Otherwise, the data were considered to be heterogenous and the random-effect model was used. $P < 0.05$ was regarded as statistically significant. Funnel plots were used to analyze potential publication bias.

Results

Search results

After the initial search of the electronic databases, a total of 578 articles were identified. The articles were further screened by titles, abstracts, and full texts according to the specific inclusion and exclusion criteria. Ultimately, 560 articles were excluded, and the other 18 were considered to be eligible for inclusion in this meta-analysis [12, 16–32] (2161 patients, 1093 in the PELD group, and 1068 in the MED group). The flow chart of the literature search strategy is shown in Fig. 1.

Baseline characteristics and methodological quality assessment

Among the included studies, eight were prospective studies [16, 17, 19, 21, 22, 25, 27, 30] and the other ten were retrospective ones [12, 18, 20, 23, 24, 26, 28, 29, 31, 32]. Nearly all the included studies were from China, with one exception that was from Korea [17]. With regard to the language, six of 18 articles were English [12, 17, 29–32], while the other 12 were Chinese [16, 18–28]. The baseline characteristics of the included studies and participants are summarized in Table 1.

The detailed information of methodological quality of the included 18 studies is exhibited in Supplementary Table 1. All of the studies scored greater than or equal to 4 points, indicating good to excellent qualities. Seven studies [16, 19, 21, 22, 25, 27, 30] reported of randomly designed, and only one [30] was of a blind method.

Meta-analysis results

Main peri-operative outcomes

With regard to the main peri-operative outcomes, eight parameters including length of incision, duration of operation,

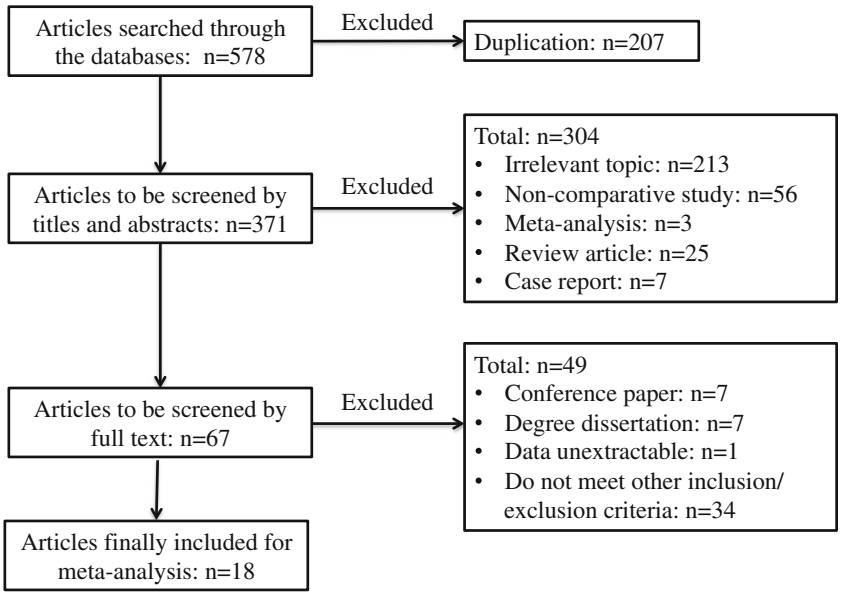

Fig. 1 Flow chart of the literature search strategy

fluoroscopy, blood loss, post-operative in-bed time, post-operative hospital stay, total hospital stay, and total hospital cost were taken into analysis.

The length of incision was available from nine of 18 studies [16, 19–22, 25–27, 32] ($n = 984$ patients; 504 in the PELD group and 480 in the MED group). The heterogeneity was high ($I^2 = 96\%$, $P < 0.00001$), and a random-effect model was used. The length of incision was significantly shorter in the PELD group compared with the MED group (MD − 1.18; 95% CI − 1.39 to − 0.97; $P < 0.00001$) (Fig. 2).

The duration of operation was available from 15 of 18 studies [12, 16, 18, 19, 21–26, 28–32] ($n = 1719$ patients; 859 in the PELD group and 860 in the MED group). The heterogeneity was high ($I^2 = 97\%$, $P < 0.00001$), and a random-effect model was used. The total effect showed that no significant difference was found between the two groups (MD 6.27; 95% CI − 2.44 to 14.98; $P = 0.16$). Furthermore, we carried out a subgroup analysis based on the publication year for further investigation. Specifically, three studies [12, 16, 18] ($n = 285$ patients; 148 in the PELD group and 137 in the MED group) were included in the subgroup "Years before 2016," seven studies [19, 21–26] ($n = 618$ patients; 315 in the PELD group and 303 in the MED group) were included in "Year 2016 to 2017", and five studies [28–32] ($n = 816$ patients; 396 in the PELD group and 420 in the MED group) were included in "Year 2018." All the heterogeneities of the subgroups were high ($I^2 = 93\%$, $P < 0.00001$; $I^2 = 81\%$, $P < 0.00001$; $I^2 = 97\%$, $P < 0.00001$; respectively), and the random-effect models were used. Interesting results emerged in the subgroup analysis, the duration of operation was significantly longer in the PELD group compared with the MED group in "Years before 2016" (MD 24.97; 95% CI 7.07 to 42.87; $P = 0.006$) and "Year 2016 to 2017" (MD 6.57; 95% CI 0.58 to 12.55; $P = 0.03$) subgroups. However, the significant difference gradually decreased with years, and finally, no significant difference was found between the two groups in the subgroup "Year 2018" (MD − 5.66; 95% CI − 18.84 to 7.53; $P = 0.40$) (Fig. 3).

The fluoroscopy was available from three of 18 studies [16, 27, 29] ($n = 549$ patients; 249 in the PELD group and 300 in the MED group). The heterogeneity was high ($I^2 = 94\%$, $P < 0.00001$), and a random-effect model was used. The fluoroscopic times was significantly more in the PELD group compared with the MED group (MD 7.63; 95% CI 5.25 to 10.01; $P < 0.00001$) (Fig. 4).

The blood loss was available from 15 of 18 studies [16, 18–29, 31, 32] ($n = 1871$ patients; 952 in the PELD group and 919 in the MED group). The heterogeneity was high ($I^2 = 100\%$, $P < 0.00001$), and a random-effect model was used. The blood loss was significantly less in the PELD group compared with the MED group (MD − 45.17; 95% CI − 64.74 to − 25.60; $P < 0.00001$) (Fig. 5).

The postoperative in-bed time was available from 10 of 18 studies [16, 19–22, 24, 26, 27, 29, 30] ($n = 1266$ patients; 628 in the PELD group and 638 in the MED group). The heterogeneity was high ($I^2 = 97\%$, $P < 0.00001$), and a random-effect model was used. The post-operative in-bed time (hours) was significantly shorter in the PELD group compared with the MED group (MD − 59.11; 95% CI − 71.19 to − 47.04; $P < 0.00001$) (Fig. 6).

The post-operative hospital stay was available from 2 of 18 studies [16, 27] ($n = 333$ patients; 167 in the PELD group and 166 in the MED group). The heterogeneity was high ($I^2 = 94\%$, $P < 0.00001$), and a random-effect model was used. The post-operative hospital stay (days) was significantly shorter in the PELD group compared with the MED group (MD − 3.07; 95% CI − 4.81 to − 1.33; $P < 0.00001$) (Fig. 7).

Table 1 Baseline characteristics of the studies included in the meta-analysis

Study (author and year)	Design	Source/ language	No. of patients (male/female)		Age (years)		Follow-up (months)		Analysis index
			PELD	MED	PELD	MED	PELD	MED	
Wu et al. 2009 [16]	Prospective	China/ Chinese	30 (18/12)	30 (17/13)	43.53 ± 13.57	45.83 ± 11.83	6	6	①②③④⑤⑥⑨⑬⑱
Yoon et al. 2012 [17]	Prospective	Korea/ English	25 (16/9)	26 (13/13)	45.9 (13–70)	56.4 (32–79)	5.75 (1.5–18)	5.25 (1.5–24)	⑭⑮⑯
Yang et al. 2015 [18]	Retrospective	China/ Chinese	82 (49/33)	57 (35/22)	48.433 ± 0.214(21–74)	47.951 ± 0.218(24–78)	3	3	②④⑦⑬⑭⑮⑯⑰
Sinkemani et al. 2015 [12]	Retrospective	China/ English	36 (23/13)	50 (29/21)	44.17 ± 6.54 (30–55)	41.46 ± 7.22 (30–55)	12	12	②⑦⑧⑨⑬⑱
Duan et al. 2016 [19]	Prospective	China/ Chinese	45 (26/19)	45 (25/20)	47.5 ± 14.9	50.1 ± 15.5	16.3 (6–22)	16.3 (6–22)	①②④⑤⑦⑬
Zhao et al. 2016 [20]	Retrospective	China/ Chinese	72	46	35.6 ± 8.7 (18–67)	35.6 ± 8.7 (18–67)	6	6	①④⑤⑦⑧⑫⑬⑭㉑
Ding et al. 2017 [21]	Prospective	China/ Chinese	40 (29/11)	40 (28/12)	54.2 ± 2.4 (28–67)	54.4 ± 2.6 (31–69)	6	6	①②④⑤⑦⑨⑩⑪⑬⑭⑱⑲⑳
Li et al. 2017 [22]	Prospective	China/ Chinese	50 (29/21)	50 (32/18)	43.0 ± 10.8	42.2 ± 9.7	6	6	①②④⑤⑦⑬⑭
Liu et al. 2017 [23]	Retrospective	China/ Chinese	48 (26/22)	44 (23/21)	43.8 ± 9.2	45.4 ± 7.9	13 (6–18)	13 (6–18)	②④⑦⑨⑩⑪⑱⑲⑳
Luo et al. 2017 [24]	Retrospective	China/ Chinese	62	54	35.65 ± 5.36	36.72 ± 4.33	10	10	②④⑤⑦⑧⑨⑫⑬⑭⑯⑰⑱㉑
Qu et al. 2017 [25]	Prospective	China/ Chinese	40 (25/15)	40 (27/13)	39.05 ± 6.82 (27–68)	38.45 ± 7.04 (26–65)	15.43 ± 3.12 (6–22)	16.34 ± 3.74 (6–24)	①②④⑦⑫⑬⑭㉑
Song et al. 2017 [26]	Retrospective	China/ English	30 (16/14)	30 (17/13)	54.8 ± 6.5	53.6 ± 6.4	18	18	①②④⑤⑨⑫⑬⑱㉑
Chen et al. 2018 [27]	Prospective	China/ Chinese	137 (68/69)	136 (67/69)	64.12 ± 3.68	64.18 ± 3.12	16.55 ± 2.36 (12–24)	16.55 ± 2.36 (12–24)	①③④⑤⑥⑨⑫⑭⑯⑰⑱㉑
Wu et al. 2018 [28]	Retrospective	China/ Chinese	126	120	41.5 (32–65)	41.5 (32–65)	15–18	15–18	②④⑦⑬
Chen et al. 2018 [30]	Prospective	China/ English	80 (52/28)	73 (37/36)	40.2 ± 11.4	40.7 ± 11.1	12	12	②⑤⑦⑧⑨⑩⑪⑭⑮⑯⑰⑱⑲⑳
Li et al. 2018 [31]	Retrospective	China/ English	48 (30/18)	30 (20/10)	18.96 ± 1.99	19.40 ± 1.50	68.87 ± 7.03	67.07 ± 6.76	②④⑦⑨⑩⑪⑭⑮⑯⑱⑲⑳
Liu et al. 2018 [32]	Retrospective	China/ English	60 (31/29)	63 (32/31)	36.2 ± 5.9	33.1 ± 6.7	28.2 ± 2.5	29.6 ± 3.7	①②④⑦⑨⑩⑪⑭⑮⑯⑰⑱⑲⑳
Abudurexiti et al. 2018 [29]	Retrospective	China/ English	82 (38/44)	134 (58/76)	38.2 ± 9.2	36.3 ± 8.6	6–24	6–24	②③④⑤⑦⑨⑩⑪⑭⑱⑲⑳

① length of incision; ② duration of operation; ③ fluoroscopy; ④ blood loss; ⑤ postoperative in-bed time; ⑥ postoperative hospital stay; ⑦ total hospital stay; ⑧ total hospital cost; ⑨ ODI at last follow-up; ⑩ VAS-back pain at last follow-up; ⑪ VAS-leg pain at last follow-up; ⑫ VAS-unspecified at last follow-up; ⑬ excellent and good rate; ⑭ complication rate; ⑮ dural tear rate; ⑯ residue or recurrence rate; ⑰ reoperation rate; ⑱ preoperative ODI; ⑲ preoperative VAS-back pain; ⑳ preoperative VAS-leg pain; ㉑ preoperative VAS-unspecified

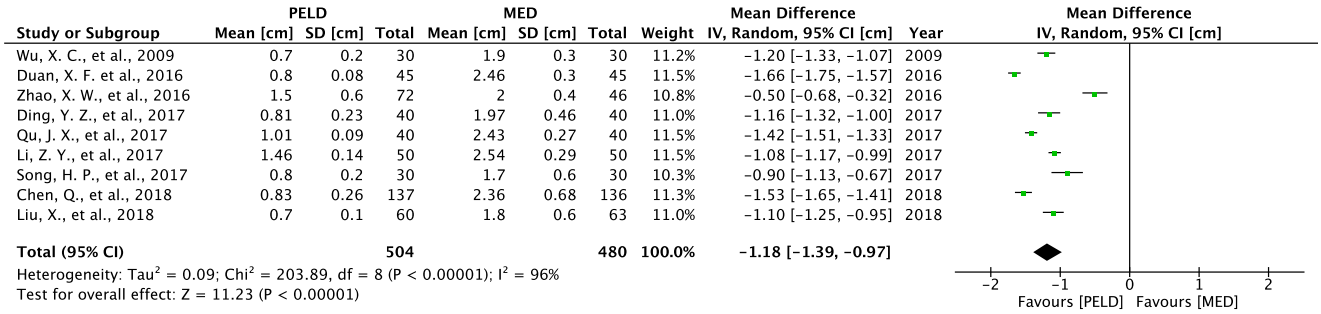

Fig. 2 Forest plot for length of incision (PELD versus MED). It was significantly shorter in the PELD group compared with the MED group

The total hospital stay was available from 14 of 18 studies [12, 18–25, 28–32] ($n = 1717$ patients; 871 in the PELD group and 846 in the MED group). The heterogeneity was high ($I^2 = 96\%$, $P < 0.00001$), and a random-effect model was used. The total hospital stay (days) was significantly shorter in the PELD group compared with the MED group (MD − 2.29; 95% CI − 3.03 to − 1.55; $P < 0.00001$) (Fig. 8).

The total hospital cost (*1000 CNY) was available from four of 18 studies [12, 20, 24, 30] ($n = 473$ patients; 250 in the PELD group and 223 in the MED group). The heterogeneity was high ($I^2 = 100\%$, $P < 0.00001$), and a random-effect model was used. The total effect showed that no significant difference was found between the two groups (MD − 0.69; 95% CI − 12.60 to 11.23; $P = 0.91$). We further conducted a subgroup analysis based on the region (Midwest of China and Southeast of China). More concretely, two studies [20, 24] ($n = 234$ patients; 134 in the PELD group and 100 in the MED group) were included in the subgroup "Midwest of China," and the other two studies [12, 30] ($n = 239$ patients; 116 in the PELD group and 123 in the MED group) were included in the subgroup "Southeast of China." Both of the heterogeneities of the subgroups were high ($I^2 = 99\%$, $P < 0.00001$; $I^2 = 88\%$, $P = 0.004$; respectively) and the random-effect models were used. Notability, no significant difference was found between the two groups in the subgroup "Midwest of China" (MD − 8.09; 95% CI − 17.99 to 1.80; $P = 0.11$), while the total hospital cost was significantly more in the PELD group compared with the MED group in the subgroup "Southeast of China" (MD 6.67; 95% CI 3.23 to 10.28; $P = 0.0002$) (Fig. 9).

Functional outcomes at last follow-up

Four functional parameters including ODI (%), VAS-back pain, VAS-leg pain, and VAS-unspecified were taken into

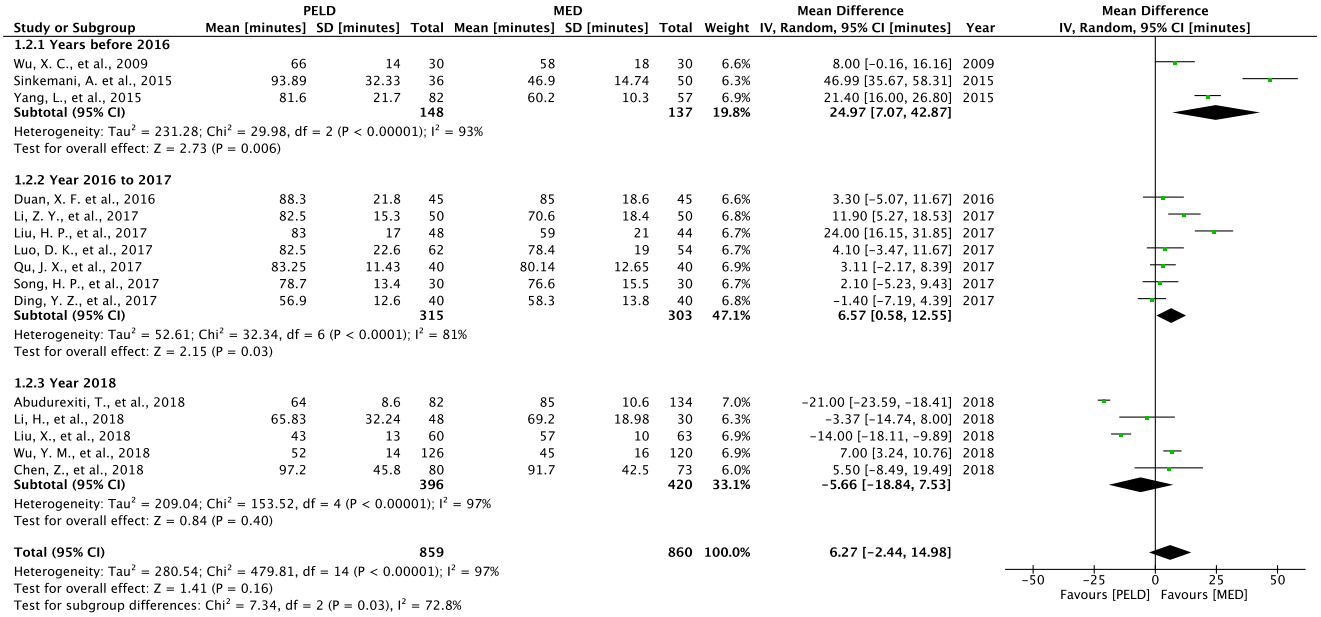

Fig. 3 Forest plot for duration of operation (PELD versus MED). The total effect showed that no significant difference was found between the two groups. While in the subgroup analysis, it was significantly longer in the PELD group compared with the MED group in "Years before 2016" and "Year 2016 to 2017" subgroups. However, the significant difference gradually decreased with years, and finally, no significant difference was found between the two groups in the subgroup "Year 2018"

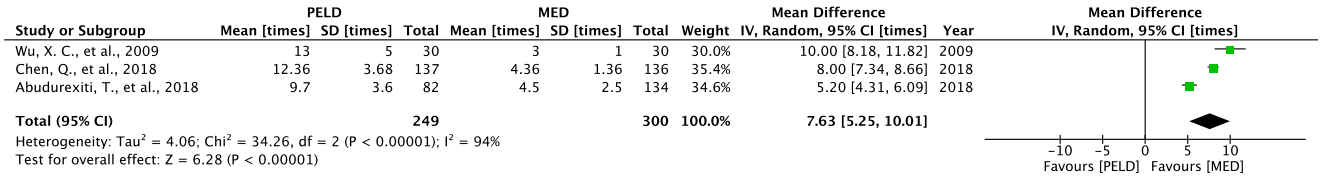

Fig. 4 Forest plot for fluoroscopy (PELD versus MED). It was significantly more in the PELD group compared with the MED group

analysis to evaluate the functional outcomes at last follow-up. Before this procedure, the corresponding pre-operative parameters were also analyzed. No significant difference was found between the two groups with respect to pre-operative ODI (random-effect model; MD −0.66; 95% CI −2.54 to 1.21; $P = 0.49$), VAS-back pain (fixed-effect model; MD −0.06; 95% CI −0.28 to 0.15; $P = 0.56$), VAS-leg pain (fixed-effect model; MD 0.03; 95% CI −0.19 to 0.25; $P = 0.76$), and VAS-unspecified (fixed-effect model; MD 0.04; 95% CI −0.16 to 0.25; $P = 0.68$) (Supplementary Figs. 1–4).

The ODI at last follow-up was available from 11 of 18 studies [12, 16, 21, 23, 24, 26, 27, 29–32] ($n = 1337$ patients; 653 in the PELD group and 684 in the MED group). The heterogeneity was high ($I^2 = 55\%$, $P = 0.01$), and a random-effect model was used. No significant difference was found between the two groups (MD −0.30; 95% CI −1.02 to 0.42; $P = 0.41$) (Fig. 10).

The VAS-back pain at last follow-up was available from six of 18 studies [21, 23, 29–32] ($n = 742$ patients; 358 in the PELD group and 384 in the MED group). The heterogeneity was high ($I^2 = 95\%$, $P < 0.00001$), and a random-effect model was used. The VAS-back pain at last follow-up was significantly lower in the PELD group compared with the MED group (MD −0.77; 95% CI −1.31 to −0.24; $P = 0.005$) (Fig. 11).

The VAS-leg pain at last follow-up was available from six of 18 studies [21, 23, 29–32] ($n = 742$ patients; 358 in the PELD group and 384 in the MED group). The heterogeneity was high ($I^2 = 88\%$, $P < 0.00001$), and a random-effect model was used. No significant difference was found between the two groups (MD −0.18; 95% CI −0.45 to 0.09; $P = 0.19$) (Fig. 12).

The VAS-unspecified at last follow-up was available from 5 of 18 studies [20, 24–27] ($n = 647$ patients; 341 in the PELD group and 306 in the MED group). No heterogeneity existed between the two groups ($I^2 = 0\%$, $P = 0.74$,) and a fixed-effect model was used. No significant difference was found between the two groups (MD −0.00; 95% CI −0.05 to 0.04; $P = 0.94$) (Fig. 13).

Surgical complications and outcomes at last follow-up

At the final follow-up, several crucial parameters that are related to the surgical outcomes were taken into analysis, including excellent & good rate, total complication rate, dural tear rate, residue or recurrence rate, and re-operation rate.

The excellent & good rate was available from 11 of 18 studies [12, 16, 18–22, 24–26, 28] ($n = 1175$ patients; 613 in the PELD group and 562 in the MED group). No heterogeneity existed between the two groups ($I^2 = 0\%$, $P = 0.99$) and a fixed-effect model was used. The excellent & good rate was 92.17% (565/613) in the PELD group and 91.81% (516/562) in the MED group, with no significant difference between the two groups (OR 1.04; 95% CI 0.68 to 1.59; $P = 0.86$) (Fig. 14).

The total complication rate was available from 12 of 18 studies [17, 18, 20–22, 24, 25, 27, 29–32] ($n = 1527$ patients; 778 in the PELD group and 749 in the MED group). No heterogeneity existed between the two groups ($I^2 = 0\%$, $P = 0.90$) and a fixed-effect model was used. The total

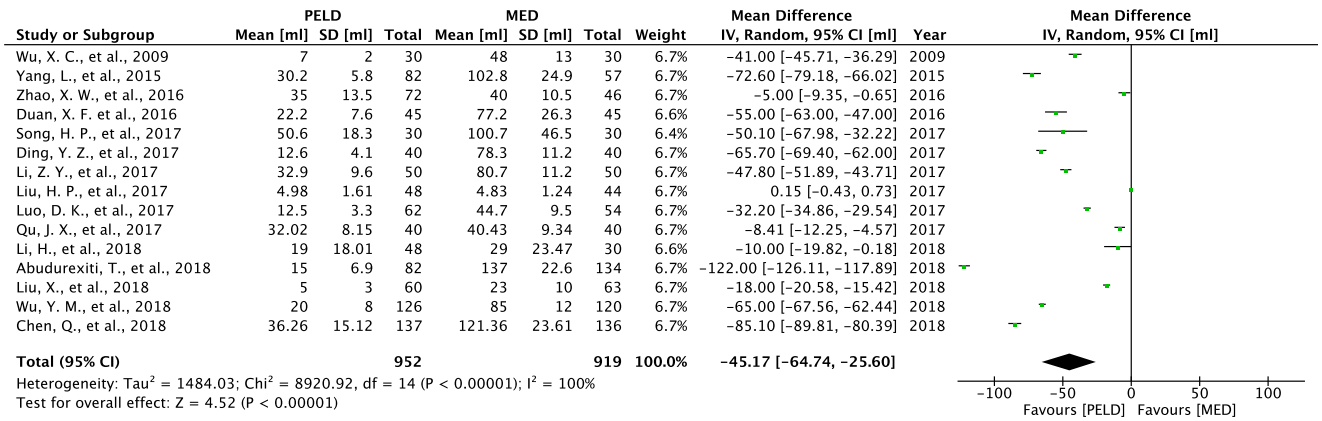

Fig. 5 Forest plot for blood loss (PELD versus MED). It was significantly less in the PELD group compared with the MED group

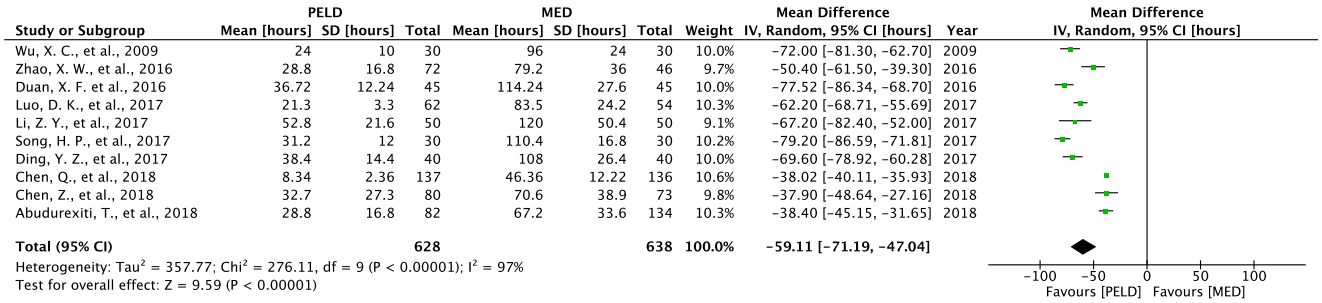

Fig. 6 Forest plot for post-operative in-bed time (PELD versus MED). It was significantly shorter in the PELD group compared with the MED group

complication rate was 6.85% (54/778) in the PELD group and 7.61% (57/749) in the MED group, with no significant difference between the two groups (OR 0.96; 95% CI 0.65 to 1.43; $P = 0.85$) (Fig. 15).

The dural tear rate was available from five of 18 studies [17, 18, 30–32] ($n = 544$ patients; 295 in the PELD group and 249 in the MED group). No heterogeneity existed between the two groups ($I^2 = 0\%$, $P = 0.72$), and a fixed-effect model was used. The dural tear rate was 0.68% (2/295) in the PELD group and 2.41% (6/249) in the MED group, with no significant difference between the two groups (OR 0.39; 95% CI 0.10 to 1.55; $P = 0.18$) (Fig. 16).

The residue or recurrence rate at last follow-up was available from seven of 18 studies [17, 18, 24, 27, 30–32] ($n = 928$ patients; 494 in the PELD group and 434 in the MED group). No heterogeneity existed between the two groups ($I^2 = 0\%$, $P = 0.86$), and a fixed-effect model was used. The residue or recurrence rate was 4.25% (21/494) in the PELD group and 1.82% (8/439) in the MED group, with no significant difference between the two groups (OR 2.22; 95% CI 1.02 to 4.83; $P = 0.05$) (Fig. 17).

The re-operation rate was available from 5 of 18 studies [18, 24, 27, 30, 32] ($n = 805$ patients; 422 in the PELD group and 383 in the MED group). No heterogeneity existed between the two groups ($I^2 = 0\%$, $P = 0.79$) and a fixed-effect model was used. The re-operation rate was 4.03% (17/422) in the PELD group and 1.31% (5/383) in the MED group. It was significantly higher in the PELD group compared with the MED group (OR 2.67; 95% CI 1.07 to 6.67; $P = 0.04$) (Fig. 18).

Discussion

The development of minimally invasive operation, PELD, has attracted growing attention for the treatment of LDH over the past few years, with the concept of less invasion, less destruction of stable structures, better safety, and faster rehabilitation. Numerous studies [11, 12, 26, 32, 33] have confirmed that PELD could reach comparable safe and effective results to conventional microsurgical technique or MED. Furthermore, Kim et al. [34] reported that PELD could be considered an alternative operation for the treatment of all kinds of LDH (including severely and extremely difficult cases) with a high success rate (more than 96%). Recently, Zhao et al. [35] even reported a newly developed "U" route transforaminal percutaneous endoscopic technique for the treatment of thoracic spinal stenosis. Along with the development of endoscopic technology, PELD may be competent for more complicated LDH. PELD seemed to be with higher priority to MED for the treatment of LHD. Nevertheless, two prospective studies [25, 27] has reported that significantly higher recurrence rate was observed in PELD when compared to MED. Besides, Chen et al. [30] was carrying out a randomized controlled trial that compares PELD with MED for LDH, and the one year results suggested that PELD was more applicable to far-lateral disc herniation but not median disc herniation and that PELD did not seem to be safer and more effective than MED.

In view of the differences of current opinions, further deliberations and data from evidence-based medicine are required on whether PELD can completely replace the classic MED for the therapy of LDH. Recently, several published systematic review and meta-analysis showed that PELD could be an alternative treatment for LDH to standard discectomy, fenestration discectomy, and open lumbar microdiscectomy, with comparable effectiveness and certain advantages in terms of length of incision, blood loss, operation time, post-operative in-bed time, and total hospital stay [33, 36, 37]. While few evidence-based review with large samples that compare PELD with MED has been reported, consequently, this systematic review and meta-analysis was conducted to

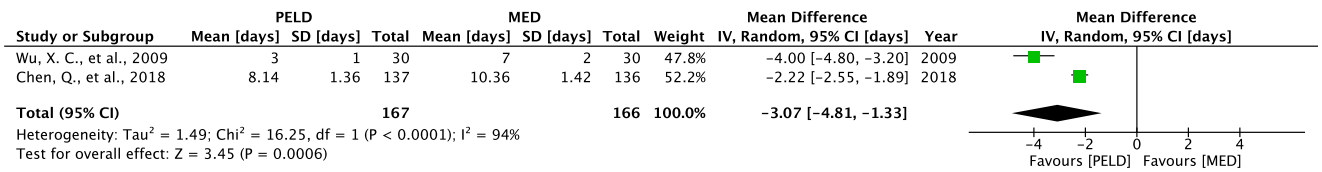

Fig. 7 Forest plot for post-operative hospital stay (PELD versus MED). It was significantly less in the PELD group compared with the MED group

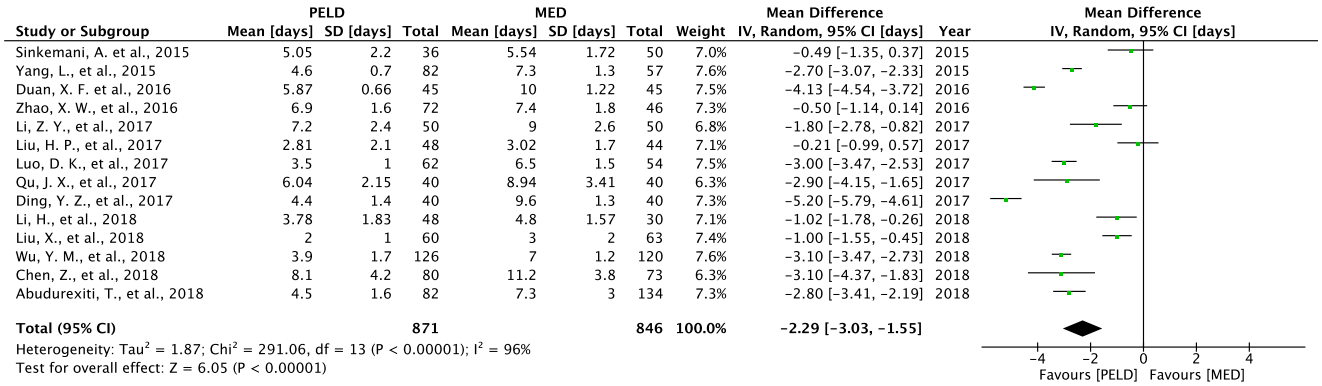

Fig. 8 Forest plot for total hospital stay (PELD versus MED). It was significantly less in the PELD group compared with the MED group

evaluate the superiority of PELD and MED for the treatment of LDH, which may contribute to proper patient selection and developing surgical strategy.

According to the strict eligibility criteria, a comprehensive search and screening was done and a total of 18 studies with 2161 participants were included in this meta-analysis with good to excellent qualities. The extracted data were then integrated and analyzed, and meaningful results were emerged.

Like other minimally invasive surgery, both of MED and PELD were developed for less trauma and rapid post-operative recovery, especially for PELD with a linear incision only about 8 mm long and far from the midline. Therefore, PELD may bring about less trauma to the muscle and few destruction of the posterior stable structures of the spine when compared to MED, which allows earlier post-operative activities and brings more benefit for patients. In this study, hardly surprising results showed that PELD exhibited overwhelming superiorities in length of incision, blood loss, post-operative in-bed time, post-operative hospital stay, and total hospital stay. In the premise of comparable curative effect, PELD can be the prior choice for LDH patients to achieve rapid rehabilitation post-operatively. Besides, shorter incision length may be associated with the reduction of infection risk and better post-operative painful feeling [32].

With respect to the duration of operation, different literature has published conflicting results. Early studies [12, 18] showed that significantly longer duration of operation was observed in PELD when compared to MED, while Liu et al. [32] recently reported that PELD took significantly shorter duration of operation than MED and microdiscectomy. In the present study, although no significant difference was found between the two groups regarding the duration of operation, further subgroup analysis revealed that the duration of operation was significantly longer in the PELD group in "Years before 2016" (MD, 24.97; 95% CI, 7.07 to 42.87; $P = 0.006$) and "Year 2016 to 2017" (MD, 6.57; 95% CI, 0.58 to 12.55; $P = 0.03$) subgroups but not in the subgroup "Year 2018" (MD, −5.66; 95% CI, −18.84 to 7.53; $P = 0.40$). Obviously, the significant difference between the two groups gradually decreased with years and finally even reversed in 2018, though the difference was not significant. This might be associated with the learning curve effects [38], so as in other minimally invasive procedures, the learning curve effect or experience curve effect should not be ignored in initial stage of PELD. Ahn et al. [39] proposed that the learning curve of PELD seemed to be acceptable with sufficient preparation, but the caution should be exercised to achieve better outcomes. With the proficiency of operational skills, the duration of operation was becoming shorter and shorter. Regarding to the

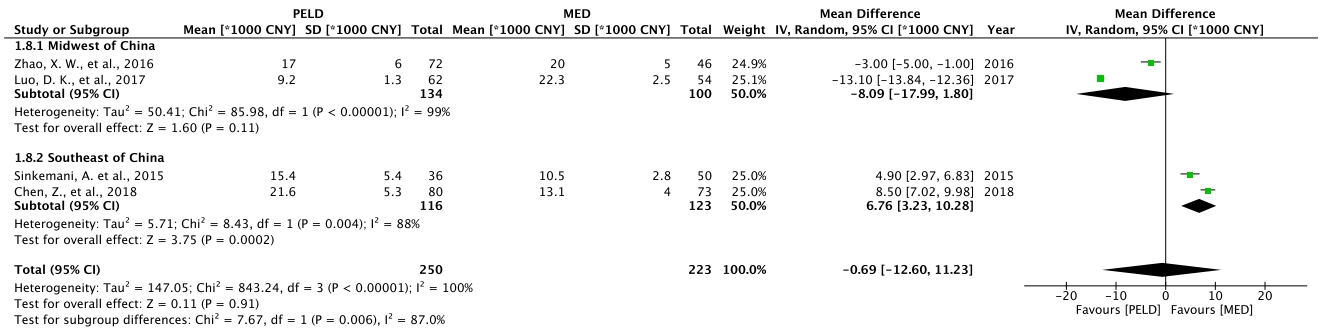

Fig. 9 Forest plot for total hospital cost (PELD versus MED). The total effect showed that there was no significant difference between the two groups. Further subgroup analysis showed that no significant difference was found between the two groups in the subgroup "Midwest of China," while it was significantly more in the PELD group compared with the MED group in the subgroup "Southeast of China"

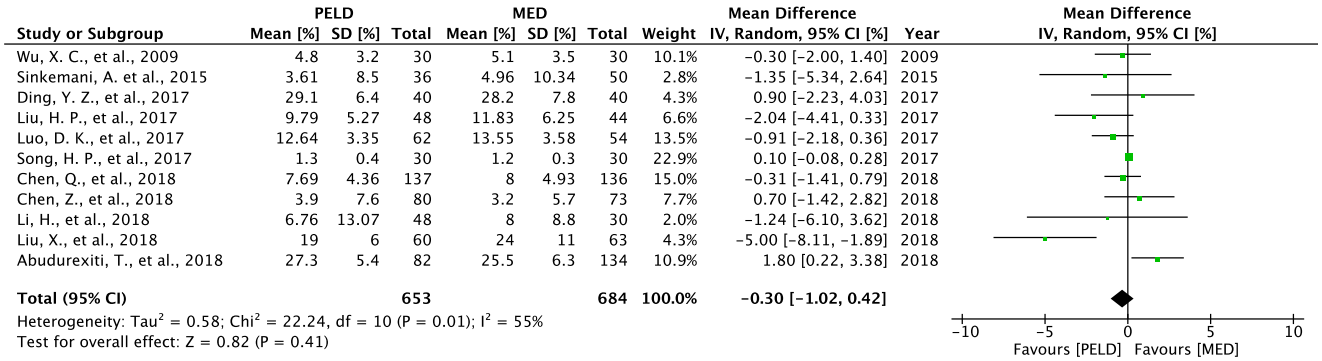

Fig. 10 Forest plot for ODI at last follow-up (PELD versus MED). No significant difference was found between the two groups

duration of operation, patients with LDH treated by PELD can achieve comparable benefit with those treated by MED, and even may benefit more in the future.

In the developing world, particularly in China, the cost is one of the primal factors that must be considered when people are hospitalized. In this study, the total effect revealed that no significant difference of total hospital costs was found between the two groups, while interesting results were obtained from the subgroup analysis. Two studies [20, 24] from the Midwest of China (Yichang in Hubei Province and Xi'an in Shanxi Province) reported that it was significantly less in the PELD group compared with the MED group, though the pooled result in the subgroup showed that the difference was not significant. Nevertheless, another two studies [12, 30] from the Southeast of China (Nanjing in Jiangsu and Guangzhou in Guangdong Province) reported that the PELD group cost significantly more than MED group, with a significant difference was also observed in the pooled result. The total hospital cost, including the cost of surgery, anaesthesia, materials, medicines, and other items, may differ from region to region in China based on the regional economic level and medical insurance system. It should be noted that the cost of high-value consumptive material (radiofrequency electrocoagulator) used in PELD, which consists of large part of the total cost, is not in the coverage of Medicare reimbursement in the Southeast of China, contributing to significantly higher cost in the PELD group when compared to MED group. Along with the improvement and comprehensive coverage of the medical insurance system, more and more patients with LDH will benefit from PELD for the acceptable cost. But for the present, the economic factor should also be considered according to different regions before choosing the treatment strategies.

Before evaluating the functional outcomes at last follow-up, the corresponding pre-operative functional parameters including ODI, VAS-back pain, VAS-leg pain, and VAS-unspecified were analyzed first, and no significant difference was found between the two groups. The final analysis of the functional data at last follow-up indicated no superiority of PELD compared to MED regarding to ODI, VAS-leg pain, and VAS-unspecified, while meaningful result was observed in VAS-back pain at last follow-up, which showed that it was significantly lower in the PELD group when compared with MED group, representing a better remission of back pain in PELD group. It has been reported that the incidences of post-discectomy LBP ranged from 5 to 36% at long-term follow-up [40]. Post-discectomy LBP may be mainly due to the trauma and destruction of the stable structures. In addition, limited discectomy may be associated with lower incidence of persistent LBP, while aggressive discectomy may contribute to higher incidence [41], although with less invasion to conventional open discectomy, a post-operative LBP rate of 23.9% was still observed after MED [42]. As mentioned above, less trauma and few destruction of the posterior stable structures of the spine (ligament and lamina bony structure) are produced in PELD than MED. Also, PELD is related to relatively more limited discectomy because of the limited microscopic vision. For these reasons, the probability of iatrogenic destabilization

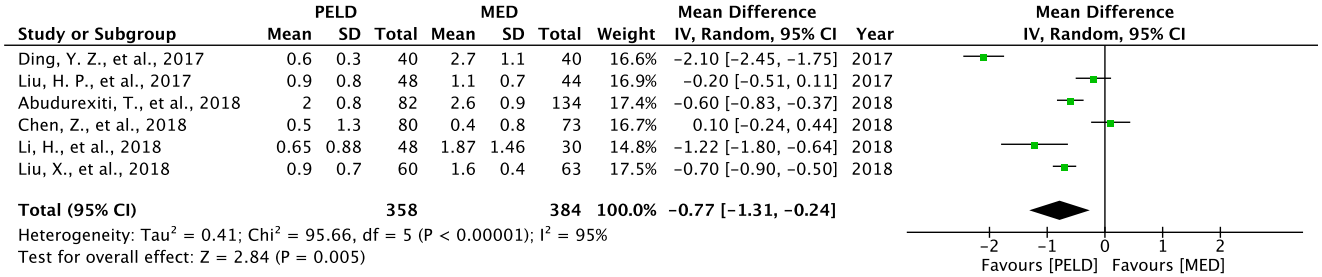

Fig. 11 Forest plot for VAS-back pain at last follow-up (PELD versus MED). It was significantly lower in the PELD group compared with the MED group

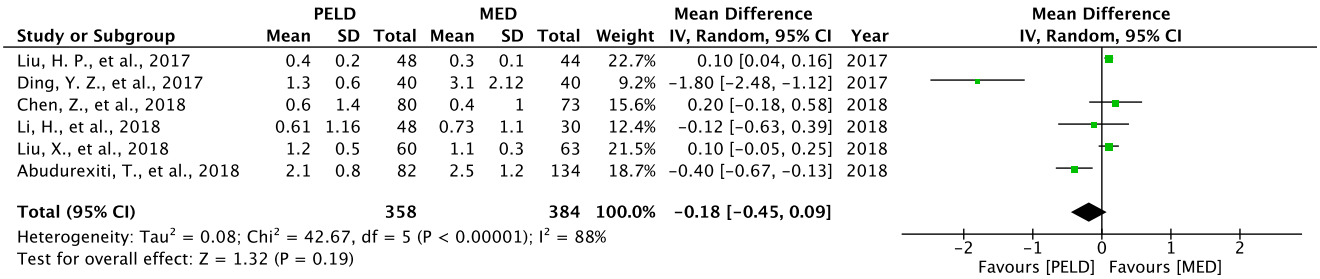

Fig. 12 Forest plot for VAS-leg pain at last follow-up (PELD versus MED). No significant difference was found between the two groups

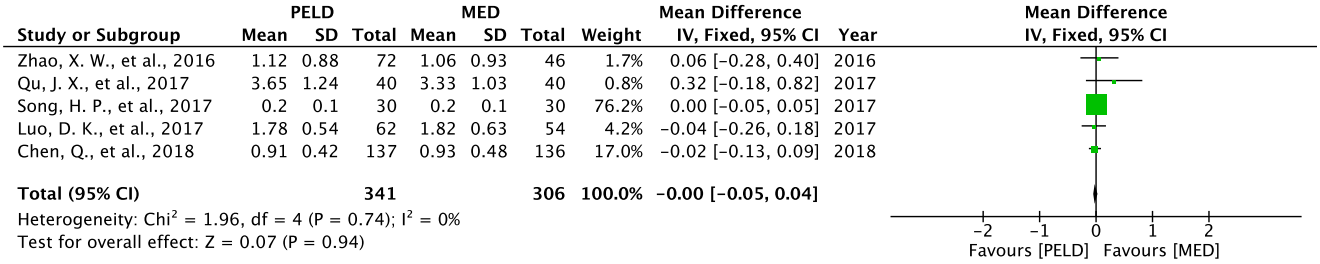

Fig. 13 Forest plot for VAS-unspecified at last follow-up (PELD versus MED). No significant difference was found between the two groups

of the spine may be reduced greatly in PELD, which may conduce to the easement of LBP. On the basis of the data in this study, we suggest that PELD should be preferentially chosen for the treatment of LDH patients with severe LBP. Though superior outcome of relieving LBP in PELD was achieved in this study, it should be noted that we only included PELD with transforaminal (TF) approach but not interlaminar (IL) approach. Further studies should be focused in the influence of different approaches of PELD (TF versus IL) and different procedures with similar approach (IL-PELD versus MED) on the treatment outcomes, especially for LBP.

At last follow-up, the results in this study showed that both PELD and MED reached satisfactory results with high excellent & good rates (> 90%) and low complication rates (< 8%), and no superiority of them was found between the two groups. Furthermore, we separately analyzed the severe complications that may bear on the prognosis, including dural tear rate, neural injury, and residue or recurrence rate. In general, MED is operated more closer to the dura and with more retraction of the nerve root than PELD. Moreover, MED is usually operated under epidural anaesthesia but not local anesthesia. We take it for granted that MED may be associated with higher dural tear rate and neural injury than PELD. While the present results revealed that no significant difference of dural tear rates was found between the two groups, only one included study [30] reported the neural injury with unexpected result that a higher incidence was observed in PELD than MED (3 in 80 versus 0 in 73), but the difference was not significant.

Though with comparable safety and efficacy to standard discectomy, minimally invasive discectomy such as PELD or MED etc. may bring about increased disc herniation recurrence [43]. Recently, one published meta-analysis revealed that PELD was correlated with a certain recurrence rate (3.6%), and the independent predictors for recurrence following PELD were

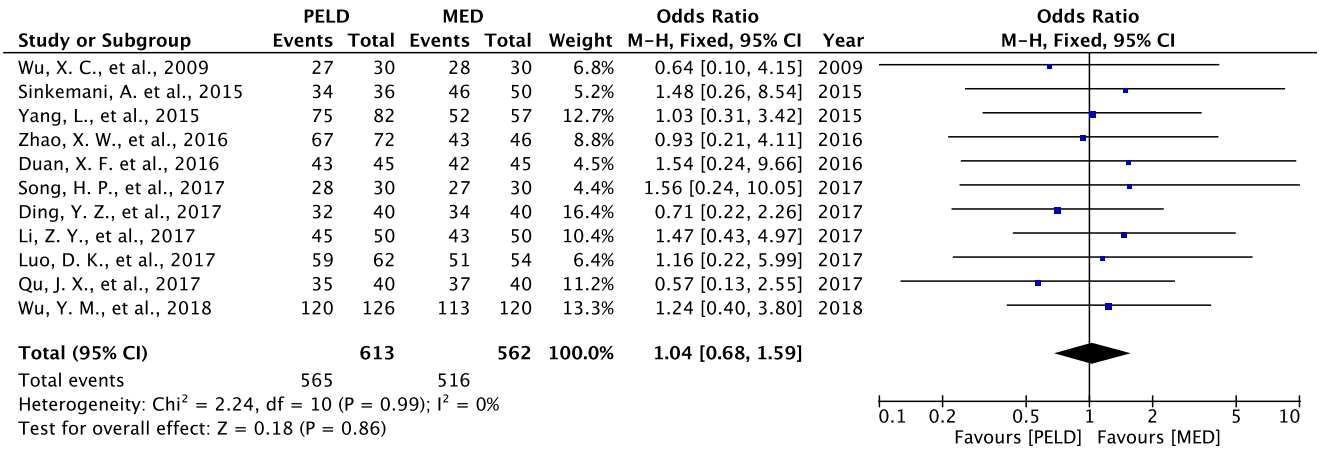

Fig. 14 Forest plot for excellent and good rate at last follow-up (PELD versus MED). No significant difference was found between the two groups

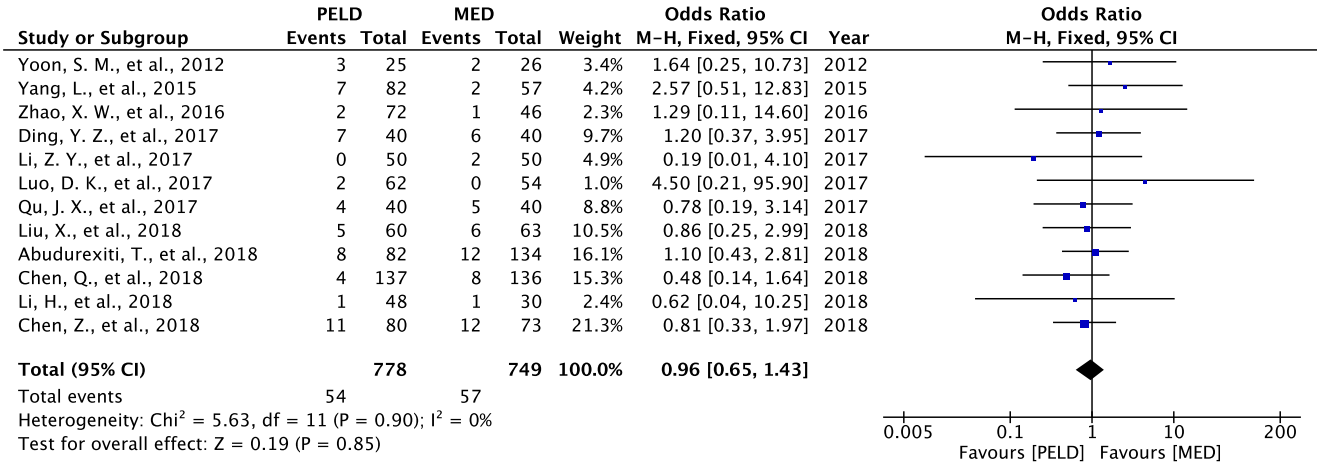

Fig. 15 Forest plot for total complication rate at last follow-up (PELD versus MED). No significant difference was found between the two groups

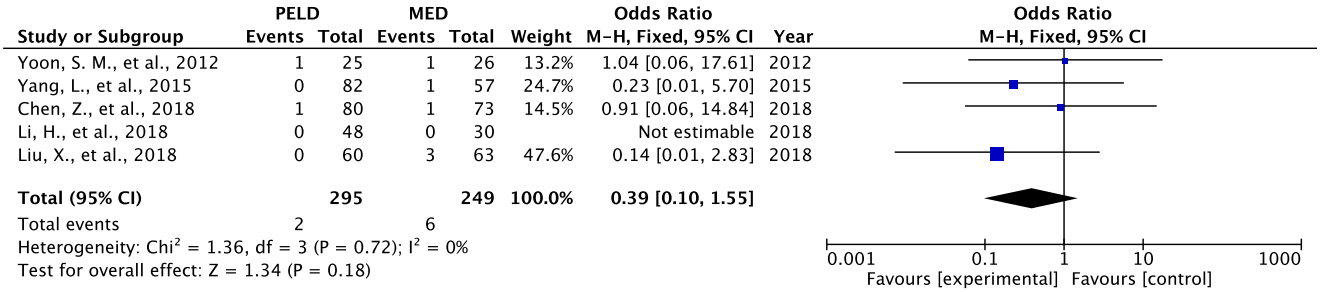

Fig. 16 Forest plot for dural tear rate (PELD versus MED). No significant difference was found between the two groups

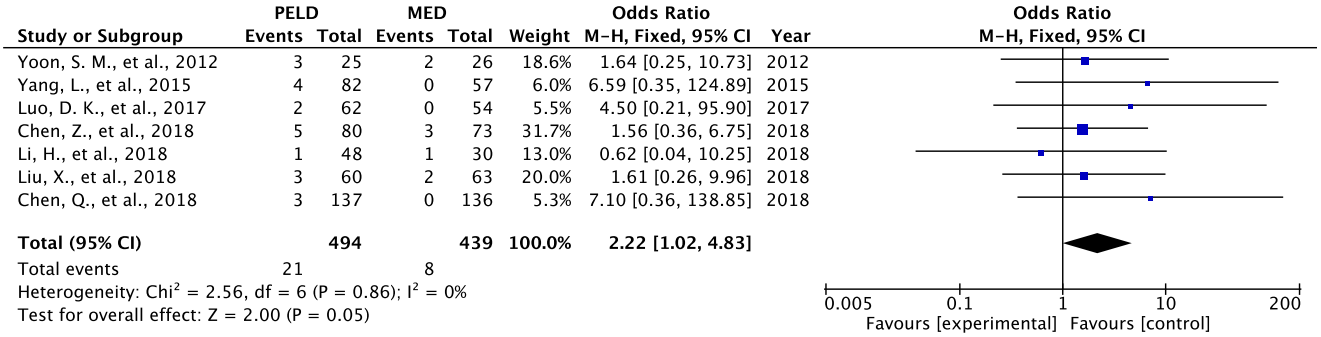

Fig. 17 Forest plot for residue or recurrence rate at last follow-up (PELD versus MED). No significant difference was found between the two groups

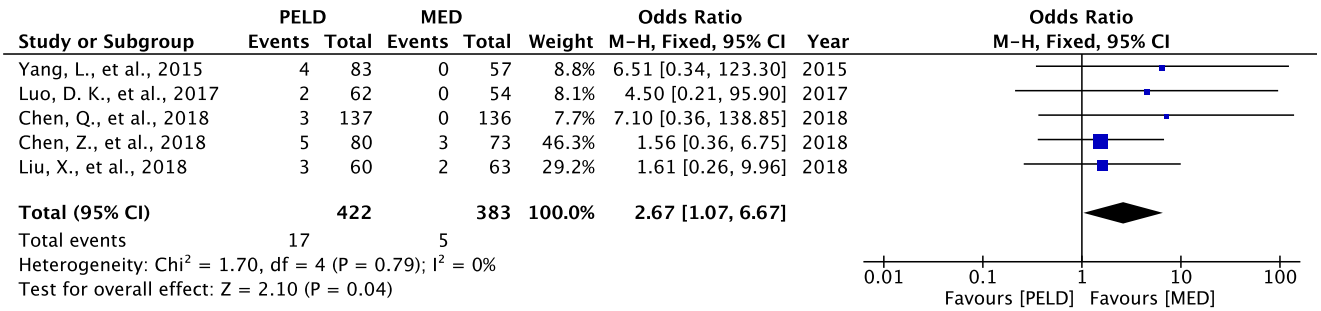

Fig. 18 Forest plot for re-operation rate at last follow-up (PELD versus MED). It was significantly higher in the PELD group compared with the MED group

determined [44]. Kosztowski et al. [45] suggested that PELD might only be equal but not superior to microdiscectomy in the recurrence rate. The present study showed that the recurrence rate was higher in PELD group (4.25%) when compared to MED group (1.82%), though the difference was not significant ($P = 0.05$). We suggest that more attention should be paid to further reduce the recurrence rate after PELD. The recommended risk factors for recurrence such as older age, obesity, and upper lumbar disc and central disc herniation should be seriously considered before PELD [38, 44].

A recent study [46] indicated that real recurrent herniation was the most common cause of re-operations after lumbar disc surgery, and minimally invasive endoscopic discectomy (including PELD and MED) was correlated with more re-operations for real recurrent herniations than open disc surgery, while Matsumoto et al. [47] demonstrated that MED could achieve comparable outcomes in recurrence rate and re-operation rate when compared to conventional discectomy for LDH. The results in the present study indicated that PELD was associated with significantly higher re-operation rate than MED (4.03% versus 1.31%; $P = 0.04$). It is noteworthy that all the causes of re-operation in this study were residue or recurrence. We speculate that it is mainly due to more limited microscopic vision and the learning curve effect or experience curve effect that has been mentioned above. Considering that the P value (0.04) nearly reached the standard of non-significance (0.05), we suggest that the re-operation rate will be significantly decreased with the proficiency of operational skills and the application of more appropriate indications. But currently, the higher incidence of re-operation following PELD and subsequent cost for revision surgery should be informed pre-operatively.

Besides, another disadvantage of PELD was acquired according to the present data. The fluoroscopic times was significantly more in the PELD group than in the MED group. PELD is usually associated with more preparations on pre-operative localization by fluoroscopy. Therefore, MED should be considered with higher priority for LDH patients who need to avoid or reduce fluoroscopy, such as gravidas and patients who is preparing for pregnancy.

The present meta-analysis is constrained by several limitations such as the following: (1) Both randomized and nonrandomized studies were included in this study, introducing selection bias; (2) the languages of the literatures were limited to Chinese or English, bringing about certain language bias; (3) the conference papers and degree dissertations were excluded, which may produce the bias in provision of data; (4) publication biases were observed by funnel plots, which may be caused by unpublished negative results; (5) high heterogeneity existed in this study, which may due to uneven patient selections, surgery indications, and familiarity of the procedures in different centers; (6) the pre-operative therapies, duration of symptoms, and the length of follow-up differ from included studies or unavailable; and (7) nearly all of the final included studies source from China. In China, both of PELD and MED are operated on in the Department of Orthopaedics, while in many other countries, PELD may be mainly operated upon by pain-specialist or belong to outpatient surgery, and MED is mainly operated upon by orthopaedic surgeons. Therefore, seldom studies compared PELD with MED in these countries. Further well-defined randomized controlled trials with large samples are needed to increase the predictive strength of this study.

Conclusions

On the basis of this meta-analysis, we can draw the following conclusions: (1) For the treatment of LDH, PELD can reach comparable excellent results to MED with regard to duration of operation, ODI, VAS-leg pain, VAS-unspecified, excellent & good rate, total complication rate, dural tear rate, and residue or recurrence rate; (2) PELD is superior to MED with shorter length of incision, less blood loss, shorter post-operative in-bed time, shorter post-operative hospital stay, shorter total hospital stay, and less VAS-back pain at last follow-up; (3) MED showed certain advantages of less fluoroscopic times and lower re-operation rate; (4) PELD is conducive to post-operative rapid rehabilitation with an ultra-minimally invasive approach, but more practice and development are needed to further improve the efficacy; (5) the treatment cost should also be considered according to different regions; and (6) these findings may contribute to pre-operative evaluation, suitable patient selection, and informed consent before making the treatment strategies for LDH.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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