Outcome Of Applying A Preoperative Three-Dimensional Anatomical Study on Complicated Abdominal Surgeries

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ABSTRACT

Background: Three-dimensional technology is currently implemented within many health specialties it used in surgery to facilitate identification of complex abdominal problems. This has led to the wide usage of robotic procedures in complex operations.

Objective: To evaluate the role of 3D assisted surgical procedures compared with conventional surgeries that rely on conventional computed tomography (CT) and magnetic resonance imaging (MRI).

Materials and Methods: A prospective comparative cohort study conducted over 12 months, from May 2025 through April 2026, included participants from local tertiary hospitals. The study included 86 adult patients. They were randomly divided into two groups; each contained 43 patients. Group one (G1) included those who underwent a 3D anatomical identification based on CT, MRI as well as other standard imaging investigations. While group two (G2) included those patients who only underwent CT, MRI and other standard imaging investigations to act as control. Outcomes included modification of the preoperative surgical strategy, unexpected intraoperative deviation from the final plan, operative time, estimated blood loss, complications, resection-margin status where applicable, and postoperative length of stay. Postoperative morbidity was graded using the Clavien-Dindo classification.

Results: The study cohort comprised 86 patients, with 43 patients in each group. Review of the 3D reconstruction (G1) modified the planned surgical strategy in 16 of 43 patients (37.2%). Unexpected intraoperative deviation from the final preoperative plan occurred in 4 patients (9.3%) in this group versus 12 patients (27.9%) in G2, (OR 0.26, 95% CI 0.08-0.90; p=0.050). Mean operative time was 178.4 ± 44.2 versus 207.1 ± 50.6 minutes (p=0.006), and median estimated blood loss was 260 mL (IQR 180-410) versus 390 mL (IQR 250-600) (p=0.012). Surgeon-rated anatomical confidence was higher with 3D planning (4.6 ± 0.5 vs 3.8 ± 0.6; p<0.001). Overall postoperative complications occurred in 10/43 (23.3%) versus 15/43 (34.9%), and median postoperative length of stay was 5 days (IQR 4-7) versus 6 days (IQR 5-8) (p=0.041).

Conclusion: Patient-specific 3D reconstruction-assisted planning (G1) was associated with modification of preoperative surgical strategy, fewer unexpected intraoperative deviations from the final plan, greater surgeon-rated anatomical confidence, shorter operative time, lower estimated blood loss, and shorter postoperative length of stay. However, non-significant differences in postoperative morbidity, major complications, and oncological margin status were not recorded.

Keywords: three-dimensional reconstruction; patient-specific anatomy; surgical planning; general surgery; CT; MRI; precision surgery; digital surgery; preoperative simulation.

INTRODUCTION

Complex general surgical procedures still pose a high challenge to surgeons. They frequently require accurate appreciation of spatial relationships among tumors, vascular structures, ducts, organ parenchyma, and adjacent viscera. Standard CT and MRI provide high-resolution cross-sectional information.(1,2) It is better for surgeons to mentally reconstruct three-dimensional anatomy from sequential two-dimensional images. Therefore, patient-specific digital reconstruction and 3D printing have emerged as tools for preoperative planning, rehearsal, education, and communication in abdominal surgery.(3–6)

Systematic reviews across surgical specialties indicate that patient-specific virtual or physical models can improve spatial understanding, surgical strategy formation, and surgeon confidence. However, the quality of evidence is variable and improvements in short-term patient outcomes are less consistently demonstrated than improvements in surgeon-centered outcomes.(5,7–9)

Most data evidence base is described in liver surgery. Earlier systematic review work showed that 3D simulation can accurately estimate liver volumes and resection margins modifying its operative strategy. Comparative studies have subsequently reported changes in planned surgical approach, improved characterization of vascular anatomy, and in some cohorts' shorter operative time or reduced blood loss.(10–17)

It was reported that 3D reconstruction visualization was associated with shorter operative time, reduced intraoperative blood loss, reduced transfusion volume, shorter hospital stays, and lower overall postoperative complication rates, although the contributing studies were predominantly non-randomized.(13)

Nevertheless, recent liver-surgery evidence emphasizes that the principal benefit may be improved anatomical comprehension and surgical decision-making rather than uniform reduction in every perioperative outcome. Another study reported that 3D rendering changed the preoperative surgical plan in approximately one-third of patients undergoing minimally invasive parenchyma-sparing liver resection, whereas a prospective pilot of patient-specific 3D-printed liver models demonstrated perceived improvements in operative safety without reductions in operative time or blood loss.(15,18)

Patient-specific 3D modeling has also been explored outside hepatic surgery. In locally advanced colon and rectal cancer, a prospective comparative study reported improved preoperative assessment of adjacent-organ infiltration with a 3D surgical planner compared with conventional CT. In pancreatic surgery, recent evidences suggest potential value for identifying anatomical variants, assessing tumor-vessel relationships and resection margins, and estimating residual pancreatic parenchyma. Yet robust comparative evidence remains limited.(19–21)

Hence, technology is increasingly aligned with the concept of precision surgery: tailoring operative strategy to the individual patient's anatomy rather than relying exclusively on generic anatomical expectations.(22) Nonetheless, the clinical value of 3D reconstruction in a broader general-surgery population requires prospective comparative evaluation.(23) The present study was designed to compare patient-specific 3D reconstruction-assisted planning with conventional CT/MRI-based planning in adults undergoing selected complex elective general surgical procedures.

MATERIALS AND METHODS

This prospective comparative cohort study took place over 12 months, from May 2025 through April 2026. It included participants from local tertiary hospitals. The manuscript was structured in accordance with the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) recommendations for cohort studies.(24)

Adult patients undergoing selected elective complex general surgical procedures were screened. Eligible operations were those in which patient-specific spatial anatomy was clinically important for defining the operative approach, resection extent, vascular control, and/or anticipated adjacent-organ relationships. The study included complex hepatobiliary, pancreatic, colorectal, and selected other abdominal or retroperitoneal procedures. Eligible participants were adults aged 18 years or older who were scheduled to undergo an elective complex general surgical procedure requiring detailed preoperative cross-sectional imaging. Inclusion required the availability of diagnostic-quality contrast-enhanced computed tomography (CT) and/or magnetic resonance imaging (MRI) suitable for anatomical segmentation and three-dimensional reconstruction. Recent imaging was sufficient for an accurate performance of anatomical verification at the time of surgery. Patients were required to have definitive operative treatment planned and to provide written informed consent for participation in the study.

Exclusion criteria included emergency surgery, inadequate imaging quality, major interval anatomical change after imaging, inability to produce a clinically interpretable 3D reconstruction, cancellation of planned surgery, or inability to provide informed consent.

The study included 86 eligible patients enrolled during the predefined 12-month study period, with 43 patients (G1) in the 3D reconstruction-assisted group and 43 (G2) which is the conventional-planning group.

Patients in G2 underwent routine preoperative planning using CT and/or MRI within the institutional picture archiving and communication system (PACS). Surgeons reviewed axial images and clinically available coronal, sagittal, and multiplanar reformations according to standard practice.

While patients in G1 source CT and/or MRI data were transferred to a dedicated workstation for segmentation and patient-specific 3D reconstruction. The general workflow followed established principles described in abdominal and hepatobiliary applications of 3D modeling.(4,6,14,25,26)

Depending on the surgical procedure and the specific anatomical requirements, the three-dimensional reconstruction included the target lesion or tumor, relevant organ parenchyma, arterial and venous anatomy, as well as biliary or pancreatic ductal structures when clinically indicated. Adjacent hollow viscera and solid organs, major anatomical landmarks, and other structures considered at risk during the planned surgical dissection were

also reconstructed as appropriate.
Segmentation was performed using semi-automated tools with manual correction as required. The final model was reviewed before surgery. Surgeons could rotate the model, alter transparency, hide or isolate structures, assess lesion-vessel relationships, and measure relevant distances. The 3D reconstruction complemented rather than replaced formal radiological interpretation.
Prior to surgery, the primary operating surgeon documented the intended operative approach, extent of resection, anticipated dissection or transection plane, vascular-control strategy, possible adjacent-organ resection, and anticipated anatomical challenges. In G1, the initial plan was based on conventional imaging that was documented before reviewing the 3D reconstruction. This may allow any subsequent 3D-related change in strategy to be recorded.
The primary outcome was unexpected intraoperative deviation from the final preoperative surgical plan, defined as an unanticipated change in operative approach, extent of resection, vascular-control strategy, or management of an adjacent structure because the operative anatomy differed materially from the preoperative plan.
Secondary outcomes included change in surgical strategy after 3D review, surgeon-rated anatomical confidence, operative time, estimated blood loss, transfusion, unintended vascular or adjacent-organ injury, conversion to open surgery when relevant, pathological margin status for malignant disease, postoperative complications, length of stay, 30-day readmission, and 30-day mortality. Postoperative complications were classified using the Clavien-Dindo system.(27)
Anatomical confidence was rated on a five-point Likert scale, with 1 representing very poor understanding and 5 representing excellent understanding of patient-specific anatomy relevant to the planned operation. The rating was recorded after completion of the final preoperative plan and before surgery.
Categorical variables were summarized as frequencies and percentages. Normally distributed continuous variables were reported as mean ± standard deviation, and skewed variables as median with interquartile range. Group comparisons used the chi-square test or Fisher exact test for categorical variables and the independent-samples t test or Mann-Whitney U test for continuous variables, as appropriate.
Effect estimates were expressed with 95% confidence intervals. Multivariable logistic regression was used for the primary binary outcome with adjustment for clinically relevant covariates including age, procedure category, operative approach, and procedural complexity. A two-sided p value <0.05 was considered statistically significant.
The study was conducted in accordance with institutional ethical requirements. Written informed consent was obtained from all participants.

RESULTS

The study cohort comprised 86 adult patients. they were divided into two groups; G1 (n=43) included in the 3D reconstruction-assisted planning. While G2 (n=43) included those to whom conventional CT/MRI-based planning took place. Mean age was 53.7 ± 13.1 years in G1 and 55.2 ± 12.6 years in G2. Baseline demographic and procedural characteristics were comparable between the two groups. (Table 1)

Table 1. Baseline characteristics of the study cohorts

Variable	G1	G2	*P* value
Age, years	53.7 ± 13.1	55.2 ± 12.6	0.591
Male sex	23 (53.5%)	22 (51.2%)	0.829
BMI, kg/m²	28.1 ± 4.5	28.6 ± 4.8	0.619
ASA I-II	32 (74.4%)	31 (72.1%)	0.810
ASA III-IV	11 (25.6%)	12 (27.9%)	0.810
Malignant indication	34 (79.1%)	33 (76.7%)	0.793
Hepatobiliary procedure	11 (25.6%)	11 (25.6%)	1.000
Pancreatic procedure	9 (20.9%)	9 (20.9%)	1.000
Colorectal procedure	12 (27.9%)	12 (27.9%)	1.000
Other complex abdominal/retroperitoneal procedure	11 (25.6%)	11 (25.6%)	1.000
Planned minimally invasive approach	25 (58.1%)	24 (55.8%)	0.827

In G1 the intended operative strategy was modified in 16 of 43 patients (37.2%). The modifications included altered resection extent in 5 patients, modification of the vascular-control or dissection strategy in 4, change in the intended transaction or dissection plane in 3, additional adjacent-structure preparation in 2, and change in operative access or port positioning in 2. Additional anatomical relationships relevant to operative planning were identified in 24 of 43 patients (55.8%). (Figure 1)

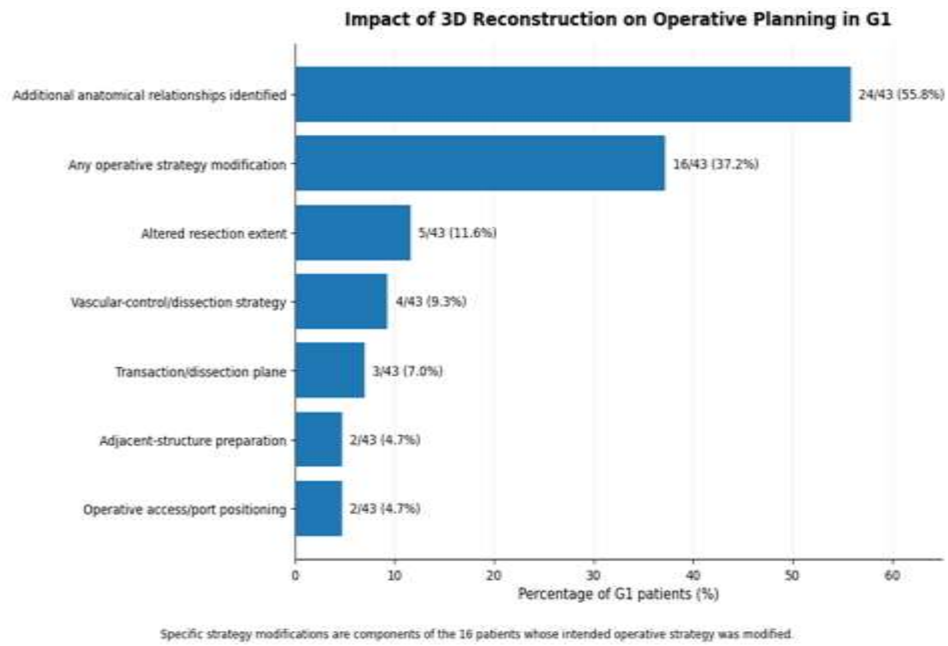

Figure 1. Impact of three-dimensional reconstruction on preoperative surgical planning in G1

Overall, 16 of 43 G1 patients (37.2%) had their operative strategy modified, and 24 of 43 (55.8%) had additional anatomical relationships identified during planning. The chart breaks down the 16 modifications by type — altered resection extent was the most common (5 patients), followed by vascular-control/dissection changes (4).

Moreover, unexpected intraoperative deviation from the final preoperative plan occurred in 4 of 43 patients (9.3%) in G1 and 12 of 43 patients (27.9%) in G2 (OR 0.26, 95% CI 0.08-0.90; p=0.050). Mean surgeon-rated anatomical confidence was 4.6 ± 0.5 with 3D-assisted planning compared with 3.8 ± 0.6 with conventional planning (p<0.001). (Table 2)

Table 2. Planning and operative-precision outcomes

Outcome	G1	G2	Comparison
Surgeon anatomical-confidence score	4.6 ± 0.5	3.8 ± 0.6	p<0.001
Preoperative plan changed after 3D review	16 (37.2%)	Not applicable	-
Unexpected intraoperative plan deviation	4 (9.3%)	12 (27.9%)	OR 0.26 (95% CI 0.08-0.90); p=0.050
Unintended vascular/adjacent-organ injury	1 (2.3%)	4 (9.3%)	p=0.360
Conversion to open surgery among planned MIS	1/25 (4.0%)	4/24 (16.7%)	p=0.189

Mean operative time was 178.4 ± 44.2 minutes in G1 compared with 207.1 ± 50.6 minutes in G2 (p=0.006). Median estimated blood loss was 260 mL (IQR 180-410) versus 390 mL (IQR 250-600), respectively (p=0.012). Overall postoperative complications occurred in 10 patients (23.3%) versus 15 patients (34.9%). Median postoperative length of stay was 5 days (IQR 4-7) versus 6 days (IQR 5-8; p=0.041). Detailed outcomes are presented in Table 3.

Table 3. Operative and postoperative outcomes

Outcome	G1	G2	Comparison	Outcome
Operative time, min	178.4 ± 44.2	207.1 ± 50.6	p=0.006	Operative time, min
Estimated blood loss, mL	260 (180-410)	390 (250-600)	p=0.012	Estimated blood loss, mL
Blood transfusion	4 (9.3%)	9 (20.9%)	p=0.228	Blood transfusion
R0 margin among malignant cases	32/34 (94.1%)	28/33 (84.8%)	p=0.259	R0 margin among malignant cases
Any postoperative complication	10 (23.3%)	15 (34.9%)	p=0.342	Any postoperative complication
Clavien-Dindo grade III or higher	2 (4.7%)	6 (14.0%)	p=0.265	Clavien-Dindo grade III or higher
Postoperative length of stay, days	5 (4-7)	6 (5-8)	p=0.041	Postoperative length of stay, days
30-day readmission	2 (4.7%)	4 (9.3%)	p=0.676	30-day readmission
30-day mortality	0 (0.0%)	1 (2.3%)	p=1.000	30-day mortality

In the adjusted analysis, 3D reconstruction-assisted planning was associated with a lower probability of unexpected intraoperative plan deviation (adjusted OR 0.27, 95% CI 0.08-0.93; p=0.038) after adjustment for age, procedural complexity, operative approach, and procedure category. Given the limited number of primary-outcome events, the adjusted estimate should be interpreted cautiously. (Table 4)

Table 4. Multivariable model for the primary outcome

Predictor	Adjusted effect estimate	95% CI	p value
3D reconstruction-assisted planning	aOR 0.27	0.08-0.93	0.038
Age (per year)	aOR 1.01	0.97-1.05	0.658
Higher procedural complexity	aOR 2.11	0.69-6.44	0.191
Minimally invasive approach	aOR 0.74	0.23-2.41	0.618
Hepatopancreatobiliary vs other procedures	aOR 1.36	0.43-4.27	0.599

DISCUSSION

In this prospective comparative cohort, 3D reconstruction-assisted planning was associated with fewer unexpected intraoperative deviations from the final surgical plan, greater surgeon-rated anatomical confidence, shorter operative time, lower estimated blood loss, and modestly shorter postoperative length of stay. Differences in overall morbidity and major complications favored the 3D group numerically but were not statistically significant. These findings suggest that the principal measurable benefit of 3D reconstruction may lie in preoperative anatomical understanding and operative planning rather than in uniform improvement across all postoperative outcomes.(28,29)

The current data coincides with previously published evidence supporting a clinically meaningful effect of 3D visualization on operative decision-making.(12) Similarly, others have reported preoperative plan variations in 33.9% of patients undergoing minimally invasive parenchyma-sparing liver resections.(15)

Moreover, other prospective work using 3D-printed liver models has shown that model inspection can change surgical strategy before laparoscopic liver resection, particularly when relationships between tumors and portal or hepatic veins are difficult to appreciate on conventional imaging.(17)

The observed reductions in operative time and estimated blood loss were directionally consistent with pooled liver-surgery evidence. It was reported that a weighted mean reduction in operative time and blood loss of took place in 3D aided surgical intervention.(30) Individual studies, however, have not been uniform, and differences in case complexity and procedure selection may influence observed effects.(13)

Improved anatomical understanding is among the more consistently reported surgeon-centered benefits of patient-specific visualization. Systematic reviews of virtual-reality planning report improvements in spatial localization, surgical decision-making, and surgeon confidence, while acknowledging that evidence for consistent patient-level benefit remains less mature.(7–9)

This distinction is important for interpretation; 3D reconstruction directly changes the information available to the operating surgeon, so planning accuracy and confidence may improve before measurable changes in rare outcomes such as major complications or mortality become detectable.(31)

Liver surgery provides the strongest clinical evidence base for 3D reconstruction. The current study results aligned with a previously published meta-analytic and systematic review analysis that included 47 studies and 7,724 patients; preoperative planning was the dominant indication, and more than half of included studies reported improved navigation or resection accuracy.(14) Hyper-accuracy and other advanced 3D systems have also demonstrated clinically relevant detection of vascular variants and frequent modification of planned complex resections.(16)

Nevertheless, for hilar cholangiocarcinoma, 3D visualization has been reported to improve preoperative assessment of respectability compared with contrast-enhanced CT, supporting the broader principle that multi-structure spatial representation can be valuable when tumors interact with complex vascular and ductal anatomy.(32)

A part of liver surgery, usage of 3D anatomical mapping is emerging. In locally advanced colon cancer, a prospective comparative non-randomized study found that a 3D reconstruction surgical planner improved assessment of adjacent-organ infiltration relative to CT. This is relevant to multivesicular planning, where the distinction between inflammatory adherence and true invasion can influence resection strategy.(19)

However, in pancreatic surgery, a recently systematic review concluded that 3D reconstruction may help in identifying anatomical variants, assessing tumor-vessel relationships and margins. This supports operative planning, although it emphasized the need for robust comparative studies before routine use can be considered evidence based.(20)

Patient-specific reconstruction is also the substrate for augmented-reality and mixed-reality navigation. These technologies can superimpose or display segmented vessels and tumors during surgery. Yet, registration errors and organ deformation remain important technical limitations, especially in liver surgery.(33)

Routine application of 3D reconstruction to all general surgical procedures may not be necessary. Selective use may provide greater clinical value in patients with complex vascular relationships, central lesions, anticipated multivesicular resection, anatomical variants, distorted anatomy after prior surgery, parenchyma-preserving operations, borderline respectability, or minimally invasive procedures where tactile information is limited.(34,35)

Practical implementation should also account for segmentation time, software and hardware costs, radiology-surgery workflow, quality assurance, and model-update requirements. Physical 3D printing offers haptic value but introduces additional production time and cost compared with screen-based interactive models.(4,6,25,26)

The strengths of the current study included its prospective comparative design, contemporaneous control cohort. Additively, inclusion of patient-specific cross-sectional imaging, evaluation of both planning and clinical outcomes, and assessment of a broader complex general-surgery population rather than a single procedure type.

The principal limitations included non-randomized allocation, single-region recruitment, modest sample size, heterogeneity of operative procedures, potential learning-curve effects, and unavoidable lack of surgeon blinding. Subjective confidence scores may have been influenced by awareness of the intervention. Procedure heterogeneity may also dilute organ-specific effects. Finally, observed associations require cautious interpretation because residual confounding by case complexity and surgeon selection cannot be excluded.

Future work may prioritize multicenter randomized or pragmatic comparative trials with procedure-specific stratification. Important endpoints include plan modification, conversion, vascular injury, margin adequacy, parenchymal preservation, operative time, blood loss, postoperative morbidity, surgeon cognitive workload, patient understanding, cost-effectiveness, and long-term oncological outcomes. Automated segmentation and artificial intelligence may reduce reconstruction time and improve scalability.

CONCLUSION

Patient-specific 3D anatomical reconstruction may be a useful adjunct to conventional CT/MRI-based planning for anatomically complex general surgical procedures. Existing literature demonstrate consistent benefits in anatomical understanding and surgical decision-making, particularly in hepatobiliary surgery, while evidence for uniform improvements in postoperative outcomes remains heterogeneous.

In this prospective comparative cohort study, patient-specific 3D reconstruction-assisted planning was associated with greater surgeon-rated anatomical confidence, fewer unexpected intraoperative deviations from the final preoperative plan, shorter operative time, lower estimated blood loss, and shorter postoperative length of stay compared with conventional CT/MRI-based planning. Overall postoperative morbidity, major complications, and oncological margin outcomes showed favorable numerical trends without statistically significant between-group differences. Patient-specific 3D reconstruction may therefore serve as a useful adjunct to conventional cross-sectional imaging when planning anatomically complex elective general surgical procedures. Larger multicenter studies with standardized reconstruction protocols and appropriate adjustments for procedure complexity are required to confirm generalizability and clinical effectiveness.

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