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RESEARCH

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Robotic-assisted costectomy using a Gigli saw for fibrous dysplasia

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Abstract

Background Fibrous dysplasia (FD) is the most common benign tumor of the ribs, with surgical resection being the preferred treatment modality for rib FD, leading to enhanced quality of life and favorable outcomes. The complexity of surgical intervention varies depending on the location of costal FD, presenting challenges for both open surgical and thoracoscopic approaches. In this study, we present a novel technique for three-port robotic-assisted costectomy utilizing a Gigli saw, detailing our initial findings and outcomes.

Methods We reviewed five patients with benign rib tumors who underwent three-port robotic-assisted rib resection using a Gigli saw between May 2021 and December 2022. Data on patient characteristics, relevant short-term surgical outcomes and clinical long-term treatment effects were collected.

Results The surgery was successful in all five patients without any need for an additional port and emergency conversion to open surgery. Median operative time was 76.8 min (range, 73–116 min), and the median intraoperative blood loss volumes was 75 ml (range, 40– 105 mL). On average, chest tubes were removed 1.2 days postoperatively (range, 1–2 days), with a mean drainage volume of 93 ml on postoperative day 1 (range, 70–135 ml). Patients were discharged between the 2nd and 4th postoperative day. During 1-year follow-up period, no recurrence was observed in either patient.

Conclusions The utilization of a three-port robotic-assisted costectomy in conjunction with a Gigli saw represents a viable, secure, and efficient approach for treating isolated benign rib lesions. Our aim is to provide clinical guidance on this technique and promote its broader application.

Keywords Robot-assisted costectomy, Fibrous dysplasia, Gigli saw, Rib resection

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Introduction

The term "rib tumor" encompasses a diverse range of both malignant and benign lesions, which are categorized based on histological type and clinical behavior. Malignant tumors have a higher incidence compared to benign tumors [1]. The most common benign lesions include fibrous dysplasia (FD), chondroma, and osteochondroma [2], among which, FD is the commonest one [3] and is considered a congenital, non-inherited disorder, appearing in the lateral or posterior tract of the ribs and arising from osteoblasts' abnormal morphological differentiation and maturation, followed by subsequently progressive replacement of normal marrow and cancellous bone by immature bone and fibrous stroma [4]. FD is frequently found incidentally through radiographic imaging and is typically asymptomatic, although it may manifest with pain, potentially due to a pathologic fracture [5]. These symptoms are often nonspecific and can hinder early diagnosis. Accurate histologic confirmation is essential for guiding the appropriate treatment method for rib tumors, necessitating preoperative diagnosis through techniques such as fine-needle aspiration and excisional biopsy [6].

While observation and regular radiographic follow-up are recommended as the initial management approach for asymptomatic FD, symptomatic patients or those with atypical lesions may require surgical excision for lesion eradication and accurate histological diagnosis. Due to the potential malignant degeneration of FD to osteosarcoma or fibrosarcoma [7], surgical resection of affected ribs has been identified as a key strategy to prevent malignant change. Historically, surgery has been the preferred treatment for rib FD because it not only reduces the risk of relapse at healthy margins but also eliminates challenges associated with differential diagnosis of malignant lesions through surveillance [7, 8], with open surgical approaches such as thoracotomy and transaxillary approaches being commonly employed based on lesion location. While traditional surgical approaches effectively extirpate lesions and improve patients' quality of life, the extensive skin incision associated with these procedures can negatively impact quality of life and increase postoperative pain. In response to this issue, there has been a shift towards utilizing minimally invasive transthoracic approaches in recent years. The introduction of minimally invasive video-assisted thoracoscopic surgery (VATS) in the early 1990s [9] and robotic-assisted thoracic surgery (RATS) in 2002 [10] has led to significant advancements in thoracic surgical techniques, with these procedures now being commonly utilized for a wide range of operations due to their superior aesthetic outcomes compared to traditional open surgery methods.

RATS represents an alternative to VATS through the implementation of high-resolution magnification of the surgical field in three dimensions, tremor reduction, and precise manipulation of multi-joint forceps with varying degrees of freedom [11]. These features contribute to a nature progression toward robotic-assisted costectomy. This robotic approach provides benefits such as enhanced exposure of rib tumors and thorough separation of neurovascular structures. However, surgeons may encounter technical challenges, particularly in the selection of effective rib resection devices, which can lead to confusion and potential pitfalls during the robotic-assisted costectomy procedure. Prior studies have documented the utilization of pneumatic surgical drill [12], Kerrison rongeurs [13] and Gigli saw [1] for rib resection; however, instances of robotic-assisted costectomy, particularly involving the use of a Gigli saw, have been infrequent. Notably, there is a dearth of literature on robotic rib resection using a Gigli saw in patients with FD. In this study, we developed a novel technique combining robotic assistance with the use of a Gigli saw for excision of rib fibrous dysplasia. This approach offers less invasiveness compared to traditional methods, while also providing superior exposure and precision in targeting the rib, ultimately leading to reduced postoperative pain and favorable aesthetic outcomes. Our findings support the adoption of robotic-assisted costectomy with a Gigli saw in clinical settings, with potential for widespread implementation.

Materials and methods

Study design and patients

In this retrospective study, we collected the clinical and pathological data of 5 patients affected by FD undergoing rib resection from May 2021 to December 2022. The study was conducted in accordance with the recommendations of the Declaration of Helsinki (as revised in 2013) and was approved by The Ethics Committee of the hospital (No. 2022 technology 37), which waived the requirement for informed consent due to the retrospective nature. Patients suffering isolated benign rib tumor were selected and those with malignant costal tumor, multiple rib involvement, metastases or chest wall reconstruction requirement were excluded. Their clinicopathological characteristics [age, gender, body mass index (BMI), comorbidities (such as hypertension and diabetes), and histological result] and symptoms were collected. Perioperative outcomes [surgical duration, amount of intraoperative bleeding, volume and duration of chest tube drainage, postoperative hospitalization, postoperative complications and pain according to visual analog score (VAS) evaluation] were retrieved from medical records. Participants' follow-up period and recurrence were also recorded. All procedures were performed by the same surgeon.

Perioperative preparation

Upon admission, the patients were required to complete laboratory tests and preoperative investigations within a 2–3 day timeframe prior to surgery. They were evaluated clinically and radiologically with X-ray, chest computed tomography (CT), and bone scan as depicted in Fig. 1A-D. Functional evaluations, such as spirometry and ultrasound cardiogram, were also performed to ensure patients' suitability for the surgical procedure. Positron emission tomography-CT (PET-CT) was conducted if necessary (Fig. 1F).

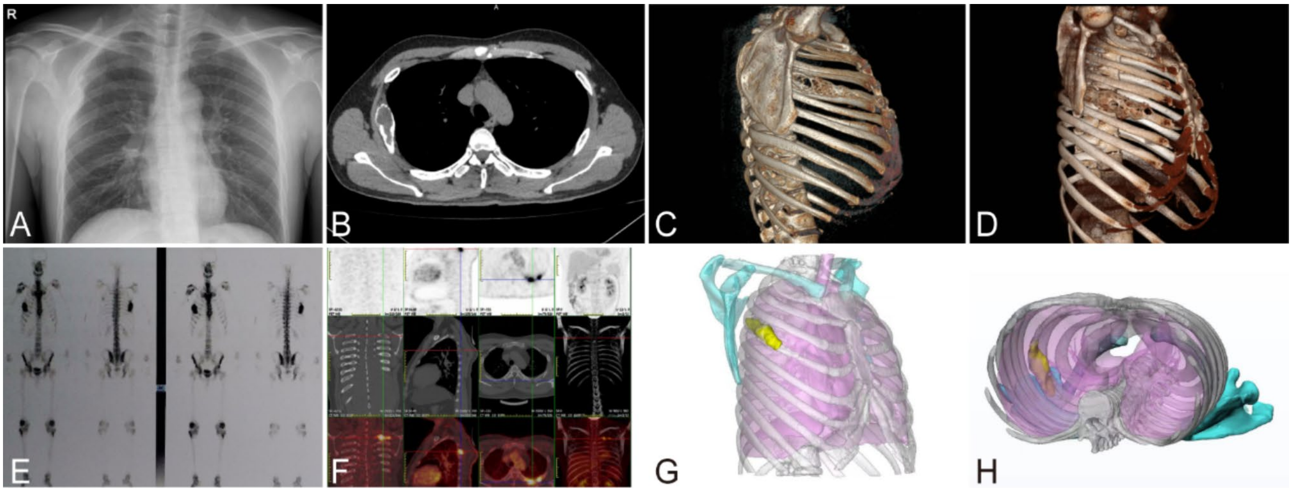

Fig. 1 Preoperative imaging examinations and 3D images of some patients. (**A**) Chest radiography shows a lesion in the right chest wall. (**B**) Chest CT revealed a fusiform lesion with ground-glass centre of the lateral aspect of the right 4th rib. (**C**, **D**) 3D reconstructions show two lesions of FD in the right 4th rib and the right 5th rib respectively. (**E**) Bone scan shows increased activity in the right 5th rib. (**F**) PET-CT shows a benign costal lesion of the post aspect of the left 4th rib in a patient with breast cancer. (**G**, **H**) 3D images reconstructed with Mimics Mecdical 21.0 software. Exact three-dimensional relationships of the rib tumor, upper and lower ribs, blood vessels, spines and pulmonary tissues. Grey: normal ribs and spines; Purple: pulmonary tissues; Blue: scapulas and clavicles; Yellow: rib tumor region

Given the potential for surgical pitfalls, particularly in determining the precise location of the lesion, we utilized the Mimics Medical 21.0 software to generate preoperative 3D reconstructions (Fig. 1G, H) for obtaining stereoscopic images, accurately identifying the costal focus, delineating its relationship to surrounding tissues and vessels, and subsequently designing an appropriate surgical procedure.

After the operation, all patients received continuous analgesic pump system and non-steroidal anti-inflammatory drugs (2 tablets per day) at postoperative day 1, if not contraindicated. The VAS was used to measure the intensity of patients' pain at 1, 2 days postoperatively, which was used in the follow-up investigation of various cancers.

Surgical procedures

As high-position rib tumors involving the first to third ribs were not present in any of the patients, artery angiography for assessing the passage of great vessels at the cervicothoracic junction was omitted. Localization of rib lesions was achieved through preoperative techniques such as wire localization or placement of paper clips near the lesion under CT guidance, with borders marked using needles. Following standard preoperative preparation in accordance with traditional surgical practices, all patients underwent robotic-assisted costectomy utilizing the da Vinci Xi Surgical System. After achieving general anesthesia and contralateral single-lung ventilation through the use of a double-lumen endotracheal tube or selective endobronchial blocking, patients were positioned in a lateral-decubitus-with-jackknife posture to facilitate expansion of the intercostal space. The da Vinci Xi robot was positioned at the patient's head and left side. A three-port procedure was utilized, with the port mapping shown in Fig. 2A. The initial utility incision, measuring 3 cm, was made at the anterior axillary line to serve as both the assistant hole and the camera port. During most of the procedure, the camera port was strategically fixed at the center of the wound protector to prevent interference with the instruments utilized by the bedside assistant. Adequate space was maintained around the camera port to facilitate tasks such as lung retraction, bleeding suction, exchange of items, and specimen retrieval. The choice of intercostal space for port placement was determined by the location of the rib tumor, typically falling within the fifth or sixth intercostal space. Under view guidance, two additional 8-mm incision were created in the fourth or fifth intercostal space of the anterior axillary line and in the seventh or eighth intercostal space of the mid-axillary line, respectively, serving as the working channels for the robotic arms after the trocar sleeve was inserted. Maryland bipolar forceps and a cautery hook were manipulated by the 1st and 3rd robotic arms respectively, corresponding to the surgeon's left and right hands (arm 1 and arm 3). In left-side procedures, the Maryland bipolar forceps was positioned in the lower left of the utility incision, while in right-side procedures, it was placed in the upper right of the utility incision. The cautery hook was controlled by the right hand with the opposite direction of the Maryland bipolar forceps relative to the utility incision.

The parietal pleura, particularly the upper and lower edges of the rib, was opened 3 cm away from either the

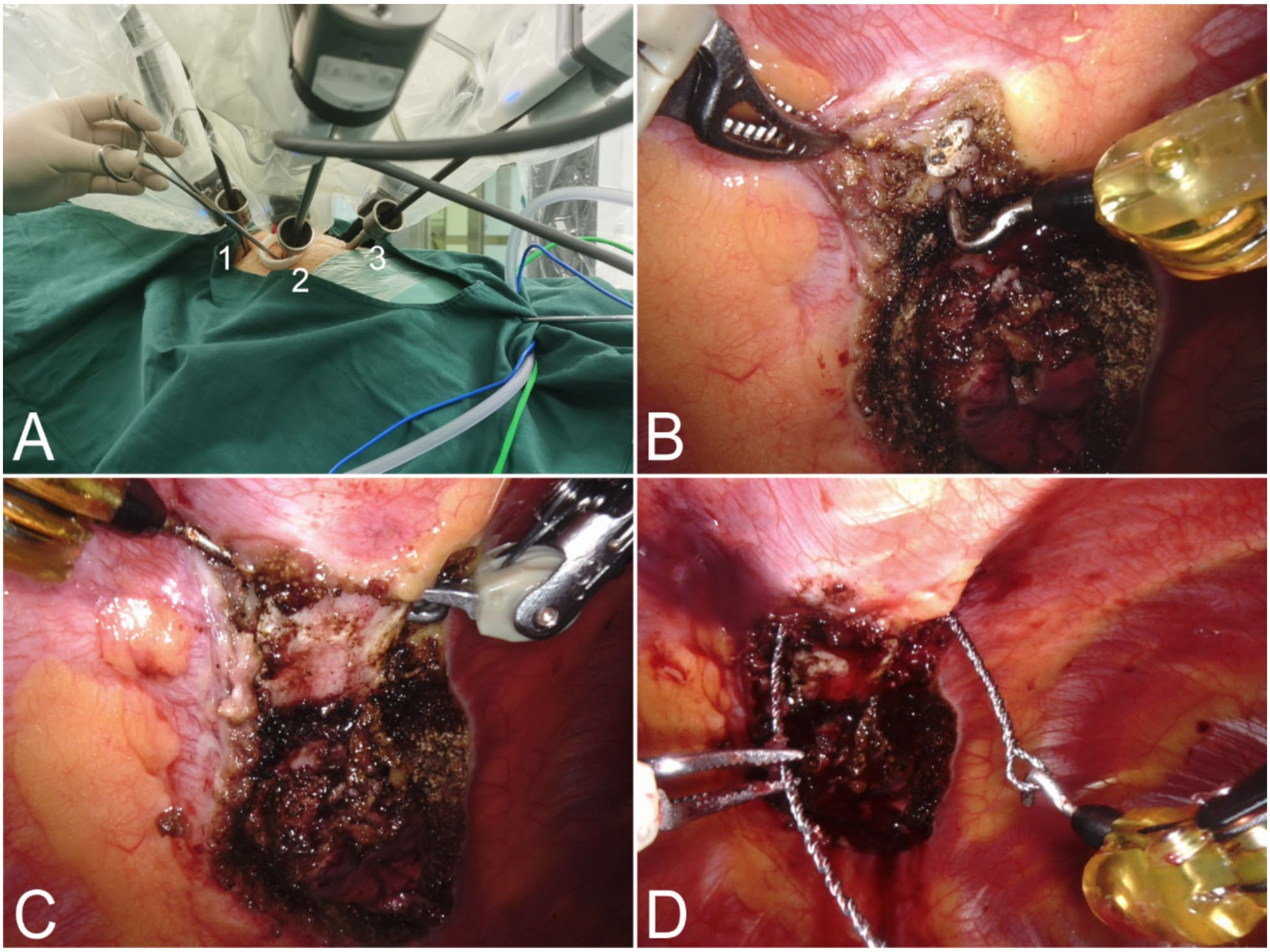

Fig. 2 Intraoperative pictures and important steps of robotic-assisted costectomy in a patient with fibrous dysplasia. (**A**) The incisions and port placement of RATS. Port 1 is equipped with a maryland bipolar forceps (surgeon left hand); The table surgeon and the camera port share the same incision as port 2; Port 3 is equipped with a permanent cautery hook (surgeon right hand). (**B**) The parietal pleural over the lesion border of the rib is opened. (**C**) The Maryland bipolar forceps and the cautery hook cooperate with each other to create a tunnel behind the target rib for placing the Gigli saw. (**D**) Two robotic instruments hold the Gigli saw for cutting the rib

end of the target area using cautery hook (Fig. 2B). Periosteal tissues at both ends of the rib tumor were dissected at least 3 cm. Following blunt dissection of the intercostal muscle, the intercostal vessels were exposed, coagulated and severed using electrical hook. Surrounding tissue around the target rib was detached to create a tunnel with the collaboration of two robotic instruments (Fig. 2C). The Gigli saw was subsequently inserted into the thoracic cavity through a utility incision, with one end held by forceps passing through the tunnel and caught by the cautery hook. Then the Gigli saw formed a loop around the lower margin of the rib and severed the rib through a back-and-forth movement (Fig. 2D). Two robotic instruments were utilized to maintain the position of the saw during the rib transection. The upper margin of the targeted rib was detached in a similar manner. Hemostasis of the broken costal end was achieved by using electrocautery. The assistant provided continuous assistance in maintaining the Gigli saw in the right position to prevent slippage while optimizing visualization with a long suction device. Following completion of the partial costectomy, a bag was introduced into the thoracic cavity to retrieve the resected rib segment. After hemostasis, one 28 Fr chest tube was inserted via the camera port, with three incisions subsequently sutured.

Statistical analysis

All patient data were retrieved from medical record system, and the data were retrospectively recorded using Microsoft Office Excel 2007.

Results

Patients' clinical and pathological characteristics

Table 1 provides the characteristics of the patients, comprising three males and two females, with an average age of 40.6 years (range, 27–51 years), an average BMI of

Table 1 Clinicopathologic characteristics of the patients

Case	Age/Sex	BMI(kg/m2)	FEV1%	Comorbidities	Symptom	Location/side	Diagnosis	Size (cm)
1	27/M	23.82	92	None	Pain	R 4th rib	FD	4.5
2	46/M	21.78	88	DM	None	R 6th rib	FD	7
3	36/F	29.65	91	None	Pain	L 4th rib	FD	6
4	51/M	28.64	85	HT, CABG	Palpable mass	L 7th rib	FD	5
5	43/F	22.91	102	None	None	R 6th rib	FD	6

BMI, body mass index; FEV1: Forced expiratory volume in 1 s; M, Male; F, Female; DM, Diabetes mellitus; HT, Hypertension; CABG, Coronary artery bypass grafting; R, Right; L, Left; FD, Fibrous dysplasia

Table 2 Intraoperative parameters of the patients

Case	Surgical duration (min)	Intraoperative blood loss (ml)	Chest tube duration (days)	Chest tube volume (ml)	postoperative hospitalization (days)
1	78	40	1	80	2
2	116	85	1	90	2
3	102	90	1	70	2
4	73	105	2	135	4
5	85	55	1	90	2

Table 3 Postoperative morbidity and pain VAS scores

Case	Complications	24 h pain VAS scores	48 h pain VAS scores	Outcome at 1-year follow-up
1	None	3.6	2.8	No recurrence
2	Wound infection	2.7	2.3	No recurrence
3	None	3.1	2.5	No recurrence
4	None	2.5	1.8	No recurrence
5	None	2.4	1.6	No recurrence

VAS, Visual Analogue Scale

25.36 kg/m2 and median FEV1% of 91%. Two patients presented to our hospital with progressively worsening chest pain, and one patient complained growing mass on the chest wall. All the final pathologic report confirmed: fibrous dysplasia of the rib, the location of which located in the middle ribs involving the 4th to 7th ribs. The target lesion on the rib was completely excised, with the mean size of tumor of 5.7 ± 0.97 cm.

Perioperative outcome of patients

No adverse events occurred during the surgeries, and there was no need for further interventions. Table 2 sets out a detailed overview of the surgical outcomes. The median operation durations were 76.8 min and the median blood loss volumes were 75 ml. The postoperative parameters revealed that the average time and volume of chest tube drainage were 1.2 days and 93 ml, respectively. The patients had an uneventful recovery and were discharged between 2 and 4 days post-surgery. No severe complications were observed in all patients postoperatively, with only one patient suffering from wound infection. Three patients reported mild pain (VAS < 3) during the first 24 h after the surgery, with two patients suffering moderate pain (VAS > 3). There were no evidence of local recurrence during routine follow-ups one year after the operation (Table 3).

Discussion

Fibrous dysplasia, initially described by Lichtenstein in 1938 and Jaffe in 1942 [14], is the most common benign rib tumor of the chest wall [15]. It can be classified into two major types: monostotic (involving a single bone) and polyostotic (involving two or more bones). Monostotic subtypes are about four–six times more common than polyostotic subtypes [8]. All patients in our research were confirmed with the monostotic FD. The monostotic forms, usually asymptomatic, is an incidental imaging finding or and typically develops between the third and fourth decade of life with a wide age of 10 and 70 years [16]. However, if sufficiently large, it may cause local pressure symptoms, such as pain, mass, discomfort or swelling. The pain can be either pleuritic (growth within the pleural space), or neuritic (intercostal nerves invasion) [17]. Meanwhile, monostotic FD is occasionally complicated by pathologic fracture and rarely by malignant change, with the estimated frequency of about 0.5% [7]. To date, many reports have discussed the diagnostic value of PET/CT in discriminating FD of the ribs, which was controversial. In 2012, Akram et al. [8] reported seven cases of rib resection with the diagnosis of monostotic FD and suggested that the utility of PET scans in differential diagnosis is limited, attributing this to the frequent occurrence of hyperfixation in benign conditions such as fibrous dysplasia (FD), which often leads to false-positive results. Conversely, Sunju et al. [18] argued that despite FD exhibiting morphologic characteristics such as intramedullary bone expansion, which are clearly delineated on radiographic and CT images, PET/CT scans remain crucial. This is particularly pertinent given that the radiographic appearance of FD can mimic malignant lesions [19] and its characteristic of malignant transformation. In particular, Three patients in our study with the rib lesion length over 5 cm refused bone biopsy and accepted PET/CT to discriminate between benign and malignant lesion, also to rule out metastasis at the same time (Fig. 1F). Most cases in our group were symptomatic presenting with chest pain or palpable enlarging mass, which appeared to be inconsistent with the asymptomatic universality of FD. This discrepancy may be resulted from our small size of sample. Although non-specific, preoperative chest CT actually showed the features of "ground-glass appearance" characterized a variable degree of mineralization with a faint homogeneous increase in density (Fig. 1B), which are highly suggestive of the diagnosis. Notably, Zarqane et al. [20] proposed that the first diagnosis to consider, for benign lesions, is FD. It is difficult to make a preoperative definite diagnosis of the rib tumors despite the correlation of imagery and needle biopsy. Some researchers [21, 22] advocated that bone biopsy or surgical excision is preferable to needle or incisional biopsy for histological confirmation encountering rib tumors. On the one hand, Mohamed et al. [23] pointed that FD lesions usually need no intervention, On the other hand, some authors [24, 25] prefer complete enbloc excision (both curative and diagnostic) than simple surveillance, especially in monostotic FD of the rib, due to the potential malignant degeneration. Despite the controversy of surgical treatment for FD, all the patients with a rib tumor considered FD diagnosis undergo rib resection in our department.

Multiple approaches to surgical treatment of rib tumors have been described, but the traditional operations have been performed through open approaches [15], such as anterolateral and posterolateral thoracotomy, during which the surgical field depends on the location of the rib lesion. Recently trend has been a minimally invasive transthoracic approach, like VATS and RATS, which may provide outstanding exposure of the tumor and surrounding structures, and decrease postoperative pain [26]. RATS has been applied in the treatment of various chest diseases, including lung, esophagus, mediastinum, chest wall, and so on [27]. Although the experience in robotic-assisted rib resection is still very limited, just like the original appearance of VATS, one can now clearly foresee its potential advantages. Moreover, the recently acquired ability of thoracic surgeons to perform robotic-assisted first rib resection successfully curing thoracic outlet syndrome, without significant mortality and limited morbidity, firmly established the role of robotic-assisted costectomy in the management of rib tumors, especially addressing FD of the rib [28–30]. The robotic procedure for rib resection was first fixed four-port pattern [31], but gradually, improvements in robotic technique, the ever-growing aesthetic demands and desire of satisfactory cosmesis have made less surgical incisions possible. Although Anna et al. recently performed surgical resection of the first rib using a single port RATS, the complex surgical techniques and less maneuverability holding back its application and development. Therefore, we designed three-port strategy for rib tumor resection, with one 3-cm utility incision sharing with the camera port and two 8-mm incisions for robotic arms (Fig. 2A). To mitigate the risk of the robotic arm colliding with the assisting table surgeon, we strategically positioned the camera port at the center of the wound protector. This methodology aligns with the triangle target principle proposed by Sasaki M [32], while also minimizing the number of surgical incisions. Throughout the procedure, the spatial configuration and the precise movement of the multi-joint forceps enhanced the surgeons' operational experience, rendering it more akin to that of a thoracotomy. To the best of our knowledge, this is the first report in the world introducing the specific port mapping and the innovative placement of the arms for robotic-assisted costectomy.

The anatomic structure of the thorax is complicated, many variations increase the challenge of performing surgical resection. To minimize this problem, we used the Mimics Medical 21.0 software to accomplish 3D reconstruction of the chest wall, to obtain stereoscopic images and to ascertain the location of the rib lesion and its relationship to the adjacent lung tissue, blood vessels and spine (Fig. 1G, H). However, it is also difficult to verify definite position of rib tumor inside the chest cavity during the operation if no changes occuring in the parietal pleura or no mass protruding into the thoracic cavity. Usually, in our patients, the use of wire localization, or by placing paper clips on the epidermis near the lesion under CT guidance, where the borders were marked with needles, can overcome this difficulty perfectly. It allows real-time monitoring of needle tip placement during the resection. Then successfully robotic-assisted costectomy was planned and performed following the sound procedure and specific costal localization method before surgery.

During the past two decades, a few reports were published about the applications of the specialized instruments for rib resection. Ohtsuka et al. [33] described a thoracoscopic rib resection using an endoscopic drill for thoracic outlet syndrome. Kocher et al. [13] reported a first rib resection employing a Kerrison rongeurs to divide ribs. Recently, several researchers used the Gigli saw to cut the rib under direct view or thoracoscopic guidance [1, 34, 35]. By comparison, due to the help of the robotic precise moving multi-joint forceps, which can hold the Gigli saw, move back and forth in a continuous perpendicular direction and transect the target rib more easily (Fig. 2D), the Gigli saw gained more preference over other equipments in our study. It was the approach of choice to perform a RATS while the Gigli saw was utilized for rib cutting. Of the 5 resections, 3 were on the right side. Our average surgical duration was 76.8 min, subsequently following with the low drainage volume and short time to chest tube removal, which results in good outcomes. No severe perioperative complications were observed in any case. Likewise, RATS procedure facilitated accelerated rehabilitation with decreased postoperative pain and an average postoperative hospitalization of 1.2 days, which is shorter than VATS route reported in 2019 [1]. These results reflect less invasiveness of RATS. One-year follow-up with no recurrence demonstrated the prognosis of FD after surgical excision is excellent [36]. It should be noted that failure to perform a radical excision is the major and main therapeutic error in handling rib tumors. "Negative margins" may be insufficient for FD with the possibility of malignant transformation, margins of at least 2 cm is recommended in our patients, which is consistent with previous reports [1, 21, 37]. Chest wall reconstruction was not needed in our series because of the isolated lesion or only one rib involved, nevertheless, lung herniation did not occur in any patient.

This study still has some certain shortcomings. First, the study was limited by its retrospective nature and a single-center setting, with a low number of cases. We are looking forward to a multicenter prospective randomized controlled trial study in more patients so as to further prove the advantages of the procedure of RATS and Gigli saw for rib resection. Second, this study only enrolled patients undergoing robotic-assisted costectomy, other relevant investigations including comparisons of RATS with VATS costectomy or open thoracotomy for costal lesion were required as well to explore the clinical benefits. Third, we did not collect the patients with high-position rib tumors where the lesion were located in the first to the third ribs, which may lead to the results of this study not generalizable.

Based on our experience, robotic-assisted rib resection was safe, effective and efficient, especially with the use of Gigli saw for cutting ribs. The three-port approach helped to improve cosmetic results and made no increase in the postoperative pain whereas not affecting clinical outcomes. Despite the technically challenging of robotic-assisted costectomy, this paper provides a reference from which thoracic robotic surgeons can adapt our method to any benign or malignant rib tumors as appropriate, not just FD.

Abbreviations

FD	Fibrous dysplasia
RATS	Robot-assisted thoracic surgery
VATS	Video-assisted thoracoscopic surgery
3D	3-dimensional
BMI	Body mass index
VAS	Visual analog scale
CT	Chest computed tomography
PET-CT	Positron emission tomography-CT
FEV1	Forced expiratory volume in 1 s

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Author contributions
CY designed the study and drafted the manuscript. LC helped in gathering patient information and analyzed the data. QW obtained the image data. HW provided the pathological results. All authors read and approved the final manuscript.

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Data availability
The datasets used are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate
All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional ethical committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. And all experimental protocols in the manuscript were approved by Soochow University. The ethics committee waived the requirement for informed consent due to the retrospective nature of the study.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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