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Original Research Article

COMPARISON OF ULTRA-HIGH-DEFINITION (4K) LAPAROSCOPY WITH CONVENTIONAL HIGH-DEFINITION LAPAROSCOPY FOR INTRAOPERATIVE ADVERSE EFFECTS ON PATIENTS UNDERGOING LAPAROSCOPIC CHOLECYSTECTOMY (LC)

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ABSTRACT

Background: Technological advancements in laparoscopic imaging have led to the introduction of ultra-high-definition (4K) systems, offering superior resolution compared to conventional high-definition (HD) systems. However, evidence supporting their clinical benefit in low-complexity procedures such as laparoscopic cholecystectomy (LC) remains limited. **Objective:** To compare ultra-high-definition (4K) laparoscopy with conventional high-definition laparoscopy in terms of intraoperative adverse effects and surgeon- and patient-related outcomes in patients undergoing elective laparoscopic cholecystectomy.
Materials and Methods: This prospective comparative study included patients undergoing elective LC, who were allocated to either HD or 4K laparoscopic systems. Intraoperative adverse events, operative time, surgeon-reported difficulty grading, trainee difficulty scores, postoperative pain, port-site infection, duration of hospital stay, and patient satisfaction were assessed and compared between the two groups.
Results: Baseline demographic and clinical characteristics were comparable between the groups. The incidence of intraoperative adverse events did not differ significantly between HD and 4K laparoscopy. Operative time, surgeon difficulty grading, and trainee difficulty scores showed no statistically significant advantage with the 4K system. Postoperative pain scores, port-site infection rates, hospital stay, and patient satisfaction were also comparable.
Conclusion: Ultra-high-definition (4K) laparoscopy did not demonstrate a significant advantage over conventional HD laparoscopy in reducing intraoperative adverse effects or improving patient outcomes in elective laparoscopic cholecystectomy. Judicious allocation of high-end imaging systems may be considered, especially in resource-limited settings.
Keywords: Laparoscopic cholecystectomy, Ultra-high-definition laparoscopy, 4K laparoscopy, High-definition laparoscopy, Intraoperative complications.

INTRODUCTION

Laparoscopic cholecystectomy (LC) is the gold standard treatment for symptomatic cholelithiasis and represents one of the most commonly performed elective surgical procedures worldwide. The procedure offers well-established advantages over open surgery, including reduced postoperative pain, shorter hospital stay, faster recovery, and lower complication rates.[1,2]

Despite these advantages, laparoscopic surgery poses technical challenges for surgeons, such as limited depth perception, reduced tactile feedback, and dependence on visual clarity. Over the past three decades, laparoscopic imaging has evolved from standard-definition systems to high-definition (HD) and, more recently, ultra-high-definition (UHD/4K)

systems. The 4K systems provide fourfold higher resolution than HD, promising enhanced visualization of fine anatomical structures and improved surgical precision.[3]

While the benefits of advanced imaging systems appear intuitive, their clinical relevance in low-complexity procedures such as LC remains uncertain. The high acquisition and maintenance costs of UHD systems raise concerns regarding cost-effectiveness, particularly in resource-constrained healthcare settings. Moreover, existing literature provides limited in vivo evidence demonstrating improved patient outcomes with UHD systems in routine laparoscopic procedures.[4]

This study was therefore undertaken to evaluate whether the use of ultra-high-definition (4K) laparoscopy offers any tangible advantage over conventional high-definition laparoscopy in terms of intraoperative adverse effects, surgeon comfort, and patient-related outcomes during elective laparoscopic cholecystectomy.

MATERIALS AND METHODS

A double-blinded, randomized trial was conducted among 84 patients in the Department of General Surgery at a tertiary care teaching hospital over the period of 18 month. Patients undergoing elective laparoscopic cholecystectomy for symptomatic gallstone disease were included after obtaining informed consent. Patients with suspected gallbladder malignancy, Prior failed attempt at laparoscopic cholecystectomy, cholecystectomy combined with any additional procedure, patients on immunosuppressive agents, steroid therapy, antipsychotic drugs and patients having an allergy to Paracetamol were excluded.

Randomization was done through a simple randomization sequencing technique using a computer-generated random number table (www.randomization.com) with a block size of six for 84 patients to divide them into two groups:

Group A (4K vision system)

Group B (HD vision system)

Allocation of patients into two groups was done using a sequentially numbered opaque sealed envelope technique by a faculty member not involved in the study. The envelope was opened for a given patient after the administration of anaesthesia. The chief operating surgeon was aware of the intervention; however, blinding was ensured for the patients and data analyst.

Patients diagnosed with symptomatic gallstone disease who met the inclusion criteria were admitted and enrolled in the study. Baseline demographic data, comorbidities, clinical presentation, physical examination findings, ultrasonographic observations, and routine laboratory investigations were recorded at admission. All patients underwent elective laparoscopic cholecystectomy under general anaesthesia following standard preoperative antibiotic prophylaxis with intravenous ceftriaxone.

The procedure was performed using a standardized four-port technique with carbon dioxide pneumoperitoneum maintained at 12–15 mm Hg. Either 4K or HD laparoscopic vision systems from the same manufacturer were used according to allocation, with identical reusable instruments across groups. Safe cholecystectomy principles were followed in all cases, and intraoperative complications and conversions to open surgery were documented. Operative time was recorded, and surgical difficulty was graded by both operating and trainee surgeons.

Postoperative pain was managed using intravenous paracetamol followed by oral NSAIDs. Pain assessment was performed using the Visual Analogue Scale at 6 and 24 hours postoperatively, with additional analgesia administered for significant pain. Patients were discharged once clinically stable. Patients were reviewed in the General Surgery outpatient department on the seventh postoperative day for port-site evaluation and suture removal, with a subsequent follow-up at one month. At each visit, patients underwent clinical assessment for surgical site infection, icterus, intra-abdominal fluid collection, and postoperative abdominal discomfort, which was evaluated using the Visual Analogue Scale.

RESULTS

A total of 84 patients undergoing elective laparoscopic cholecystectomy were analyzed, with 44 patients operated using the ultra-high-definition (4K) vision system and 40 patients using the high-definition (HD) system. Baseline demographic and clinical characteristics were comparable between the two groups.

Baseline Characteristics

The mean age did not differ significantly between the 4K and HD groups. Female patients constituted the majority in both groups, with a similar gender distribution. The prevalence and pattern of comorbidities were comparable across groups, with hypertension being the most common comorbidity (Tables 3 and 4). Mean body mass index (BMI) and BMI category distribution were also similar between the two groups. Preoperative ultrasonography findings, including gallbladder wall thickness, number of stones, and associated features, showed no statistically significant intergroup differences.

Operative Outcomes

The mean operative duration in the 4K Group and HD Group was 105.47 ± 50.38min (range 30 – 254 min) and 105.03 ± 48.29min (range 25 – 228 min), respectively. The mean operative time was not significantly shorter in the 4K group compared to the HD group.

Inter-group comparison of mean operative time.

Operative time	4K Group (n=43)		HD Group (n=40)		p - value
	Mean	SD	Mean	SD	
Operative time (min)	105.47	50.38	105.03	48.29	0.966^{NS}
Values are mean and standard deviation, p - value by independent sample t test. p - value<0.05 is considered to be statistically significant. NS – Statistically non-significant.					

Of the 83 patients taken for analysis of mean operative time, the operative time did not differ significantly in patients of different BMI.

Table 10: Operative time of LC and number of stones

Calculi	**N = 83**	**Mean operative time**	**4K**	**HD**	**P – value**
Multiple	60	106.87 ± 49.31	119.32 ± 59.74	99.1 ± 42.84	0.63^{NS}
single	23	101.04 ± 49.318	84.37 ± 31.11	122.8 ± 61.02	
Values are mean and standard deviation, p - value by independent sample t test. p - value<0.05 is considered to be statistically significant. NS – Statistically non-significant.					

Table 11: Operative time and gall bladder wall thickness (as reported on USG)

Wall thickness	**N = 83**	**Mean operative time**	**P – value**
Normal	74	103.69 ± 50.33	**0.022**
≥ 3mm	9	145.00 ± 51.022	
Values are mean and standard deviation, p - value by independent sample t test. p - value<0.05 is considered to be statistically significant. NS – Statistically non-significant.			

Of the 83 patients considered to analyze the mean operative duration of LC, 60 had multiple stones, and 23 had single stones. The mean operative duration for patients with multiple and single stones was 106.87 + 49.31 mins and 101.04 + 49.31 mins, respectively. The operative duration did not have significant variation concerning the number of gall bladder stones in preoperative imaging (p= 0.63). Operative duration increased with a higher number of gallstones and increased gallbladder wall thickness, irrespective of the vision system used.

Intraoperative Adverse Events

The incidence of gallbladder perforation did not differ significantly between the two study groups (p =0.19). There was no discernible difference in the incidence of cystic artery injury (p = 0.99), CHD injury (p =0.99) or bile duct injury (p = 0.99).

Surgeon-Reported Difficulty

Surgeons reported slightly difficulty grades when using the 4K system compared to the HD system, however it was not significant. The incidence of intra-operative adverse events did not differ significantly between the 4K and HD groups for each level of surgeon's difficulty grade (p = 0.37, p= 0.99 and p= 0.73 for Grade I, II and III levels, respectively). The mean operative time did not differ significantly between the 4K and the HD Group corresponding to the Surgeon's difficulty grading (p= 0.66, p=0.19 and p=0.15 for Grades I, II and III, respectively).

Table 1: Inter-group comparison of surgeon's difficulty grades

Surgeon's difficulty grade	4K Group (n=44)		HD Group (n=40)		Overall (n=84)	p - value
	n	%	n	%		
Grade I	16	36.4	20	50.0	36 (42.8%)	0.207^{NS}
Grade II	9	20.5	14	35.0	23 (27.3%)	0.135^{NS}
Grade III	19	43.1	6	15.0	25 (29.7%)	**0.005****
Total	**43**	**100.0**	**40**	**100.0**		

Values are n (% of patients), p - value by Chi-Square test. p - value<0.05 is considered to be statistically significant. **p - value<0.01, NS – Statistically non-significant.

Table 2: Comparison of mean operative time of LC according to surgeon's difficulty grades (n=83)

		Operative time (min)						
Surgeon's difficulty grade		4K Group (n=43)		HD Group (n=40)		Overall (n=83)		p - value 4K vs HD
	n	Mean	SD	Mean	SD	Mean	SD	
Grade I	36	81.81	34.79	86.65	31.54	84.50	32.63	0.665^{NS}
Grade II	23	79.56	19.63	101.07	45.31	92.65	38.32	0.195^{NS}
Grade III	24	139.44	54	175.50	41.49	148.46	2.77	0.151^{NS}
P - value (Between Grades)		0.001***		0.001***		0.001***		

4K versus HD p - value determined using independent sample t test; the remaining p - values determined by ANOVA. p - values lower than 0.05 are regarded as statistically significant. ***Statistically significant with a p - value of 0.001.

Trainee Surgeon Assessment

The overall mean of total trainee difficulty scores in 84 patients was 33.37 ± 10.74 (range 20 – 66). The mean trainee difficulty score in the 4K and HD groups was 35.16 ± 12.05 (range 20-66) and 31.40 ± 8.83 (range 20-57), respectively. The mean total trainee difficulty score did not differ significantly between the two study groups (p = 0.10). The mean trainee difficulty score did not differ significantly between the two study groups. The trainees more precisely identified the different aspects of the liver bed in the 4K group. However, the mean trainee difficulty score related only to oedematous change in the gallbladder bed was significantly higher in the 4K Group than in the HD Group (p = 0.01).

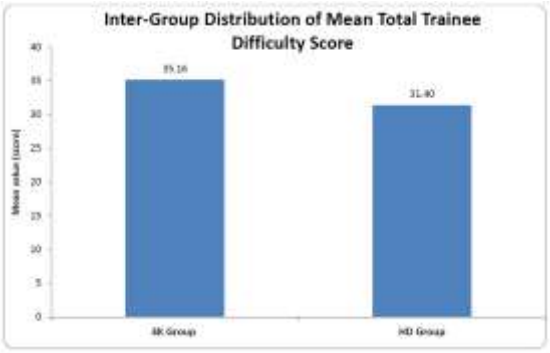

Figure 1: Inter-group comparison of mean total trainee difficulty score

Table 3: Inter-group comparison of mean trainee difficulty score (appearance of Calot's triangle)

Appearance of Calot's triangle	4K Group (n=44)		HD Group (n=40)		p - value
	Mean	SD	Mean	SD	
Oedematous changes in the Calot's triangle	1.84	1.14	1.65	1.05	0.429^{NS}
Fibrotic change in the Calot's triangle	2.00	1.29	1.78	1.23	0.417^{NS}
Bleeding during dissection of Calot's triangle	1.98	1.17	1.78	1.23	0.442^{NS}
Impacted gall stone in cystic duct	1.36	0.97	1.48	1.15	0.632^{NS}
Anomalous cystic duct	1.23	0.74	1.03	0.16	0.095^{NS}
Short cystic duct	1.64	1.18	1.28	0.99	0.134^{NS}
Values are mean and SD, P - value by independent sample t test. P - value<0.05 is considered to be statistically significant. NS – Statistically non-significant. Higher mean score indicated higher difficulty level and vice-versa.					

Postoperative Outcomes

The mean VAS score at 6 and 24 hours was 4.89 ± 1.71 and 3.64 ± 1.46, respectively. The mean VAS score is slightly less in the 4K group than in the HD group, but the distribution of mean VAS scores did not differ significantly between the two study groups (p= 0.77 for 6 hours and 0.96 for 24 hours). The incidence of postoperative PSI at one week did not differ significantly between the two study groups (P - value>0.05). The overall incidence rate of PSI at one-week follow-up was 7.1%. None of the patients had PSI at one-month follow-up. The mean patient satisfaction score at one week in the 4K Group and HD Group was 3.61 ± 0.58 (range 2-5) and 3.68 ± 0.73 (range 2-5), respectively. The mean patient satisfaction score at one month in the 4K Group and HD Group was 3.80 ± 0.55 (range 2-5) and 3.93 ± 0.83 (range 2-5) respectively. The mean patient satisfaction score at both the points of evaluation did not differ significantly between the two study groups (p= 0.66 and p=0.39, respectively).

Table 4: Inter-group comparison of mean post operative pain score (VAS)

Pain score (VAS)	4K Group (n=44)		HD Group (n=40)		Overall Group (n=84)		p - value
	Mean	SD	Mean	SD	Mean	SD	
At 6 Hrs	4.84	1.68	4.95	1.75	4.89	1.71	0.772^{NS}
At 24 Hrs	3.64	1.38	3.65	1.56	3.64	1.46	0.966^{NS}
Values are mean and standard deviation. p - value by independent sample t test. p - value<0.05 is considered to be statistically significant. NS – Statistically non-significant.							

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Histopathological Correlation

The histopathological findings of the patients revealed 86.9% (n=73) had chronic cholecystitis, 8.33% (n=7) had cholecystitis with foci of cholestrolosis, 2.3% (n=2) had follicular cholecystitis and 1.15% each had xanthogranulomatous cholecystitis and fibrosing cholecystitis. Histopathological findings showed a significant association with operative time, with longer durations observed in cases of chronic inflammatory changes

and fibrosis. Higher surgeon difficulty grades were more frequently associated with advanced histopathological changes of the gallbladder.

Table 5: Surgeon's difficulty grading and histopathological findings

Surgeon's difficulty grade	Chronic cholecystitis	Cholecystitis with cholestrolosis	Follicular cholecystitis	Xanthogranulomatous cholecystitis	Fibrosing cholecystitis
I	32	4	0	0	0
II	22	1	0	0	0
III	19	2	2	1	1

DISCUSSION

This study evaluated 84 patients undergoing elective laparoscopic cholecystectomy (LC) to compare ultra-high-definition (UHD/4K) and high-definition (HD) laparoscopic imaging systems. The mean patient age was 44.95 ± 13.88 years (range 18–82), with a marked female predominance (female-to-male ratio 3.4:1). More than half of the patients (51.12%) were overweight or obese, with a mean BMI of 25.75 ± 4.69 kg/m². Comorbidities were present in 30 patients (35.7%), and affected patients had significantly higher BMI values than those without comorbidities ($p = 0.01$); however, comorbidities did not significantly influence operative time ($p = 0.7$) or surgeon difficulty grading ($p = 0.169$).

The age of our patient population was similar to those with cholelithiasis (44.73 ± 11.59 years) reported by Khan et al,[5] from Central India. Studies by Sharma et al. and Tyagi et al in Northern India had a mean patient age of 39.5 ± 11.6 years and 43.6 years, respectively.[6,7]

Gallbladder wall thickening (>3 mm) was identified on preoperative ultrasound in nine patients and was associated with significantly longer operative times ($p = 0.005$). The overall mean operative time was 105.25 ± 49.09 minutes and increased significantly with higher surgeon difficulty grades ($p = 0.01$). No significant difference in operative duration was observed between the UHD and HD groups overall ($p = 0.966$) or after stratification by difficulty grade ($p = 0.72$).

Intraoperative adverse events occurred in 26 patients (30.9%), with gallbladder perforation being the most common (23.8%), most frequently during liver bed dissection (17.8%). The incidence of adverse events was significantly higher in patients with Grade III surgeon difficulty ($p = 0.001$) but did not differ significantly between the UHD and HD groups ($p = 0.19$). Conversion to open surgery was required in one patient (1.19%) in the UHD group.

Surgeon difficulty Grade III was significantly higher in the UHD group ($p = 0.005$), reflecting better recognition of operative complexity. Trainee difficulty scores related to gallbladder appearance, adhesions, bleeding tendency, and gallbladder bed oedema were also significantly higher with UHD imaging ($p < 0.05$), indicating improved visualization and anticipation of dissection challenges.

Postoperative outcomes were comparable between groups. The mean VAS pain scores at 6 and 24 hours were 4.89 ± 1.71 and 3.64 ± 1.46, respectively, with no intergroup difference ($p > 0.7$). The median hospital stay was one day (range 1–6). Port-site infection occurred in 7.1% of patients at one week, with no infections at one month; 50% of PSI cases were associated with intraoperative bile spillage. Histopathology revealed chronic cholecystitis in 86.9% of cases.

Overall, UHD laparoscopy improved anatomical visualization and difficulty assessment but did not significantly reduce operative time, intraoperative adverse events, or postoperative morbidity compared to HD systems in elective LC. Its primary benefit appears to lie in enhanced recognition of operative complexity and potential educational advantages rather than measurable improvements in short-term clinical outcomes.

In a similar study conducted by Dunstan et al with 109 patients; no significant differences were found in operative time (median ~20.9–23.4 min; $p = 0.91$) or intraoperative error scores between 3D HD and 4K systems during laparoscopic cholecystectomy. Complication and reattendance rates were also similar. This aligns with our finding that UHD did not significantly reduce operative time or intraoperative adverse events compared to HD systems.[8]

CONCLUSION

Our randomized controlled study compared the outcomes of patients undergoing laparoscopic cholecystectomy in 4K versus HD laparoscopic systems. Our study concludes that there was no difference in operative time in both the systems. The intra operative adverse events such as bile duct

injury, gall bladder perforation also did not differ in the two groups. However, the operative time and intra operative adverse events were significantly higher with higher grades of difficulty. The post operative stay and pain was also not significantly different in the two groups. There was no clear advantage of 4K system in terms of reduced operative time or reduced adverse events in laparoscopic cholecystectomy. This study was performed for a simple laparoscopic procedure that is laparoscopic cholecystectomy. Further studies are needed to determine if this applies to complicated laparoscopic surgeries.

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