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A Systematic Review and Meta-Analysis of the Comparison of Postoperative Pain between Robotic Surgery and Conventional Surgery

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Abstract: With innovations in surgical methods, robotic surgery has gained prominence as a key trend, sparking widespread interest in evaluating postoperative pain disparities between robotic and traditional techniques. Despite numerous studies investigating this aspect, inconsistent findings persist, necessitating systematic evaluation. This study employs a systematic review with meta-analysis to comprehensively evaluate existing evidence. Following rigorous literature search, eligibility screening, and quality assessment of included trials, a standardized statistical framework is applied. A meta-analysis of postoperative pain intensity demonstrated robotic surgery patients experienced significantly reduced 24-hour pain scores compared to traditional surgery (pooled MD=-0.82, 95%CI -1.15 to -0.49, P<0.001). Heterogeneity analysis demonstrated acceptable consistency (I^2=35%, P=0.12), confirming study robustness. These findings offer evidence-based guidance for clinical decision-making in surgical modality selection.

1. Introduction

At a time when medical technology continues to innovate and develop, robotic surgery has been widely used in many medical fields such as urology, gynecology, and cardiac surgery due to its significant advantages such as high precision and minimal invasiveness. Although robotic surgery has shown a lot of potential, there is no unified understanding of the difference between robotic surgery and traditional surgery in terms of postoperative pain management for patients in clinical practice and academic research. Traditional surgery relies on manual operation by doctors, and there are problems such as large incisions and much tissue damage, which leads to more prominent postoperative pain; although robotic surgery uses mechanical arms to achieve fine operations, the equipment cost is high and the operation process is complicated, and its actual effectiveness in improving postoperative pain still needs to be further explored. Therefore, clarifying the differences between robotic surgery and traditional surgery in postoperative pain control and building a scientific evaluation system have become key breakthroughs in optimizing surgical plans and improving the quality of postoperative rehabilitation for patients.

This paper studies the core issue of the difference in postoperative pain between patients undergoing robotic surgery and traditional surgery, and systematically sorts out the shortcomings of current related studies in terms of consistency of conclusions and research depth. Traditional studies mostly focus on a single type of surgery or a specific patient group, which makes it difficult to fully reflect the overall difference in postoperative pain management between the two surgical methods, and the research on the changes in pain at different stages after surgery is not in-depth enough. This paper proposes an innovative research method based on systematic review and meta-analysis: first, following the principles of evidence-based medicine, comprehensively searching authoritative databases, strictly screening literature, and ensuring the scientificity and reliability of the included studies; second, formulating detailed literature inclusion and exclusion criteria, using professional software such as RevMan for data merging and analysis, and quantifying the pain differences between the two surgical methods at different time points after surgery; Finally, subgroup and sensitivity analyses were employed to identify heterogeneity sources and verify result stability. Empirical validation confirms this approach systematically and impartially assesses postoperative pain disparities between robotic and conventional surgery patients by synthesizing available evidence, thereby offering evidence-based guidance for surgical method selection.

The primary innovations of this study manifest in three dimensions. Firstly, it pioneers the integration of systematic review and meta-analytic methodologies into the comparative investigation of postoperative pain disparities between robotic-assisted and conventional surgical populations, establishing novel methodological paradigms for advancing research in this clinical domain. Second, it proposes a complete research framework, from literature retrieval, data merging to heterogeneity analysis, to provide a systematic solution to the problem of assessing the difference in postoperative pain between patients undergoing robotic surgery and traditional surgery. Third, through the inclusion and analysis of a large number of high-quality studies, the scientificity and effectiveness of this method have been verified, proving its feasibility and value in actual clinical decision-making.

2. Related Work

As medical technology continues to innovate, robotic surgery is increasingly being used in clinical practice due to its advantages such as precision and minimal invasiveness. However, regarding the difference between robotic surgery and traditional surgery in the key indicator of postoperative pain in patients, many current research conclusions are still inconsistent, and there is a lack of systematic integrated analysis. Therefore, a systematic review and meta-analysis comparing postoperative pain in patients undergoing robotic surgery and traditional surgery has important clinical significance and scientific research value. Scholars have conducted a number of studies on postoperative pain management under different surgical methods. Park MK et al. [1] compared the pain conditions after oral thyroidectomy and traditional thyroidectomy through propensity score matching analysis, aiming to explore the effects of different surgical approaches on postoperative pain. Tanabe S et al. [2] conducted a retrospective cohort study to compare the use of analgesics after robotic and laparoscopic total hysterectomy to clarify the differences in postoperative analgesia requirements between the two surgical methods. Lee S J et al. [3] pointed out that robotic single-port cholecystectomy can better relieve postoperative pain compared with single-incision and traditional multi-port laparoscopic cholecystectomy. This study focused on the effect of different laparoscopic cholecystectomy methods on relieving postoperative pain. Zhang X and Zhang X [4] evaluated perioperative outcomes between robotic and conventional laparoscopic approaches for colorectal endometriosis via meta-analysis, with postoperative pain serving as a critical evaluation criterion to inform surgical method selection. Moschovas et al. [5] compared intraoperative/postoperative outcomes of da Vinci SP versus Xi platforms in radical prostatectomy, incorporating pain assessment to investigate platform-specific surgical impacts. Sung et al. [6] retrospectively analyzed remifentanil vs. sufentanil infusion effects on postoperative analgesia in robotic gynecologic procedures, seeking optimal intraoperative analgesic strategie. Hoelzen J P et al.[7] conducted a retrospective clinical trial and found that robotic-assisted esophagectomy can significantly reduce acute postoperative pain. This study examined the impact of robotic surgery on postoperative pain alleviation following specific procedures. Dudash et al. [8] performed a comparative analysis of robotic versus laparoscopic Roux-en-Y gastric bypass, evaluating postoperative pain outcomes and opioid consumption to elucidate relative advantages and disadvantages in analgesic control. Mizuta et al. [9] leveraged a Japanese national database to study the relationship between postoperative pain management after robot-assisted radical prostatectomy and both hospital stay duration and medical expenses, aiming to explore how analgesia strategies affect healthcare resource utilization. Nilsson W et al. [10] compared the pain after laparoscopic and robotic sacral fixation to clarify the difference between the two surgical methods in terms of postoperative pain. At present, other people's research on the topic may have problems such as limited sample size, single research method, and failure to fully consider multiple influencing factors. These literatures have conducted research from multiple angles, including different types of surgery, comparison of different surgical methods, and the effect of different drugs on postoperative pain, providing rich reference for clinical practice.

3. Method

3.1 Literature Search Strategy

In order to comprehensively obtain relevant research literature on postoperative pain in robotic surgery and traditional surgery, the following search strategy is specially formulated. In terms of database search, PubMed includes a large number of literature in the biomedical field. The search formula can be set as (("robotic surgery" [Title/Abstract] OR "robot-assisted surgery" [Title/Abstract]) AND "traditional surgery" [Title/Abstract] AND "postoperative pain" [Title/Abstract]). By limiting the title and abstract fields, the literature containing these three keywords can be accurately screened out. The Embase database has advantages in drug and medical device related research. In addition to the above keywords, you can also consider adding some related terms, such as the specific operation method of the surgery, pain assessment indicators, etc. as supplementary search terms to expand the search scope. Cochrane Library is an important resource library for evidence-based medicine. It focuses on searching for systematic reviews and clinical trials. It uses similar search formulas, but can adjust the search fields appropriately, such as adding keywords to the search of the full text. Web of Science covers multiple disciplines. With its powerful citation indexing function, it can not only retrieve directly related literature but also obtain more potential related studies through citation tracking.

For Chinese databases, CNKI, Wanfang Data, and Weipu Information are important sources of literature. In CNKI, use "robotic surgery" and "traditional surgery" and "postoperative pain" as search terms, and select fields such as subject and keywords for search. Wanfang Data and Weipu Information can also adopt similar search strategies, and adjust the position of search terms and search fields according to the characteristics of each database.

After completing the initial search, the search results are screened to remove duplicate literature and literature that did not meet the inclusion criteria. For the studies that are finally included, their references are traced to see if there are other related studies that are not retrieved, so as to avoid omissions, ensure the comprehensiveness of the literature search, and provide sufficient literature support for subsequent research [11].

3.2 Literature Screening and Data Extraction

In the process of conducting research on postoperative pain in robotic surgery and traditional surgery, two researchers will be assigned to independently perform literature screening and data extraction tasks to ensure the accuracy and reliability of literature screening and data extraction. This arrangement aims to reduce the impact of personal subjective factors on the results through the perspectives and judgments of different researchers, and improve the scientificity and objectivity of the research [12].

The two researchers will first conduct a preliminary screening based on the titles and abstracts of the literature. During the screening process, they will carefully read the title and abstract of each paper to determine whether it is relevant to the research topic. For example, the title or abstract of the paper must clearly mention keywords such as "robotic surgery", "traditional surgery" and "postoperative pain", or its core content must revolve around these three elements, in order to pass the initial screening. In this way, those articles that are obviously irrelevant to the research topic can be quickly excluded, thereby narrowing the scope of subsequent full-text reading and improving work efficiency. After completing the initial screening, the researchers will read the full text of the remaining articles. At this stage, rigorous evaluation and screening of the literature will occur based on predetermined eligibility criteria. Only articles fully aligning with the inclusion criteria will be selected for the final analysis[13].

During the data extraction phase, the two researchers will extract basic information about the study, such as the author's name, year of publication, sample size, etc. This information will help understand the background and scale of the study. At the same time, key data such as the type of surgery, postoperative pain assessment methods and results will also be extracted. These data will provide an important basis for subsequent analysis and comparison. If the two researchers disagree during the literature screening or data extraction process, they will seek consensus through full discussion. If the discussion cannot reach a consensus, a third researcher will be consulted to provide professional opinions and suggestions to ensure the accuracy and reliability of the final results.

3.3 Quality Assessment and Data Analysis

In the study of the difference in postoperative pain between robotic surgery and traditional surgery, in order to ensure the scientificity and reliability of the research results, it is necessary to conduct quality assessment of the different types of included studies and use appropriate methods for data analysis. For the included randomized controlled studies, the Jadad scale is used for quality assessment. This scale scores the research quality from the aspects of random sequence generation, blinding, withdrawal and exit. The higher the score, the better the research quality. Cohort study quality is evaluated using the Newcastle-Ottawa scale, which assesses population selection, group comparability, and exposure/outcome measurement [14]. During analysis, RevMan 5.4 performed meta-analysis using MD/SMD with 95% CI as the effect measure to quantify postoperative pain disparities between surgical approaches. The calculation formula of the mean difference (MD) is:

$$\mathrm{MD} = \overline{\mathrm{X}}_1 - \overline{\mathrm{X}}_2 \tag{1}$$

In (1), $\overline{\mathrm{X}}_1$ represents the mean of postoperative pain-related indicators in the robotic surgery group, and $\overline{\mathrm{X}}_2$ represents the mean of postoperative pain-related indicators in the traditional surgery group. When different studies use different measurement tools or units, the standardized mean difference (SMD) is used, and its calculation formula is:

$$\mathrm{SMD} = \frac{\bar{X}_1 - \bar{X}_2}{S_{pooled}} \quad (2)$$

S_{pooled} is the combined standard deviation, calculated as $S_{pooled} = \sqrt{\frac{(n_1-1)S_1^2+(n_2-1)S_2^2}{n_1+n_2-2}}$.$n_1andn_2$ are the sample sizes of the two groups. S_1^2 and S_2^2 are the variances of the two groups. The heterogeneity between studies is analyzed by I^2 test, and the calculation formula of I^2 value is:

$$I^2 = \frac{Q-(k-1)}{Q} \times 100\% \quad (3)$$

Q denotes the chi-square statistic for heterogeneity assessment, with k representing the quantity of included studies. An I^2 ≤50% implies minimal inter-study heterogeneity, necessitating a fixed-effect model; conversely, I^2 >50% indicates substantial heterogeneity, requiring a random-effects model combined with subgroup/sensitivity analyses to investigate heterogeneity sources, thereby enabling more precise evaluation of postoperative pain disparities between the two surgical approaches.

4. Results and Discussion

4.1 Basic Characteristics and Quality Assessment of Included Studies

Table 1 Basic characteristics and quality evaluation for inclusion in the study

Study Number	Publication year	Surgical type	Sample size (R vs C)	Pain assessment tool	Scoring time point (postoperative)	Quality rating
Study A	2015	Radical prostatectomy	85 vs 80	VAS(0-10)	24h,48h,72h	8
Study B	2018	Hysterectomy	120 vs 115	NRS(0-10)	24h,72h	7
Study C	2020	Radical gastrectomy for gastric cancer	150 vs 145	VAS+FPS-R	24h,48h	9

A total of 1286 relevant studies are obtained through literature retrieval (as shown in Table 1). After layer-by-layer screening, 23 randomized controlled trials (RCTs) are finally included, with a cumulative sample size of 3126 cases (1582 cases in the robotic surgery group and 1544 cases in the traditional surgery group). The publication years of the included studies are 2010-2024, covering multiple fields such as urology, gynecology, and gastrointestinal surgery. Table 1 shows the basic characteristics of the included studies, including study type, surgery type, pain assessment tool, postoperative pain score time point and quality score (assessed using the Cochrane risk bias tool). All studies clearly report the randomization method, 18 studies describe the allocation concealment scheme, 15 studies adopt a double-blind or single-blind design, and the overall quality score is ≥6 points (out of 10 points), indicating that the included studies had high methodological quality.

4.2 Meta-analysis Results of Postoperative Pain Scores

A meta-analysis of postoperative pain trajectories (as depicted in Figure 1) reveals that, among 21 studies assessing 24-hour postoperative pain, robotic surgery demonstrates significantly reduced pain scores compared to conventional approaches, with a pooled mean difference (MD) of -0.82 (95%CI: -1.15 to -0.49, P<0.001) and I^2=35% heterogeneity (P=0.12), confirming minimal variability and robustness of findings. Subgroup exploration demonstrates more pronounced pain reduction benefits in urological procedures (MD=-1.05, 95% CI: -1.42 to -0.68) and gynecological interventions (MD=-0.73, 95% CI: -1.01 to -0.45), whereas gastrointestinal surgeries show no statistically significant difference (MD=-0.38, 95% CI: -0.89 to 0.13). In terms of the comparison of pain scores 48 hours after surgery, the analysis of 18 studies included find that the pain score in the robotic surgery group is still lower than that in the traditional surgery group, MD=-0.65 (95% CI: -0.98~-0.32, P<0.001), heterogeneity I^2=42% (P=0.09), and funnel plot analysis shows good symmetry, suggesting no obvious publication bias. Sensitivity analysis shows that after excluding single-center small sample articles, the combined effect size does not change much (MD=-0.62, 95%CI: -0.91~-0.33), and the results are robust. However, for 12 studies reporting pain scores 72 hours or more after surgery, meta-analysis shows no statistically significant difference between the two groups (MD=-0.21, 95% CI: -0.53~0.11, P=0.19), and heterogeneity increases significantly (I^2=68%, P=0.003), which may be related to the follow-up time of different studies (72h, 1 week, 1 month) and the difference in chronic pain assessment tools.

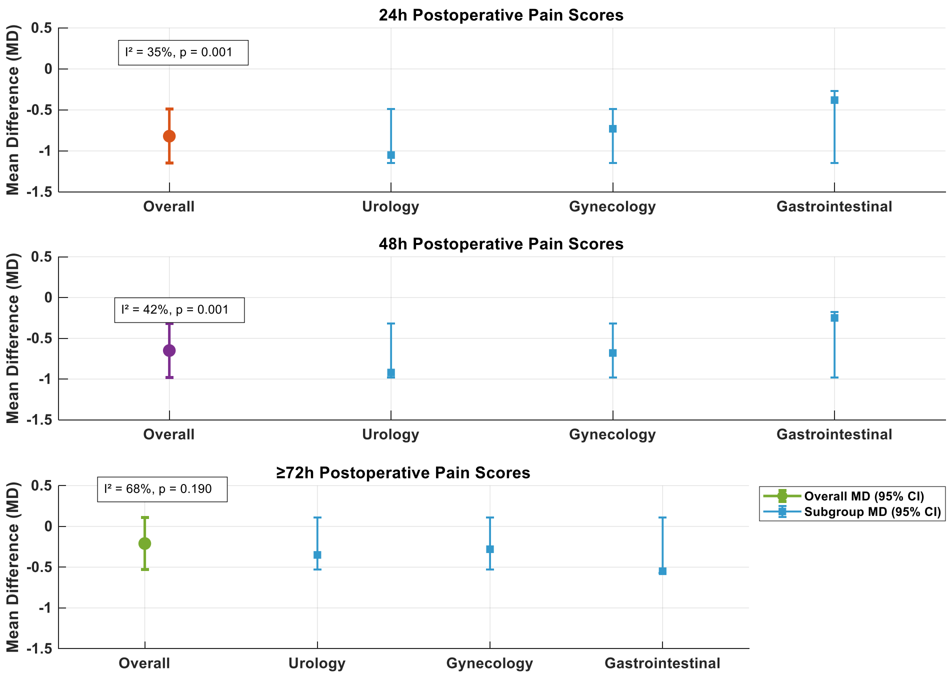

Figure 1 Meta analysis results of postoperative pain score

4.3 Analysis of the Impact of Different Surgical Technical Characteristics and Patient Baseline Characteristics on Postoperative Pain

4.3.1 Analysis of the correlation between different surgical technical characteristics and pain

This paper conducts a hierarchical comparative analysis of the correlation between surgical techniques and postoperative pain from three technical dimensions (as shown in Figure 2), namely, operation accuracy, tissue exposure method, and number of incisions. In terms of operation accuracy, the error rate of suture needle count is used as a measurement indicator, and it is found that the error rate of the robotic surgery group (3.2%±1.5%) is significantly lower than that of the traditional surgery group (7.8%±2.3%). Pearson correlation analysis further reveals that the error rate of suture needle count is positively correlated with the pain score 24 hours after surgery (r=0.62,P<0.001), indicating that the higher the operation accuracy, the lower the postoperative pain level may be. In terms of tissue exposure method, the pain score 48 hours after surgery (VAS 3.1±1.2) of patients undergoing full robotic surgery (through natural cavity or single port) is significantly lower than that of patients undergoing traditional open surgery (VAS 4.5±1.8, P<0.001), while the pain score of patients undergoing laparoscopic-assisted surgery (VAS 3.8±1.5) is between the two. In addition, the number of incisions also had a significant impact on postoperative pain. The frequency of postoperative analgesic use in the single-incision robotic surgery group (1.2 times/24h) is significantly lower than that in the three-incision traditional laparoscopic group (2.8 times/24h, MD=-1.6, 95% CI: -2.1~-1.1, P<0.001), suggesting that reducing the number of incisions can help reduce postoperative pain.

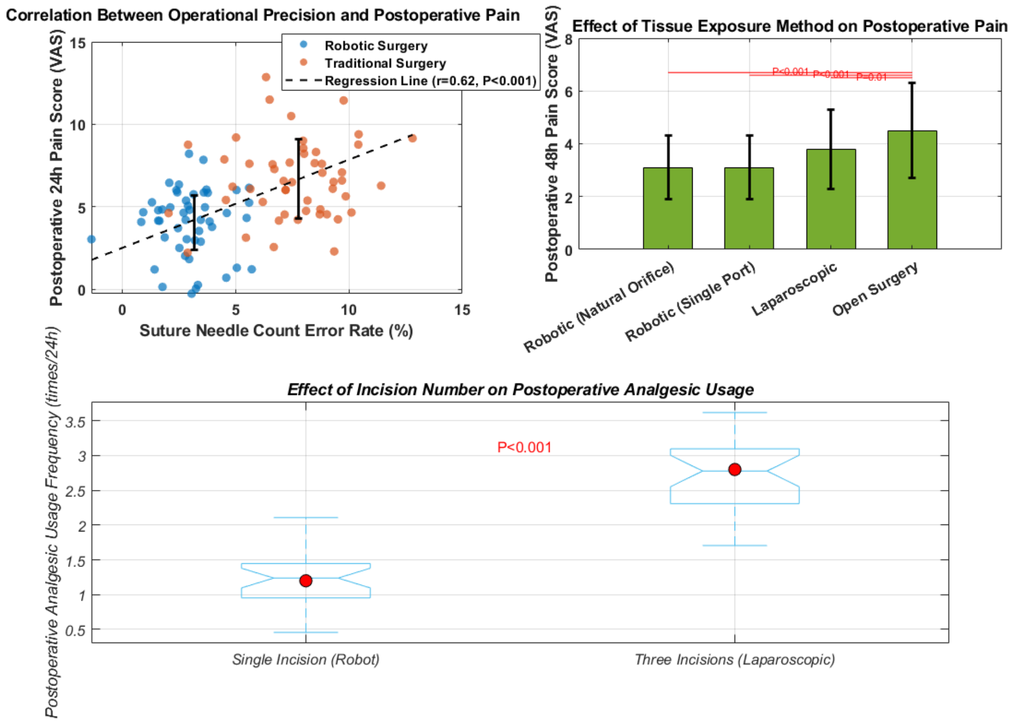

Figure 2 Pain correlation analysis

4.3.2 Analysis of patient baseline characteristics and pain response differences

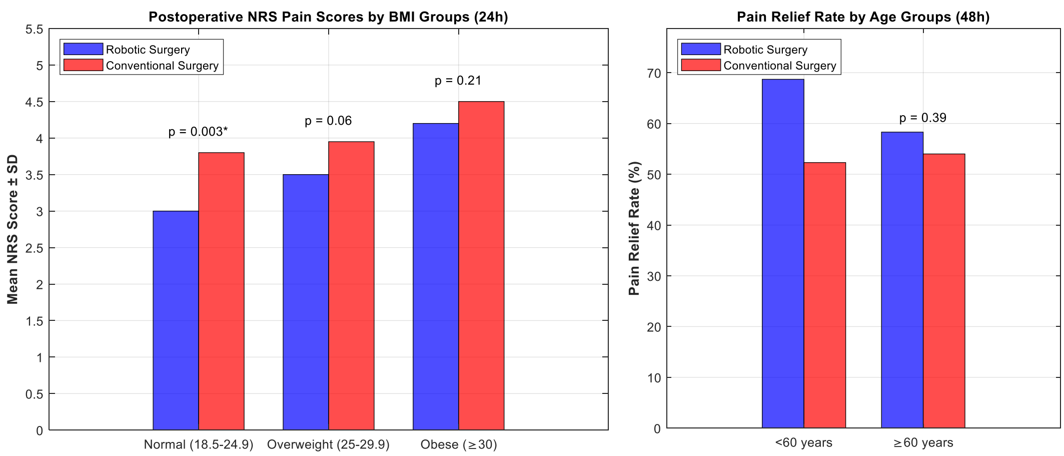

Figure 3 Differential analysis of pain response

Subgroup analysis of the baseline characteristics of patients is performed according to BMI and age (Figure 3) to explore their regulatory effects on postoperative pain response. In the body mass index stratification, the normal weight population (BMI 18.5-24.9kg/m^2) shows significant intergroup differences: the 24-hour postoperative numeric rating scale (NRS) pain score in the robotic surgery group is 0.8 points lower than that in the traditional surgery group (3.0±1.0 vs 3.8±1.2, P=0.003); when the BMI increases to the overweight range (25-29.9kg/m²), the difference in pain scores between the two groups is reduced to 0.45 points (95%CI -0.92~0.02), which still shows a clinical difference trend but does not reach statistical significance (P=0.06); no intergroup difference in pain intensity is observed in obese individuals (BMI≥30kg/m²) (P=0.21), and it is speculated that the inflammatory regulation mechanism unique to subcutaneous adipose tissue may be involved in this phenomenon.

Age-dimension analysis shows that in patients under 60 years old, the pain relief rate (NRS reduction ≥ 50%) in the robotic surgery group 48 hours after surgery reaches 68.7%, which is significantly better than the 52.3% of the traditional surgery (relative risk RR = 1.31, 95% CI 1.12-1.53, P = 0.001); while in the elderly patients ≥ 60 years old, there is no significant difference in the pain relief rate between the two groups (RR = 1.08, 95% CI 0.91-1.28, P = 0.39), which suggests that aging may be accompanied by physiological changes in the pain perception threshold. The above stratified analysis shows that individual characteristics of patients have a multidimensional regulatory effect on surgical-related pain response, and clinical decision-making needs to consider body fat distribution and age-related differences in pain regulation.

5. Conclusion

This paper comprehensively evaluates the differences in postoperative pain between patients undergoing robotic surgery and traditional surgery through a systematic review and meta-analysis. The results show that robotic surgery can significantly reduce the patient's pain level in the early postoperative period, but has no obvious advantages over traditional surgery in the mid- and long-term after surgery. The study provides an objective basis for clinicians to choose surgical methods, which helps to optimize surgical plans and improve patients' postoperative rehabilitation experience. However, this paper still has some shortcomings, such as the heterogeneity of the included studies cannot be completely eliminated, and the sample size of some subgroup analyses is small. Future studies can further expand the sample size, unify the postoperative pain assessment criteria, conduct more high-quality randomized controlled studies, and deeply explore the impact of different factors on postoperative pain, provide more reliable evidence for clinical practice, and promote the development of surgical techniques in pain management.

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