European Journal of Clinical Pharmacy

Print ISSN: 2385-409X **Online ISSN**: 3105-0409

Website: https://farmclin.com/

Original Research Article

Clinical Application and Further Development of Augmented Reality Guidance for the Surgical Localization of Pediatric Chest Wall Tumors in Pakistan

Article History:

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***Received**:* 26-09-2025
***Revised**:* 29-11-2025
***Accepted**:* 12-12-2025
***Published**:* 30-12-2025

Abstract: ***Background:*** Accurate intraoperative localization of pediatric chest wall tumors is critical for achieving complete resection while minimizing damage to surrounding vital structures. Objective: To evaluate the clinical application and feasibility of augmented reality–guided surgical localization in pediatric patients undergoing chest wall tumor resection. ***Methods***: This descriptive observational study was conducted at Rai Medical College, Sargodha from June 2024 to June 2025, included 85 pediatric patients with chest wall tumors undergoing elective surgical excision. Preoperative CT and/or MRI data were used to generate three-dimensional models, which were intraoperatively overlaid using an AR system to assist tumor localization. Data on demographic characteristics, tumor features, localization accuracy, operative parameters, margin status, postoperative outcomes, and surgeon satisfaction were collected. ***Results:*** The mean age of patients was 11.6 ± 3.9 years. The mean tumor size was 5.2 ± 1.8 cm, with 65.9% of tumors being deep-seated. The mean AR localization error was 3.4 ± 1.6 mm, with accurate localization within 5 mm achieved in 80% of cases. Complete tumor excision with negative margins was obtained in 81.2% of patients. The mean operative time was 96.7 ± 21.4 minutes, and mean blood loss was 118 ± 54 ml. Postoperative complications occurred in 12.9% of patients, while reoperation was required in 2.4%. Surgeon satisfaction with AR guidance was high, with a mean score of 4.3 ± 0.6 on a 5-point scale. ***Conclusion:*** Augmented reality–guided surgical localization is a feasible and effective adjunct in pediatric chest wall tumor surgery, offering high localization accuracy, acceptable operative outcomes, and strong surgeon acceptance.

Keywords: Augmented reality, pediatric surgery, chest wall tumors, surgical navigation, tumor localization.

INTRODUCTION

The pediatric chest wall tumors are a clinically important but rare group of neoplasms, some of which are benign (fibromatosis and osteochondroma), and others of which are malignant (Ewing sarcoma, soft-tissue sarcomas). Although they are relatively rare, these tumors are operationally difficult owing to their location, in close relation to vital thoracic organs such as the lungs, heart, intercostal vessels and developing ribs, and the effect they may have on the development of the chest wall and respiratory mechanics in children [1][2]. Proper localization and resection of the tumor with negative margins have been the key to the best oncologic outcome and minimal functional and cosmetic morbidity [3]. Conventional surgical planning of pediatric chest wall tumors has been dependent on a preoperative imaging technique of computed tomography (CT) and magnetic resonance imaging (MRI). These imaging datasets are, however, normally understood in the form of two dimensions and hence, the surgeon is expected to build the three-dimensional anatomical associations in the course of surgery in the mind. This mental translation poses the risk of misjudging the space especially in deep, small, and anatomically complex lesions that may result in incomplete resected lesions, excessive tissue loss or may lead to increased surgery time [4][5]. Such difficulties are even exacerbated in the case of pediatric patients because of the reduced anatomical sizes and low ability to tolerate the surgical error. AR has become one of the latest visualization processes that allow the real-time overlay of digital anatomy models on the physical surgery stage. Relying on the combination of preoperative imaging data and intraoperative visualization, AR gives the surgeons a direct view of the subsurface tumor boundaries, anatomical features, and planes of resection during surgery [6]. As opposed to traditional navigation systems which involve bulky hardware or indirect screen-based display, AR offers highly intuitive, surgeon-friendly interface with potential to improve spatial awareness and precision of operations [7].

AR-surgical navigation has shown encouraging outcomes in the last few years in most types of surgery, such as neurosurgery, orthopedic oncology, hepatobiliary, and maxillofacial reconstruction. It has been noted in the literature that there is better localisation accuracy, shorter operations time, and better surgeon confidence with the use of AR guiding in addition to traditional methods [8][9]. Nevertheless, AR use in pediatric oncologic surgery, and especially chest wall tumors, has not yet been fully explored, and the current evidence is mostly confined to a case report, feasibility studies, or small series in high-resource environments [10]. The possible usefulness of AR guidance is particularly applicable in the low- and middle-income nations, where the affordability, infrastructure, and technical proficiency may limit access to sophisticated intraoperative navigation systems. Pediatric surgical oncology services are often constrained in resources in Pakistan and localization of surgery remains largely the domain of surgeon experience and traditional interpretation of imaging [11]. The integration of AR based guidance systems, which are flexible, scalable and economical can provide a viable avenue to precision surgery without necessarily involving the use of costly navigation platforms. Besides, pediatric patients are a group where the accuracy of surgery has long-term consequences; because an inappropriate resection can lead to reoperations, adjuvant treatment, or the development of growth retardation and chest wall anomalies [12]. AR guidance can positively impact the morbidity and healthcare burden in the long term by enhancing immediate surgical outcomes through an improved intraoperative localization and margin delineation [13].

Objective:
To evaluate the clinical application and feasibility of augmented reality–guided surgical localization in pediatric patients undergoing chest wall tumor resection.

METHODOLOGY

This was a descriptive, observational study conducted at Rai medical college Sargodah from June 2024 to June 2025, including 85 pediatric patients diagnosed with chest wall tumors and planned for surgical excision.

Inclusion Criteria

- Pediatric patients aged ≤18 years
- Radiologically confirmed chest wall tumors on CT and/or MRI
- Patients planned for elective surgical resection
- Availability of preoperative imaging suitable for three-dimensional reconstruction
- Patients whose parents or legal guardians provided informed consent

Exclusion Criteria

- Recurrent chest wall tumors
- Emergency surgical cases
- Poor-quality imaging unsuitable for AR-based reconstruction
- Patients with contraindications to surgery
- Patients whose guardians declined consent

Data Collection

Data were collected using a structured proforma. Recorded variables included patient demographics, tumor characteristics (size, location, and type), imaging modality used, intraoperative AR localization findings, operative time, margin status, and intraoperative complications. Surgeons' feedback regarding the usability, accuracy, and clinical utility of the AR system was documented using a Likert-scale questionnaire. Localization accuracy was assessed by comparing AR-predicted tumor boundaries with intraoperative findings.

Statistical Analysis

Data were analyzed using SPSS version 24. Quantitative variables such as age, tumor size, and operative time were expressed as mean ± standard deviation, while categorical variables including gender, tumor type, margin status, and complication rates were presented as frequencies and percentages. Descriptive statistics were used to summarize study outcomes. A p-value of ≤0.05 was considered statistically significant where applicable.

RESULTS

Data were collected from 85 pediatric patients with a mean age of 11.6 ± 3.9 years, with most children clustered around early adolescence (median age 12 years, IQR 9–15). Male patients slightly predominated, accounting for 57.6% of cases, while females comprised 42.4%, with comparable age distributions across genders. The mean body weight was 34.8 ± 11.2 kg, reflecting the broad pediatric age range. Tumors were more commonly located on the right side of the chest wall (51.8%), followed by the left side (43.5%), with midline involvement being uncommon (4.7%). Clinically, chest wall swelling was the predominant presenting symptom, observed in nearly three-quarters of patients (72.9%), whereas pain was reported in 17.6% and incidental detection occurred in 9.4%.

Table 1. Baseline Demographic and Clinical Characteristics of Pediatric Patients (n = 85)

Variable	Category	n (%)	Mean ± SD	Median (IQR)
Age (years)	Overall	85 (100)	11.6 ± 3.9	12 (9–15)
Gender	Male	49 (57.6)	11.9 ± 3.8	12 (10–15)
	Female	36 (42.4)	11.2 ± 4.0	11 (8–14)
Body weight (kg)	Overall	85 (100)	34.8 ± 11.2	33 (26–42)
Tumor side	Right	44 (51.8)	11.8 ± 3.7	12 (9–15)
	Left	37 (43.5)	11.4 ± 4.1	11 (8–14)
	Midline	4 (4.7)	10.9 ± 3.5	11 (8–13)
Presenting symptom	Swelling	62 (72.9)	11.7 ± 3.8	12 (9–15)
	Pain	15 (17.6)	12.3 ± 3.6	13 (10–15)
	Incidental	8 (9.4)	9.8 ± 4.2	10 (7–13)
Symptom duration (months)	Overall	85 (100)	4.8 ± 2.1	5 (3–6)

CT alone was the most frequently used imaging modality (44.7%), followed by combined CT and MRI (30.6%) and MRI alone (24.7%). Overall tumor size averaged 5.2 ± 1.8 cm, with a median size of 5.1 cm (IQR 3.9–6.4), indicating moderate-sized lesions at presentation. Tumors imaged with combined CT and MRI tended to be slightly larger, with a mean size of 5.7 ± 1.9 cm, compared with 5.1 ± 1.7 cm for CT-only and 4.8 ± 1.6 cm for MRI-only cases. The mean tumor volume was 48.6 ± 22.3 cm³, suggesting substantial three-dimensional disease burden in many patients. Deep-seated tumors were predominant, accounting for 65.9% of cases and demonstrating larger mean sizes than superficial lesions. Rib involvement was noted in 36.5% of patients, while close pleural proximity of less than 5 mm was observed in 22.4%, highlighting the anatomical complexity of these tumors.

Table 2. Radiological and Tumor Characteristics on Preoperative Imaging

Parameter	Category	n (%)	Mean ± SD	Median (IQR)
Imaging modality	CT only	38 (44.7)	Tumor size 5.1 ± 1.7 cm	5.0 (3.9–6.2)
	MRI only	21 (24.7)	Tumor size 4.8 ± 1.6 cm	4.7 (3.6–5.8)
	CT + MRI	26 (30.6)	Tumor size 5.7 ± 1.9 cm	5.6 (4.4–6.8)
Tumor size (cm)	Overall	85 (100)	5.2 ± 1.8	5.1 (3.9–6.4)
Tumor volume (cm³)	Overall	85 (100)	48.6 ± 22.3	45 (32–61)
Tumor depth	Superficial	29 (34.1)	3.9 ± 1.2	3.8 (3.0–4.7)
	Deep	56 (65.9)	5.9 ± 1.6	5.8 (4.7–7.0)
Rib involvement	Present	31 (36.5)	6.1 ± 1.7	6.0 (4.8–7.2)
Pleural proximity	<5 mm	19 (22.4)	6.4 ± 1.5	6.5 (5.3–7.5)
Radiologic margins	Well-defined	52 (61.2)	4.7 ± 1.5	4.6 (3.6–5.6)

The overall mean AR localization error was 3.4 ± 1.6 mm, with a median deviation of 3.1 mm, demonstrating high spatial accuracy of the AR system. Accurate localization within 5 mm was achieved in 80.0% of patients, while 20.0% exhibited deviations greater than 5 mm, with a mean error of 6.8 ± 1.1 mm in this subgroup. AR guidance resulted in modification of planned skin incisions in 34.1% of cases and assisted margin planning in 71.8%, reflecting its tangible influence on surgical decision-making. The mean operative time was 96.7 ± 21.4 minutes, with a median of 92 minutes, indicating procedural efficiency despite the use of advanced technology. Mean intraoperative blood loss was 118 ± 54 ml, remaining within acceptable pediatric surgical limits. En bloc resection was successfully achieved in 85.9% of patients, and intraoperative complications occurred in 10.6%, suggesting favorable operative outcomes with AR assistance.

Table 3. Intraoperative Augmented Reality Localization and Surgical Parameters

Variable	Category	n (%)	Mean ± SD	Median (IQR)
AR localization error (mm)	Overall	85 (100)	3.4 ± 1.6	3.1 (2.2–4.6)
Localization accuracy	≤5 mm	68 (80.0)	2.6 ± 0.9	2.5 (1.9–3.2)
	>5 mm	17 (20.0)	6.8 ± 1.1	6.6 (6.0–7.4)
AR-assisted incision change	Yes	29 (34.1)	Error 2.8 ± 1.1	2.7 (2.0–3.4)
AR-assisted margin planning	Yes	61 (71.8)	Error 2.9 ± 1.3	2.8 (2.0–3.7)
Operative time (min)	Overall	85 (100)	96.7 ± 21.4	92 (82–110)
Blood loss (ml)	Overall	85 (100)	118 ± 54	105 (80–150)
Resection method	En bloc	73 (85.9)	Time 92 ± 18	90 (80–102)

Complete tumor excision with negative margins (R0) was achieved in 81.2% of patients, while microscopic positive margins (R1) were observed in 18.8%, with R1 cases associated with larger tumors averaging 6.4 ± 1.8 cm compared to 4.9 ± 1.6 cm in R0 resections. Postoperative complications occurred in 12.9% of patients, and the mean hospital stay was 4.6 ± 1.9 days, with most children discharged within a median of 4 days. Chest wall deformity was observed in 7.1% of cases, predominantly among younger patients with a mean age of 8.9 ± 2.7 years. Reoperation was required in only 2.4% of patients, both of whom experienced prolonged hospital stays averaging 9.5 ± 1.2 days.

Table 4. Margin Status, Postoperative Outcomes, and Surgeon Evaluation

Parameter	Category	n (%)	Mean ± SD	Median (IQR)
Margin status	R0 (Negative)	69 (81.2)	Tumor size 4.9 ± 1.6	4.8 (3.7–5.9)
	R1 (Positive)	16 (18.8)	Tumor size 6.4 ± 1.8	6.2 (5.1–7.6)
Postoperative complications	Present	11 (12.9)	LOS 6.8 ± 2.1 days	6 (5–8)
Chest wall deformity	Present	6 (7.1)	Age 8.9 ± 2.7	9 (7–11)
Length of hospital stay (days)	Overall	85 (100)	4.6 ± 1.9	4 (3–6)
Reoperation required	Yes	2 (2.4)	LOS 9.5 ± 1.2	9.5 (9–10)
Surgeon satisfaction score (1–5)	Overall	85 (100)	4.3 ± 0.6	4 (4–5)
AR usefulness perception	High	61 (71.8)	Score 4.6 ± 0.4	5 (4–5)

DISCUSSION

The current research indicates that augmented reality (AR)-guided localization of surgeries is a viable and clinically applicable supplement during the treatment of pediatric tumors of the chest wall with satisfactory quality of localization, tolerable surgery durations, and promising oncolytic results. The patient age (11.6 ± 3.9) and the majority of the patients noted in this group of patients are in line with the trends of demographics in the past studies where pediatric chest wall tumours have been identified to be more prevalent in school-going children and early adolescents with a comparative male predisposition [14]. Equally, the high occurrence of chest wall swelling as the major presenting symptom and the relatively low mean duration of symptom of 4.8, 2.1 months, coincides with the results of earlier studies, which should consider that observable or palpable chest wall masses tend to trigger early clinical assessment. The radiological presentation of 5.2 cm mean tumor and high percentage of deep-seated lesions (65.9%), highlights the technical challenge of the surgery of pediatric chest wall tumor. Such tumor sizes and equally high rates of deep or rib-related lesions were reported in previous studies, and the translation of two-dimensional images into intraoperative locality is intrinsically challenging [15][16]. The fact that 36.5 percent and close pleural proximity were present in 22.4 percent of patients, further supports the rationale of increased intraoperative visualization, as stated in past studies that have studied resections of chest wall tumors in children. Among the most significant results of this research is the high accuracy of the AR-guided localization, mean error of localization is 3.4 ± 1.6 mm, and the localization success is 80 percent and 5 mm. These findings are more than consistent with prior studies that assessed the AR-based navigation support in oncologic and orthopedic surgeries, and usually, localization errors were within the range of 2 to 5 mm [17]. The fact that spatial accuracy has been significantly improved proves the notion that AR can be effectively used to fill the void between preoperative imaging and real-time anatomy of the surgery, especially in anatomically restricted pediatric practice.

The effect of AR on intraoperative decision making was also clear because AR guidance resulted to adjustment in planning of skin incision in 34.1% patients and margin planning in 71.8%. Past studies have already indicated similar results that AR guidance often results in a change in surgical plan through the refinement of incision sites and resection courses of action, despite the original plans being seemingly sufficient before surgery [18]. This implies that AR does not simply reproduce the already existing image data set, but it refines real time anatomical knowledge, which in turn assists in more personalized surgical practices. Operative efficiency was also good with an average of 96.7 minutes and 21.4 minutes as the mean operative time and blood loss respectively. Such values can be compared with, and in certain reports lesser than, operative measures outlined in prior studies, of conventional resections of the chest wall tumors [19]. Notably, the application of AR did not seem to increase the time of operation, an issue often mentioned with new technologies in the field of intraoperative. This observation concurs with prior studies that AR systems do not add up to sizeable time fines, when incorporated into surgical workflow. The outcomes regarding oncology were also promising as complete (R0) resection was observed in 81.2% of patients. R0 resection rates in children with Tumor surgery of the chest wall have been reported in previous studies to be around 70 percent to 85 percent so the current study will fall right in the middle of this range and close to the top of the same range [20]. The positive correlation between positive margins and large tumor size in this study is similar to results in the previous studies indicating that tumor size and depth are the most important predictors of margin status. In general, the results of this paper are well aligned with the existing literature and building on the existing body of research, the authors prove the usefulness of AR-guided surgical localization in pediatric chest wall tumors, in the context of a developing healthcare facility. The findings indicate that AR guidance does not increase the risk or complexity of the operations and can improve the accuracy of surgery.

CONCLUSION

It is concluded that augmented reality–guided surgical localization is a feasible, safe, and clinically valuable adjunct in the surgical management of pediatric chest wall tumors. The use of augmented reality demonstrated high localization accuracy, acceptable operative times, and favorable oncologic outcomes, with the majority of patients achieving complete tumor excision and low rates of intraoperative and postoperative complications. The technology showed a meaningful impact on intraoperative decision-making, particularly in incision planning and margin delineation, without increasing operative complexity. High levels of surgeon satisfaction further support its clinical acceptability.

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