Oncologic and functional outcomes of different reconstruction modalities after resection of chondrosarcoma of the scapula: a medium- to long-term follow-up study

Xiao-Jun Yu†, Qi-Kun Liu†, Ying-Guang Wang, Shan-Xi Wang, Rui Lu, Hao-Ran Xu, Jun-Lai Wan and Hao Kang*

Abstract

Objectives: To evaluate the oncologic and functional results of scapular reconstruction after partial or total scapulectomy for chondrosarcoma.

Materials and methods: Twenty-one patients with chondrosarcoma who underwent partial or total scapulectomy between January 2005 and July 2019 were reviewed retrospectively.

Results: At a mean follow-up of 62.6 months (range, 13–123 months), four patients developed local recurrence, and three developed distant metastases, one of which developed both recurrence and metastasis. The overall survival rate of patients at 5 years was 84.6%, the disease-free survival rate was 69.3%, and the complication rate was 19% (4/21). The 1993 American Musculoskeletal Tumor Society (MSTS93) scores of patients in the partial scapulectomy group, total scapulectomy + humeral suspension group and prosthetic reconstruction group were 26.50 ± 1.38, 19.00 ± 2.58, and 21.38 ± 2.62, respectively. There was a statistically significant difference between the partial scapulectomy group and the total scapulectomy + humeral suspension or prosthetic reconstruction group (P = 0.006 and 0.0336, respectively). The range of motion of the shoulder joint for forward flexion was 80.83° ± 11.14°, 51.25° ± 21.36°, and 52.50° ± 11.02°, respectively. The p-values for the comparison between the partial scapulectomy group and the total scapulectomy + humeral suspension or prosthetic reconstruction group were 0.0493 and 0.0174, respectively. And the range of motion of abduction was 75.00° ± 10.49°, 32.50° ± 11.90°, 41.88° ± 11.63°, respectively. Patients in the partial scapulectomy group had significantly better postoperative shoulder abduction function than the total scapulectomy + humeral suspension or prosthetic reconstruction group (P = 0.0035 and 0.0304, respectively). There was no significant difference in MSTS93 scores and flexion and abduction function of the shoulder joint in the upper extremity after total scapulectomy with humeral suspension or prosthetic reconstruction (P > 0.05).

†Xiao-Jun Yu and Qi-Kun Liu contributed equally to this work.
*Correspondence: kanghao100@vip.sina.com

Department of Orthopedics, Tongji Hospital, Tongji Medical College, Huazhong University of Science and Technology, Qiaokou District, Hubei Province, No. 1095, Jiefang Avenue, 430030 Wuhan, China

© The Author(s) 2022. Open Access This article is licensed under a Creative Commons Attribution 4.0 International License, which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons licence, and indicate if changes were made. The images or other third party material in this article are included in the article’s Creative Commons licence, unless indicated otherwise in a credit line to the material. If material is not included in the article’s Creative Commons licence and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this licence, visit http://creativecommons.org/licenses/by/4.0/. The Creative Commons Public Domain Dedication waiver (http://creativecommons.org/publicdomain/zero/1.0/) applies to the data made available in this article, unless otherwise stated in a credit line to the data.
Introduction
Chondrosarcoma occurring in the scapula is rare. Tumors occurring in the scapula and other flat bones have shown worse prognoses than those occurring in the extremities [1, 2]. Meanwhile, chondrosarcoma is not sensitive to radiotherapy or chemotherapy; thus, to better control the development of the tumor, patients with malignant tumors occurring in the scapula have previously required amputation [3, 4]. With the advancement of neoadjuvant therapy, surgical technology and materials, limb salvage therapy for malignant tumors of the scapula has reached approximately 95% [5, 6]. Current studies have shown that limb salvage treatment has comparable or even better outcomes than amputation [7]. However, reconstruction after scapulectomy has been an important challenge for clinicians because of the special location of the scapula adjacent to important neurovascular and cardiopulmonary structures. To date, there are three main reconstruction strategies. One is humeral suspension treatment, in which the rotator cuff or joint capsule is directly sutured or reconstructed with the proximal structures, such as the clavicle or the residual scapula. The second is reconstruction with autologous or allogeneic bone grafts, and the third is the more prevalent regimen, in which reconstruction is performed with a constrained or nonconstrained prosthesis. These different reconstruction modalities are reported to have their own advantages and corresponding complications [2, 8–12]. To date, most of the studies on reconstruction after resection of malignant tumors of the scapula have included small sample sizes and short- to medium-term follow-up results, and there is a lack of studies comparing the functional outcomes of different reconstruction modalities. In addition, few studies have reported the outcome of scapula resection and reconstruction for chondrosarcoma. Our aim was to review the cases of scapular chondrosarcoma with scapulectomy in our hospital; summarize the postoperative tumor recurrences, metastasis and postoperative complications; and evaluate the functional outcome of the upper limb after surgery by the 1993 American Musculoskeletal Tumor Society (MSTS93) scores. Additionally, we compared the results of different scapular reconstruction modalities.

Materials and methods
Patient inclusion criteria
(1) Chondrosarcoma originating from the scapula or invading the scapula from the surrounding soft tissues; (2) Postoperative positive pathological diagnosis of chondrosarcoma; (3) Partial or total scapulectomy + scapular reconstruction; (4) Enneking surgical staging of no more than stage IIB.

Exclusion criteria
(1) No definite histological diagnosis; (2) The tumor was located in the soft tissue around the scapula without invasion of bone; (3) No reconstruction after scapulectomy.

Surgical procedures
After anesthesia, the patient was placed in the lateral supine or lateral prone position with the ipsilateral shoulder up. Then, through a combined anterior and posterior surgical approach, the incision began from the coracoid process, crossed the outer 1/3 of the clavicle, followed the spine of the scapula and the medial border of the scapula to the inferior angle of the scapula, and sequentially incised the tissue structures to the tumor lesion (Fig. 1F). The extent of surgical resection was determined by the tumor border shown by preoperative MRI, and the normal tissue structures 2–3 cm around the tumor lesion were removed together. According to the location and extent of the scapular tumor, surgical resection and reconstruction were classified into three types. Partial scapulectomy was defined as partial resection of the scapula with preservation of the glenoid, and resection of either the supraspinous, infraspinous or acromion. Total scapulectomy was defined as resection of the glenoid of the shoulder together. In our series, 10 patients were treated with prosthetic reconstruction after total

Conclusions: Surgical treatment of chondrosarcoma of the scapula can achieve a satisfactory prognosis and shoulder function. Total scapulectomy followed by prosthetic reconstruction or humeral suspension are both feasible treatments.

Highlights
Surgical treatment of chondrosarcoma of the scapula can achieve good oncologic and functional outcomes. Prosthetic reconstruction of the scapula after scapulectomy does not provide better functional results than humeral suspension, and both are feasible treatment modalities.

Keywords: Scapula, Chondrosarcoma, Scapulectomy, Prosthesis, Reconstruction
scapulectomy (Fig. 1, prostheses are all from Chunli Zhengda Medical Company of Beijing, China), 5 with humeral suspension after total scapulectomy (Fig. 2), and 6 with partial scapulectomy (Fig. 3). All patients underwent soft tissue reconstruction after scapulectomy. The biceps was sutured to the clavicle, the deltoid was sutured to the trapezius, the serratus anterior was sutured to the latissimus dorsi and rhomboid, and the soft tissue surrounding the prosthesis could be sutured directly to the anchoring holes at the edge of the prosthesis by nonabsorbable sutures (Fig. 1G). The main purpose was to restore the structural integrity and stabilizing role of the deltoid, biceps, and rotator cuff. Finally, the drainage tube was placed, and the incision was closed layer by layer.

Postoperative patient management and follow-up
After surgery, patients received fluid administration and antibiotic therapy to prevent wound infection. The drainage tube is removed when the volume of drainage fluid is less than 30 ml/d, generally for 2–3 days. Postoperatively, the patient wore a brace to maintain the affected limb at 90° elbow joint flexion, 60° shoulder joint flexion and 60° abduction, and the brace was fixed for 4–6 weeks. Patients were encouraged to exercise the hands, wrists, and elbows early after surgery and gradually exercise the shoulder joints after the brace was removed.

After discharge from the hospital, regular outpatient follow-up was performed once a month within 3 months, once every 3 months within 3–12 months, once every 6 months for 1–3 years, and then once a year. X-ray examination of the shoulder was performed during each
outpatient follow-up to assess whether the tumor had recurred, whether the prosthesis was loose and other abnormalities. For suspicious cases, CT or MRI tests were performed for further confirmation. A CT scan of the lungs was performed every six months to one year to exclude metastases. At the final follow-up, the MSTS93 scoring system was used to evaluate the patient’s shoulder function, including pain, function, emotional acceptance, hand position, manual dexterity, and lifting ability. Each item was 0–5 points, with a total score of 30 points.

Statistical analysis
GraphPad Prism 8.0 (Graphpad Inc, San Diego, CA, USA) software was used for data processing and statistical analysis. Overall survival and disease-free survival were estimated using the methods of Kaplan and Meier. The results of continuous variables are shown as the means and standard deviation. The functional results between the three groups were compared by the non-parametric Kruskal–Wallis test because these data were not normally distributed.

Results
From January 2005 to July 2019, 21 eligible patients were treated in our hospital. Among them, 13 were males, and 8 were females. The patients were 27–65 years old, with an average age of 47.5 years. All patients underwent surgical treatment, of which 15 patients achieved wide surgical margins, and 6 underwent intralesional or marginal resection because of tumor invasion of the ribs, chest wall, or adjacent important neurovascular structures. All cases were pathologically confirmed as chondrosarcoma, most of which were conventional type (13/21). The complication rate was 19% (4/21), with no serious complications occurring after surgery. Two patients had wound healing problems (cases 4 and 18), which were completely healed after long-term dressing change and anti-infection treatment for approximately 1 month. One patient developed postoperative upper limb paresthesia, which recovered after neurotrophic treatment at approximately 3 months postoperatively. Shoulder dislocation occurred in one patient, and function was not significantly affected after open reduction. No patient had complications such as fracture, skin flap necrosis, deep soft tissue infection, or prosthesis loosening.

As shown in Table 1, at a mean follow-up of 62.6 months (range, 13–123 months), eighteen patients were still alive at the final follow-up, three of whom survived with disease. Of the remaining 3 patients, 2 died of systemic multiple organ failure caused by lung metastasis at 13 and 41 months after surgery, respectively, and 1 patient died of cardiac disease at 33 months postoperatively (case 20). Among all
Table 1  Patient characteristics, surgical modalities and outcomes (2005/1–2019/7)

| Case | Gender/Age (years) | Histological types | Enneking Stage | Malawer classification | Surgical modality | Margin | Complications | Relapse/metastasis | Status | Follow-up (months) |
|------|-------------------|--------------------|----------------|------------------------|-------------------|--------|---------------|-------------------|--------|-------------------|
| 1    | M/34              | Mesenchymal        | IIB            | IIA                    | Partial scapulectomy | Marginal | No             | Relapse           | AWD    | 123               |
| 2    | F/56              | Conventional       | IB             | IIA                    | Partial scapulectomy | Wide    | No             | No                | NED    | 75                |
| 3    | M/46              | Myxoid             | II A           | IIIA                   | Total resection + humeral suspension | Wide | No | Relapse | NED 85 |
| 4#   | F/49              | Conventional       | IB             | IIIA                   | Total resection + humeral suspension | Marginal | Poor wound healing | No | NED 56 |
| 5#   | M/58              | Conventional       | IIB            | IIIA                   | Total resection + Prosthesis | Intralesional | No | Relapse + Metastasis | AWD 41 |
| 6#   | M/27              | Conventional       | IB             | IIA                    | Partial scapulectomy | Wide | No | No | NED 23 |
| 7    | M/58              | Myxoid             | IIB            | IIIA                   | Total resection + Prosthesis | Wide | Dislocation | No | NED 102 |
| 8    | M/32              | Conventional       | IIB            | IIIA                   | Total resection + Prosthesis | Wide | No | Metastasis | DOD 13 |
| 9    | M/48              | Dedifferentiated   | IIB            | IIIA                   | Total resection + Prosthesis | Wide | No | Relapse | AWD 35 |
| 10   | F/50              | Myxoid             | IIB            | IIIA                   | Total resection + Prosthesis | Wide | No | No | NED 53 |
| 11   | F/65              | Dedifferentiated   | IIB            | IIIA                   | Total resection + Prosthesis | Wide | No | No | NED 53 |
| 12   | M/35              | Mesenchymal        | IIB            | NA                     | Total resection + humeral suspension | Marginal | No | No | NED 115 |
| 13   | F/48              | Conventional       | IIB            | NA                     | Partial scapulectomy | Wide | No | No | NED 97 |
| 14   | M/58              | Conventional       | IIB            | NA                     | Total resection + humeral suspension | Wide | No | Metastasis | DOD 41 |
| 15   | M/59              | Myxoid             | IIB            | NA                     | Total resection + humeral suspension | Intralesional | Paresthesia | No | NED 77 |
| 16   | F/49              | Conventional       | IB             | IIIA                   | Total resection + Prosthesis | Wide | No | No | NED 66 |
| 17   | M/50              | Conventional       | IIB            | IIA                    | Partial scapulectomy | Wide | No | No | NED 55 |
| 18   | F/41              | Conventional       | IIB            | IIA                    | Total resection + Prosthesis | Wide | Wound necrosis | No | NED 48 |
| 19   | M/27              | Conventional       | IB             | IIIA                   | Total resection + Prosthesis | Wide | No | No | NED 39 |
| 20   | M/65              | Conventional       | IIB            | IIIA                   | Total resection + Prosthesis | Marginal | No | No | DOD 33 |
| 21   | F/42              | Conventional       | IIB            | IIA                    | Partial scapulectomy | Wide | No | No | NED 51 |

*Male, F Female, AWD Alive with disease, NED No evidence of disease, DOD Died of disease, #, representative case.*
patients, four had local recurrence after surgery, and three had distant metastases, one of whom had both recurrence and metastasis (case 5). The overall survival rate of patients at 5 years was 84.6%, and the disease-free survival rate was 69.3%. The Kaplan–Meier survival curve is shown in Fig. 4.

As shown in Table 2, we evaluated postoperative shoulder function and upper extremity MSTS93 scores in 18 patients. Six patients who underwent partial scapulectomy had significantly better shoulder function, with MSTS93 scores, shoulder forward flexion and abduction range of 26.50 ± 1.38, 80.83° ± 11.14°, and 75.00° ± 10.49°, respectively. We further compared the postoperative shoulder function in the three groups and the results are shown in Additional file 1: Supplementary Table 1 and Fig. 5. The partial scapulectomy group compared with the total scapulectomy + humeral suspension or prosthesis reconstruction group had better MSTS93 scores ($P = 0.006$ and 0.0336, respectively), larger range of motion for shoulder flexion ($P = 0.0493$ and 0.0174, respectively) and abduction ($P = 0.0035$ and 0.0304, respectively). However, there was no significant difference in postoperative MSTS93 scores and shoulder range of motion between patients in the humeral suspension and prosthetic reconstruction groups ($P > 0.05$). Moreover, most patients achieved good pain control and satisfactory shoulder contours, and all patients maintained normal hand, wrist and elbow function postoperatively.

**Discussion**

Before the 1970s, shoulder disarticulation was the main treatment for malignant bone tumors of the shoulder girdle [13], and the appearance and function of the affected limb were seriously damaged, placing a serious burden on the psychological and social functions of the patients. In 1857, Syme [14] first reported total scapulectomy for the treatment of malignant scapular tumors. In 1999, Nakamura et al. [15] showed that patients who undergo total scapulectomy may achieve much better upper limb function than those who undergo forequarter amputation. Subsequently, an increasing number of patients with scapular malignant tumors have achieved limb salvage. At present, limb salvage surgery has become the preferred treatment for scapular malignant tumors, and limb salvage treatment can be achieved in approximately 95% of patients [6].

Reconstruction after scapular tumor resection is a major surgical challenge and also has important implications for postoperative shoulder function. Humeral suspension was the most popular reconstruction method after scapulectomy in the early 1990s [12]. A study [16] from Japan included 23 patients who underwent humeral suspension reconstruction, and after a mean follow-up of 61.9 months, the mean Enneking functional score was 21.1 (70.3%), and the active shoulder range of motion was 42.7 degrees in flexion and 39.7 degrees in abduction. The authors concluded that humerus suspension after scapular resection can achieve ideal shoulder function. Xu et al. [17] reported that the average MSTS score of 8 patients
with humeral suspension reconstruction was 16.3 (57%), there was no recurrence or major complications after the operation, and the average emotional acceptance was 3.6 (72.5%). However, some studies have found that patients with humeral suspension have problems, such as floating humerus, poor cosmetic outcomes, and restricted joint functions [12], and some patients may experience limb numbness and muscle atrophy due to traction of vascular nerve bundles. In our study, the MSTS93 scores of the four patients who underwent humeral suspension were 19.00 ± 2.58. Of these, two patients had superior shoulder motion with 55° and 80° of forward flexion, and both had

| Resection type          | Case | MSTS93 score | Flexion | Abduction |
|-------------------------|------|--------------|---------|-----------|
| Partial resection       | 1    | 27           | 85°     | 80°       |
|                         | 2    | 25           | 60°     | 55°       |
|                         | 6    | 26           | 90°     | 85°       |
|                         | 13   | 28           | 90°     | 80°       |
|                         | 17   | 28           | 80°     | 75°       |
|                         | 21   | 25           | 80°     | 75°       |
| Mean ± SD               | /    | 26.50 ± 1.38 | 80.83° ± 11.14° | 75.00° ± 10.49° |
| Humeral suspension      | 3    | 18           | 55°     | 30°       |
|                         | 4    | 22           | 80°     | 50°       |
|                         | 12   | 16           | 35°     | 25°       |
|                         | 15   | 20           | 35°     | 25°       |
| Mean ± SD               | /    | 19.00 ± 2.58 | 51.25° ± 21.36° | 32.50° ± 11.90° |
| Prosthesis reconstruction | 5    | 22           | 50°     | 30°       |
|                         | 7    | 20           | 50°     | 35°       |
|                         | 8    | 23           | 65°     | 50°       |
|                         | 10   | 20           | 45°     | 40°       |
|                         | 11   | 22           | 55°     | 35°       |
|                         | 16   | 26           | 50°     | 55°       |
|                         | 18   | 17           | 35°     | 30°       |
|                         | 19   | 21           | 70°     | 60°       |
| Mean ± SD               | /    | 21.38 ± 2.62 | 52.50° ± 11.02° | 41.88° ± 11.63° |

SD: Standard deviation

Fig. 5 MSTS93 scores, range of motion in forward flexion and abduction of the shoulder joint and comparative results of patients with chondrosarcoma of the scapula among three different treatment groups. *, p value < 0.05; **, p value < 0.01
more than 30 degrees of abduction. All patients obtained satisfactory shoulder contour and pain control, and no patients had glenohumeral joint droop or flail shoulder (Fig. 2E).

With the development of prosthetic materials, manufacturing processes and surgical techniques, surgeons have made unremitting efforts and attempts to reconstruct the scapular region after tumor resection. In 1987, Eckardt [18] made the first attempt to perform prosthetic reconstruction after total scapulectomy. Since then, several studies have reported that prosthetic reconstruction can achieve good oncological and functional outcomes [8, 19, 20]. Li [21] reported 17 cases of scapular malignant tumors undergoing total scapulectomy and reconstruction with prostheses. After an average follow-up of 45.4 months, the upper limb MSTS function score was 26.1 ± 1.4, and the ranges of shoulder joint flexion, extension, and abduction were 70° ± 7.5°, 31.2° ± 11.3°, and 54.4° ± 12.5°, respectively. The overall postoperative survival rate was 88.2% (15/17), and the disease-free survival rate was 70.6% (12/17). In addition, several studies have shown that prosthetic reconstruction can obtain better shoulder joint function and shape than humeral suspension [22, 23]. Pritsch et al. [12] included 32 patients who had total scapulectomies (reconstructions with humeral suspensions in 16 patients and scapular endoprostheses in 16 patients), and the results showed that scapular endoprosthetic reconstruction led to better functional and cosmetic results than humeral suspension. The mean MSTS scores for patients with scapular endoprostheses and humeral suspensions were 78.5% and 58.5%, respectively. Seven patients with scapular endoprostheses had greater than 40 degrees of abduction, and 11 patients with humeral suspensions could not abduct the shoulder greater than 20 degrees. However, our study found that humeral suspension or prosthetic reconstruction after total scapulectomy both achieved good functional outcomes, with MSTS93 scores of 19.00 ± 2.58 and 21.38 ± 2.62, respectively. Both treatment strategies achieved good shoulder contour and pain control. We did not find significant differences in MSTS93 score and shoulder flexion and abduction function between the two groups, which may be related to the fact that only four cases were treated with humeral suspension, two of which had superior function. Therefore, these cases may not truly reflect the efficacy of humeral suspension. Nevertheless, we found that the patients treated with humeral suspension had poorer shoulder abduction, with only one case beyond 30 degrees.

In addition, the amount of muscles and ligaments preserved around the scapula, the quality of soft tissue reconstruction, and the preservation of the glenoid and acromion have an important impact on improving shoulder function and reducing complications. A study from Japan [16] found that preserving the glenoid or acromion compared to total scapulectomy can achieve better function. Min et al. [20] showed that patients with rotator cuff reconstruction could achieve better upper limb lifting ability and shoulder abduction. Similar studies [24–26] have also reported the importance of the deltoid, subscapular and latissimus dorsi for shoulder function after scapular resection. Our study also demonstrated that a smaller extent of resection of the scapula led to better postsurgical function. Partial scapulectomy had nearly normal shoulder function, which we believe was due to the retention of the acromion and glenoid in these patients. In addition, adequate reconstruction of soft tissues, especially the deltoid, biceps and rotator cuff, is guaranteed to obtain good function of the shoulder joint.

Our study also has several limitations. The first is the relatively small number of cases included in this study, which may have affected the reliability of the conclusions and a larger sample may be required for further validation. Second, this study was retrospective, and the results may have been somewhat biased. Furthermore, the MSTS scores may have been influenced by subjective factors and suffered from insufficient accuracy. Nevertheless, our study is a relatively large series on chondrosarcoma of the scapula, and our results can be helpful for its management.

Conclusions
Surgical treatment of chondrosarcoma of the scapula can obtain satisfactory oncologic and functional outcomes, and preservation of the important structures of the scapula and adequate reconstruction of the soft tissues are critical to the patient’s function. Total scapulectomy followed by prosthetic reconstruction or humeral suspension are both feasible options.

Abbreviation
MSTS93: The 1993 American Musculoskeletal Tumor Society.

Supplementary Information
The online version contains supplementary material available at https://doi.org/10.1186/s12891-022-05661-7.

Additional file 1: Supplementary Table 1. Comparison of postoperative shoulder function among patients in different treatment groups.

Acknowledgements
We would like to thank all the physicians of the Department of Orthopedics, Tongji Hospital, Tongji Medical College, Huazhong University of Science and Technology for their support of this study.
Authors' contributions
(I) Conception and design: Hao Kang; (II) Collection and assembly of data: Xiaojun Yu and Qikun Liu; (III) Data analysis and interpretation: Qikun Liu, Xiaojun Yu, and Rui Lu; (IV) Manuscript review and revision: Qikun Liu, Xiaojun Yu, Yingyu Wang, Junlie Wan, Shanxi Wang and Haoran Xu; (V) Manuscript writing: All authors; (VI) Final approval of manuscript: All authors.

Funding
This work was supported by the National Natural Science Foundation of China (81472106).

Availability of data and materials
The datasets generated and/or analyzed during the current study are not publicly available due to limitations of ethical approval involving the patient data and anonymity but are available from the corresponding author on reasonable request.

Declarations

Ethical approval and consent to participate
Written informed consent was obtained from the patients or the deceased subject’s parent and/or legal guardian. The study was approved by the ethics committee of Tongji Hospital, Tongji Medical College, Huazhong University of Science and Technology (No. LLHBC2020W-015). The study was conducted according to the guidelines of the Declaration of Helsinki.

Consent for publication
Not applicable.

Competing interests
The authors declare that they have no conflicts of interest.

Received: 18 September 2021 Accepted: 11 July 2022 Published online: 08 August 2022

References
1. Leddy LR, Holmes RE. Chondrosarcoma of bone. Cancer Treat Res. 2014;162:117–30. https://doi.org/10.1007/978-3-319-07323-1_6.
2. Puchner SE, Panotopoulos J, Puchner R, et al. Primary malignant tumours of the scapula—a review of 29 cases. Int Orthop. 2014;38(10):2155–62. https://doi.org/10.1007/s00264-014-2417-8.
3. MacDonald IJ, Lin CY, Kuo SJ, et al. An update on current and future treatment options for chondrosarcoma. Expert Rev Anticancer Ther. 2019;19(9):773–86. https://doi.org/10.1080/14737384.2019.1659731.
4. Erstad DJ, Ready J, Abraham J, et al. Amputation for extremity sarcoma: contemporary indications and outcomes. Ann Surg Oncol. 2018;25(2):394–403. https://doi.org/10.1245/s10434-017-6240-5.
5. Malawer MM, Meller J, Dunham WK. A new surgical classification system for shoulder-girdle resections. Analysis of 38 patients. Clin Orthop Relat Res. 1991;(267):33-44.
6. Hayashi K, Kanta M, Yamamoto N, et al. Functional outcomes after total scapulectomy for malignant bone or soft tissue tumors in the shoulder girdle. Int J Clin Oncol. 2011;16(5):568–73. https://doi.org/10.1007/s10147-011-0229-z.
7. Villalobos CE, Hayden BL, Silverman A, et al. Limb-sparing resection of the scapula and reconstruction with a constrained total scapula prosthesis: a case of multicentric epithelioid hemangioendothelioma involving the scapula and surrounding soft tissues. Ann Surg Oncol. 2009;16(8):2321–2. https://doi.org/10.1245/s10434-009-0522-5.
8. Wang B, Wu Q, Zhang Z, et al. Reconstruction with constrained scapular prosthesis after total scapulectomy for scapular malignant tumor. J Surg Oncol. 2018;118(1):177–83. https://doi.org/10.1002/jso.25118.
9. Elkhoneymy AM, Zaghoul MS, Zaky I, et al. Reconstruction of the scapula in pediatric and adolescent patients after total Scapulectomy: A report of 10 patients treated by extracorporeal irradiation and implantation of the Scapula. J Pediatr Orthop. 2018;38(2):e91–6. https://doi.org/10.1097/BPO.0000000000001100.
10. Capanna R, Totti F, Van der Geest IC, et al. Scapular allograft reconstruction after total scapulectomy: surgical technique and functional results. J Shoulder Elbow Surg. 2015;24(8):e203-211. https://doi.org/10.1067/jsse.2015.02.006.
11. Nota SR, Russchen MJ, Raskin KA, et al. Functional and oncological outcome after surgical resection of the scapula and clavicle for primary chondrosarcoma. Musculoskelet Surg. 2017;101(1):67–73. https://doi.org/10.1007/s12306-016-0437-9.
12. Pritsch T, Mickels J, Wu CC, et al. Is scapular endoprosthetic functionally superior to hemispheric suspension? Clin Orthop Relat Res. 2007,456:88–95. https://doi.org/10.1097/01.blo.0000238840.26423.b6.
13. Yang Q, Li J, Yang Z, et al. Limb sparing surgery for bone tumours of the shoulder girdle: the oncological and functional results. Int Orthop. 2010;34(6):869–75. https://doi.org/10.1007/s00264-009-0857-3.
14. Syme J. On Disarticulation of the Scapula from the Shoulder-Joint. Med Chir Trans. 1857;40:107–12. https://doi.org/10.1177/09595287570400107.
15. Nakamura S, Kusuzaki K, Murata H, et al. Clinical outcome of total scapulectomy in 10 patients with primary malignant bone and soft-tissue tumors. J Surg Oncol. 1999;72(3):130–5. https://doi.org/10.1002/(sici)1096-9089(19991117)2:3<129::aid-jso4%3e3.0.co;2-o.
16. Hayashi K, Iwata S, Ogose A, et al. Factors that influence functional outcome after total or subtotal scapulectomy. Japanese musculoskeletal oncology group (JMOG) study. PloS ONE. 2014;9(6):e100191. https://doi.org/10.1371/journal.pone.0100191.
17. Xu SF, Yu XC, Xu M, et al. Functional results and emotional acceptance after scapulectomy for malignant shoulder tumors. Orthop Surg. 2016;8(2):186–95. https://doi.org/10.1111/ots.12248.
18. Eckardt JJ. Orthopedics: endoprosthetic limb salvage operation for malignant bone tumors. J Bone Oncol. 2017;6:55–68. https://doi.org/10.1016/j.jbono.2016.10.003.
19. Savvidou OD, Zampeli F, Georgopoulos G, et al. Total scapulectomy and shoulder reconstruction using a scapular prosthesis and constrained reverse shoulder arthroplasty. Orthopedics. 2018;41(6):e888–93. https://doi.org/10.3928/01477447-20181023-05.
20. Min L, Zhou Y, Tang F, et al. Reconstruction with scapular hemiarthroplasty endoprosthetic after scapulectomy for malignant tumor. Int Orthop. 2017;41(5):1057–63. https://doi.org/10.1007/s00264-017-3429-y.
21. Li J, Bi J, Zhao X, et al. Evaluation of total scapular arthroplasty after total scapulectomy for scapular tumors. Zhongguo Xu Fu Chong Jian Wai Ke Za Zhi. 2020;34(2):179–83. https://doi.org/10.7507/1002-1892.2019070716.
22. Hayashi K, Niu X, Tang X, et al. Experience of total scapular excision for musculoskeletal tumor and reconstruction in eastern Asian countries. J Bone Oncol. 2017;6:55–8. https://doi.org/10.1016/j.jbono.2016.10.003.
23. Mavrogenis AF, Mastorakos DP, Triantafyllopoulos G, et al. Total scapulectomy and shoulder reconstruction in a case of multicentric epithelioid hemangioendothelioma involving the scapula and reconstruction with a constrained total scapula prosthesis: a case of multicentric epithelioid hemangioendothelioma involving the scapula and surrounding soft tissues. Ann Surg Oncol. 2009;16(8):2321–2. https://doi.org/10.1245/s10434-009-0522-5.
24. Wang B, Wu Q, Zhang Z, et al. Reconstruction with constrained scapular prosthesis after total scapulectomy for scapular malignant tumor. J Surg Oncol. 2018;118(1):177–83. https://doi.org/10.1002/jso.25118.
25. Terrier A, Larrea X, Malfroy Canive, et al. Importance of the subscapularis muscle after total shoulder arthroplasty. Clin Biomech (Bristol, Avon). 2013;28(2):146–50. https://doi.org/10.1016/j.clinbiomech.2012.11.010.
26. Mimata Y, Nishida J, Nagai T, et al. Importance of latissimus dorsi muscle after total shoulder arthroplasty. Clin Biomech (Bristol, Avon). 2020;77:6d.

Publisher’s Note
Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.