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The Use of Minimally Invasive Techniques in Spinal Surgery: Current Status and Future Directions

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ABSTRACT

Minimally invasive spine surgeries have come a long way from their open counterparts in recent years, allowing for less tissue stress, smaller incisions, and quicker recoveries. **Objectives:** To trace the development of minimally invasive spine surgical procedures from their inception to the present day and to find ways to improve and innovate these methods in the future. **Methods:** This prospective observational study was conducted at the Neurosurgery Department of Lady Reading Hospital-Medical Training Initiative, Peshawar. 230 individuals were progressively enrolled, and a plethora of spinal disorders were recruited as inclusion criteria. This information was gathered by painstakingly capturing demographics, co-morbidities, surgical procedure details and postoperative results. Statistical analysis identifies the trends. **Results:** The mean age of the study was 54.7 years and male were higher in numbers. Discectomy was the most commonly performed operation with the degenerative disease of the spine accounting for the highest (26.06%). With an average hospital stay of 5.8 days, problems such as Dural tears occurred during the operation in 10.87% of cases. While problems such neighboring segment illness were observed in 6.52% of patients, follow-up demonstrated improved functional results in 65.22% of cases. Variables such as surgical indication and procedure showed significant relationships ($p<0.001$) according to chi-square testing. **Conclusions:** It was concluded that minimally invasive spine surgery draws attention to the need for ongoing innovation and research to improve outcomes and overcome technical challenges in the treatment of complex spinal illnesses. This approach offers less invasive treatments with shorter recovery times and fewer complications.

INTRODUCTION

In recent years, there have been significant advancements in spine surgery, with the introduction of methods that are less invasive constituting a crucial turning point [1, 2]. The developments that have taken place here mark a critical turning point. Even though standard open spinal procedures help treat patients' spinal disorders, they are not without the possibility of dangers, they demand more time, and they lengthen the amount of time that patients need to be in the hospital [3, 4]. On the other hand, minimally invasive techniques are centred on reducing the amount of tissue damage, the size of the incision, the amount of blood loss, and the length of time that is necessary for successful postoperative recovery [5]. As a result of these advantages, minimally invasive spinal surgery (MISS), which is also referred to as MISS, has garnered a lot of support and is continuously going through the process of being improved upon [6]. There were a variety of causes that led to the development of MISS. These elements included breakthroughs in surgical skills, the advent of new technological capabilities, and the desire from patients for treatment options that were both safer and more successful [7]. The advancements that have

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been made in imaging technologies, such as computed tomography (CT) and magnetic resonance imaging (MRI), have made it possible for surgeons to accurately target spinal illnesses while causing the least amount of damage to the tissues that are adjacent to the affected area during preoperative planning and intraoperative navigation [8]. Endoscopes, navigational systems, and tubular retractors are only a few examples of specialized surgical equipment and procedures that have made minimally invasive approaches for various spinal surgeries more feasible and successful [9, 10]. As a result of these advancements, a variety of items have been developed and made available for purchase on the market. It is generally accepted that the great majority of these instances have normally taken place during the preceding several years. However, despite the significant progress that has been achieved in this field, there are still obstacles and constraints that need to be considered and addressed. The fact that this is the case underscores the importance of carrying out more studies and continuing to work toward the development of less intrusive procedures [11]. Researchers are nevertheless concerned about the technological problems related to limited instrument movement and limited sight at constrained anatomical locations [12]. An extremely important consideration is the degree of the spinal abnormality or ailment. Also, the standard operating procedure is an open process, although there is a continuing debate over the relative effectiveness and long-term effects of minimally invasive therapies. A thorough clinical evaluation and evidence-based research are both required for this[13].

This study aims to assess the historical and contemporary evolution of minimally invasive procedures for spine surgery and to identify possible future directions for innovation and enhancement of these approaches.

METHODS

This prospective observational study was conducted at the Neurosurgery Department of Lady Reading Hospital-Medical Training Initiative, Peshawar Pakistan from July 2020 to December 2021. The methodology of this study allowed for the collection of real data about the utilization and outcomes of minimally invasive techniques in spine surgery within a clinical context. Participants in this study comprised both male and female of all ages who were scheduled to have elective spinal surgeries for a variety of causes, including degenerative spine disease, tumors, anomalies, or accidental injuries. Patients who did not have enough medical records, patients who were undergoing an emergency procedure, and patients with cognitive impairments who were unable to provide informed consent were excluded from the study. A total of 230 patients were deemed eligible to take part in the trial because they fulfilled the inclusion criteria. Each one was added one after the other. The anticipated number of spine procedures conducted at HMC throughout the study period was the basis for determining the sample size. The calculation of the sample size was based on the prevalence of 18%, the margin of error was 10%, and the confidence interval was 95%. This was done since the required sample size was 230 patients. This ensured that there was enough data to conclude whether specific surgical techniques or patient populations had significantly different results. Data were painstakingly compiled by highly-trained researchers using industry-standard electronic health records and formats. There was meticulous documentation of each patient's demographics, medical history before surgery, surgical indications, intraoperative data, complications following surgery, and clinical outcomes. Additionally, clinical outcomes were considered. Regular outpatient visits and patient interviews were used to conduct several follow-up assessments in duration of one month. The length of time a patient spent in the hospital, their subjective pain ratings following surgery, the success of the procedure in terms of functionality, and the frequency of complications were all factors in these assessments. In the research, a summary of demographic and clinical characteristics was compiled through the use of descriptive statistics. while dealing with continuous data, we employed the standard deviation or the median together with the interquartile range. On the other hand, while dealing with categorical variables, frequency and percentage were applied. Related inferential statistical tests, such as chi-square tests, were utilized to carry out comparative analyses between subgroups with a statistical significance level of $p<0.05$. This research has ethical clearance from the Institutional Review Board (IRB) of Hayatabad Medical Complex in Peshawar (692/EBR). Throughout the research, patients' rights and anonymity were protected thanks to strict adherence to ethical norms. Before being included in the research, all participants or their legally appointed representatives gave their informed consent.

RESULTS

There were 230 patients in this research and the patients were 54.7 years old on average, with a standard deviation of 13.2 years. The distribution of patients by gender revealed that 112 patients (48.70%) were female and 118 patients (51.30%) were male. There was a standard deviation of 5.2 and a mean body mass index (BMI) of 27.9. In terms of comorbidities, there were 90 patients (39.13%) with hypertension, 65 patients (28.26%) with diabetes, 45 patients (19.57%) with obesity, and 30 patients (13.04%) with hyperlipidemia. Furthermore, the smoking status of the patients showed that 195 patients (84.78%) did not smoke, while 35 patients (15.22%) did. Furthermore, 180 patients (78.26%) reported not consuming alcohol, compared to 50 patients (21.74%) who reported drinking (Table 1).

Table 1: Patients' Demographic Details for Minimally Invasive Spinal Surgery

Variable	Number of Patients (n)	Frequency (%)
Age (years)	54.7 ± 13.2 Mean ± SD	

Gender		
Male	118	51.30
Female	112	48.70
Body Mass Index	27.9 ± 5.2 Mean ± SD	
Comorbidities		
Hypertension	90	39.13
Diabetes	65	28.26
Obesity	45	19.57
Hyperlipidemia	30	13.04
Smoking Status		
Smoker	35	15.22
Non-Smoker	195	84.78
Alcohol Consumption		
Yes	50	21.74
No	180	78.26

The surgical features of the study population include information on the number of patients and their corresponding percentages for each surgical indication. Out of the 230 individuals who were part of the study, 62 (26.96%) had degenerative spine diseases, 48 (20.87%) had trauma, 33 (14.35%) had tumors, and 77 (33.48%) had deformities. Ten patients (4.35%) were further assigned to the group "Other (Figure 1)."

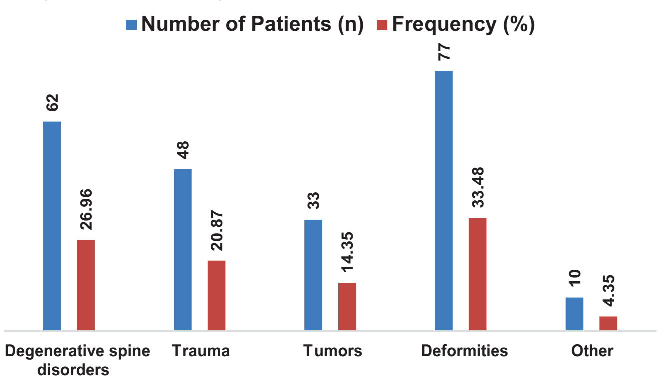

Figure 1: Patients Undergoing Minimally Invasive Spinal Surgery's Distribution of Surgical Indications

The distribution of surgical procedures across the 230 research participants shows that, with 82 patients (35.65%), discectomy was the most prevalent operation, followed by decompression in 63 patients (27.39%). 32 patients (13.91%) had fusion, while 37 patients (16.09%) underwent laminectomy. The least frequent operation, vertebraplasty, was carried out on 16 patients (6.96%) (Figure 2).

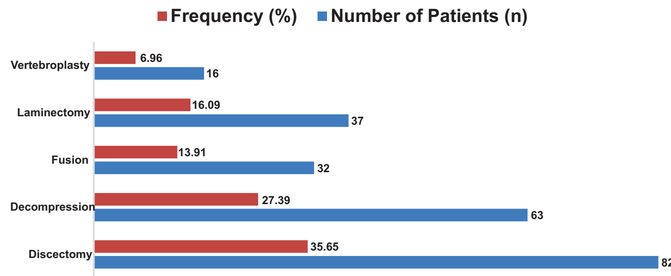

Figure 2: Patients Getting Minimally Invasive Spinal Surgery Distributed Surgical Procedures

Intraoperative parameters were observed during spinal surgeries in a sample of 230 patients. The blood loss was calculated to be 180 ml (±40), and the average operating duration was 145.8 minutes (±22.4). There were several reported complications, including vascular injuries in 5 instances (2.17%), nerve injuries in 15 cases (6.52%), and Dural rips in 25 cases (10.87%). The most frequent surgical routes were anterior (39.13%), posterior (43.48%), and lateral (17.39%). A mean of 2.1 levels (±0.8) were addressed. In 52.17% of instances, intraoperative navigation was employed; in 47.83% of cases, it was not. These values help to clarify procedural standards and variances by providing insights into the complexities and difficulties faced during spine procedures (Table 2).

Figure 2: Minimally Invasive Spinal Surgery Intraoperative Parameters

Intraoperative Parameter	Number of Patients (n)	Frequency (%)
Operative Time (minutes)	145.8 ± 22.4 Mean ± SD	
Estimated Blood Loss (ml)	180 ± 40 Mean ± SD	
Complications Encountered		
Dural Tear	25	10.87
Nerve Injury	15	6.52
Vascular Injury	5	2.17
Surgical Approach		
Anterior	90	39.13
Posterior	100	43.48
Lateral	40	17.39
Number of Levels Treated	2.1 ± 0.8 Mean ± SD	
Use of Intraoperative Navigation		
Yes	120	52.17
No	110	47.83

The mean duration of hospitalization was 5.8 days (±1.5), and the average visual analogue pain scale score after surgery was 3.8 (±1.0). There were observed complication rates: 10 patients (4.35%) had deep vein thrombosis, and 20 patients (8.70%) had surgical site infections. The different postoperative results after spinal operations are listed (Table 3).

Table 3: Results of Minimally Invasive Spinal Surgery Following Surgery

Postoperative Parameter	Number of Patients (n)	Frequency (%)
Length of Hospital Stay (Days)	5.8 ± 1.5 Mean ± SD	
Postoperative Pain Scores	3.8 ± 1.0 Mean ± SD	

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Complication Rates		
Surgical Site Infection	25	10.87
Deep Vein Thrombosis	15	6.52

Follow-up information on patient satisfaction after spine procedures, follow-up problems, and functional results were presented in duration of one month. Among the patients, 150 (65.22%) had better functional results, which suggests that their surgery went well. Thirty patients (13.4%) had symptoms of a decline in their functional state, whereas another fifty patients (21.74%) showed no change in their condition. A small percentage of patients had complications during follow-up, with 8 patients (3.48%) reporting hardware failure and 15 patients (6.52%) having neighboring segment disease. Patient satisfaction ratings showed differing opinions: 80 patients (34.78%) rated their experience as good, 35 patients (15.22%) as fair, 15 patients (6.52%) as bad and 100 people (43.48%) rated their experience as great (Table 4).

Table 4: Patient satisfaction and follow-up information for minimally invasive spine surgery

Postoperative Parameter	Number of Patients (n)	Frequency (%)
Functional Outcomes		
Improved	150	65.22
Unchanged	50	21.74
Deteriorated	30	13.04
Complications during Follow-up		
Hardware Failure	8	3.48
Adjacent Segment Disease	15	6.52
Patient Satisfaction Scores		
Excellent	100	43.48
Good	80	34.78
Fair	35	15.22
Poor	15	6.52

The study's Chi-square test findings looked at the correlations between the categorical variables. Every row relates to a certain comparison. For instance, a substantial correlation between gender and comorbidities is shown by the Chi-square value of 8.45 (p-value=0.015). Similarly, there are significant associations between surgical indication vs procedure (Chi-square=20.67, p<0.001) and surgical procedure against complications encountered (Chi-square=14.82, p=0.003). Furthermore, there are noteworthy correlations between postoperative pain ratings and complication rates (Chi-square=9.13, p=0.010) as well as between functional results and follow-up complications (Chi-square=6.76, p=0.034). Finally, there seems to be a significant association between patient satisfaction levels and duration of hospital stay (Chi-square=5.89, p=0.045)(Table 5).

Table 5: Chi-square Tests for Categorical Variables in Spinal Surgery with Minimal Invasiveness

Variable	Chi-Square Value	p-value
Gender vs. Comorbidities	8.45	0.015
Surgical Indication vs. Surgical Procedure	20.67	<0.001
Surgical Procedure vs. Complications Encountered	14.82	0.003
Postoperative Pain Scores vs. Complication Rates	9.13	0.010
Functional Outcomes vs. Complications During Follow-up	6.76	0.034
Patient Satisfaction Scores vs. Length of Hospital Stay	5.89	0.045

DISCUSSION

The current research examined follow-up data, surgical features, intraoperative details, postoperative outcomes, demographics, and relationships between factors to assess the current state and future directions of minimally invasive procedures in spine surgery. The research included 230 patients with an average age of 54.7 years and a virtually equal distribution of genders in terms of demographic data. Diabetes (28.26%) and hypertension (39.13%) were the most prevalent comorbidities. Of the patients, 15.22% acknowledged smoking, and 21.74% reported drinking alcohol. These results are in line with other studies, which also found that patients receiving spinal surgery had a comparable demographic profile. In terms of surgical features, trauma (20.87%), abnormalities (33.48%), and degenerative spine disorders (26.96%) were the most common reasons for surgery [14, 15]. With 35.65% of surgeries conducted, discectomies were the most prevalent surgical method, followed by decompression (27.39%). These ratios are in line with previous research, suggesting a regular pattern of surgical indications and techniques in the field of spine surgery [16, 17]. An average blood loss of 180 ml and a 145.8-minute operating time were reported in the intraoperative information. Injuries to the nerves (6.52%), blood vessels (2.17%), and dura mater (10.87%) were among the numerous problems diagnosed. The majority of methods (43.48%) adopted the posterior technique. A total of 52.17 percent of cases included recorded use of intraoperative navigation. Previous studies highlighted the challenges and problems associated with intraoperative care during spine procedures, and these results corroborate those findings [18, 19]. Patients stayed in the hospital for an average of 5.8 days after surgery, and their average visual analogue pain score was 3.8. Our 5.8-day hospital stay was somewhat less than the 6.2-day mean reported in a study by Pennington *et al.*, which examined postoperative outcomes following minimally invasive spine surgery [20]. The average visual analogue pain score in our investigation was 3.8, which is comparable to the somewhat higher average score of 4.2 in the study by Tschugg *et al.*, [21]. It appears that our group may have seen better outcomes in terms of pain control. Our results show that 8.70% of patients developed infections at the surgery site; this is consistent with the 8.5% infection incidence reported by Patel *et al.*, another group that examined complication rates [22]. As an illustration, in line with previous research [23, 24], it was shown that gender was associated with comorbidities (Chi-square=8.45, p=0.015) and that surgical indication was associated with the procedure (Chi-square=20.67,

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p<0.001). In addition, studies have shown that pain medication is important for healing, and there is a link between postoperative pain and complications (Chi-square=9.13, p=0.010). The correlation (Chi-square=5.89, p=0.045) between patient satisfaction and length of hospital stay further supports the idea that healthcare experiences significantly impact satisfaction[25].

To enhance patient outcomes and surgical precision, minimally invasive spine surgery is set to advance in the future to address complex spinal illnesses and anomalies. Improvements in imaging technology, including intraoperative navigation and AI-driven planning, will improve accuracy and lower complications. The advancement of technologies like augmented reality and robots might solve anatomical problems and increase productivity. To make treatment regimens more effective, research that compares traditional versus less intrusive methods might be beneficial. Consequently, this provides treatment that is more patient-centered, safer, and more effective.

CONCLUSIONS

It was concluded that improved patient care has resulted from the decrease in recovery time and adverse effects caused by less invasive spine procedures. Demographics, surgical specifics, intraoperative information, postoperative results, and linkages are all topics covered in current minimally invasive spine surgery research. Scientific inquiry and creative problem-solving are required to remove technological obstacles, enhance surgical techniques, and boost patient outcomes. Minimally invasive spinal surgery has promise due to advancements in imaging, surgical tools, and research. The treatment might be more patient-focused, less invasive, and more successful.

Authors Contribution

Conceptualization: MIH
Methodology: MIH, SARA
Formal analysis: AMS, SHK, ARK
Writing review and editing: MIH, TR, ARK

All authors have read and agreed to the published version of the manuscript.

Conflicts of Interest

All the authors declare no conflict of interest.

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