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REVIEW ARTICLE

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Upper extremity compartmental anatomy: clinical relevance to radiologists

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Abstract Malignant tumors of the upper extremity are uncommon, and their care should be referred to specialized facilities with experience treating these lesions. The Musculoskeletal Tumor Society (MSTS) staging system is used by the surgeon to determine appropriate surgical management, assess prognosis, and communicate with other healthcare providers. Magnetic resonance imaging (MRI) is employed preoperatively to identify a lesion's compartment of origin, determine extent of spread, and plan biopsy and resection approaches. Involvement of neurovascular structures may result in devastating loss of upper extremity function, requiring amputation. Violation of high-resistance compartmental barriers necessitates more extensive surgical resection. Biopsy may be performed by the radiologist using imaging guidance. Knowledge of compartmental anatomy allows the radiologist or surgeon to use an easily excisable biopsy approach and prevent iatrogenic spread to unaffected compartments. Case examples are presented to illustrate the importance of compartmental anatomy in the management of benign and malignant upper extremity tumors.

Keywords MRI · Tumor · Upper extremity · Compartmental anatomy

Introduction

Tumors of the upper extremity pose diagnostic and therapeutic challenges not encountered with lower extremity tumors. Upper extremity malignancies are less common than lower extremity malignancies, limiting the experience of the radiologist, pathologist, and orthopaedic surgeon [1]. The presence of small, highly specialized extrinsic hand muscles located close together and in proximity to critical neurovascular structures makes diagnosis and surgical excision challenging [2]. Functional deficits that result from surgical tumor excision or amputation can be particularly debilitating in the upper extremity, due to the profound role the upper extremity plays in performing activities of daily living. Lastly, definitions of compartmental anatomy and the role they play in dictating surgical management have not been defined as clearly in the upper extremity as in the lower extremity [3].

For the practicing radiologist, knowledge of upper extremity compartmental anatomy helps to provide useful pre-operative staging information to the surgeon. If called upon to perform closed biopsy, the radiologist must understand locations of compartments in order to use an easily excisable biopsy tract and prevent iatrogenic tumor spread [4]. Principles of extremity sarcoma staging and percutaneous biopsy of the suspicious lower extremity mass have been reviewed previously, but briefly include traversing the minimum number of compartments, avoiding neurovascular structures, and placing biopsy tracts along proposed limb salvage incision lines [5]. Any question regarding the placement or route of an image-guided biopsy should be discussed with the surgeon ultimately responsible for the surgical treatment of the lesion. This review focuses on defining compartmental anatomy of the upper extremity and highlighting its usefulness in performing biopsies and communicating important pre-operative information to the surgeon.

Epidemiology

Malignant tumors of bone and soft tissue are relatively rare. In 2004, there were an estimated 2,440 new malignant bone tumors and 8,680 new malignant soft-tissue tumors diagnosed in the United States [6]. Bone and soft-tissue tumors combined account for less than 1% of all newly diagnosed malignancies. Approximately twice as many malignant bone and soft tissue neoplasms occur in the lower extremity as compared to the upper extremity [7, 8]. Many practitioners therefore have little experience managing patients with upper extremity malignancies.

Benign upper extremity tumors are more common than malignancies and include ganglion cysts, epidermoid inclusion cysts, giant cell tumors of tendon sheath, lipomas, benign peripheral nerve sheath tumors, and palmar nodules of Dupuytren's contracture [9, 10]. Despite the likelihood that an upper extremity tumor is benign, the physician must approach all upper extremity tumors with the suspicion of malignancy [11]. It is therefore recommended that the care of patients with these lesions be undertaken by a team of surgeons, radiologists, and pathologists with experience managing malignant upper extremity lesions. Often this requires referral to a specialized multi-disciplinary medical center.

Staging

Bone and soft-tissue sarcomas arising from mesenchymal tissue are staged for surgery by the Musculoskeletal Tumor Society (MSTS) staging system [12]. This system has been preferred by surgeons, while medical oncologists generally use the American Joint Committee on Cancer (AJCC) staging system [11, 13]. The MSTS staging system characterizes musculoskeletal sarcomas other than Ewing's sarcoma, leukemia, lymphoma, undifferentiated round cell tumors, and metastatic carcinoma, by grade (G), site (T), and metastasis (M) (Table 1) [14, 15]. Grade is determined by histopathology as benign, low-grade malignant, or high-grade malignant. Site is characterized as intracompartmental or extracompartmental. Metastasis is defined as present or absent. The MSTS staging system is useful for determining appropriate surgical management, providing prognostic stratification, and communicating information to other providers in a concise, yet uniform and reliable fashion [11].

Table 1 Musculoskeletal Tumor Society (MSTS) sarcoma staging system

Stage	Grade	Site	Metastasis
IA	Low (G1)	Intracompartmental (T_1)	None (M_0)
IB	Low (G1)	Extracompartmental (T_2)	None (M_0)
IIA	High (G_2)	Intracompartmental (T_1)	None (M_0)
IIB	High (G_2)	Extracompartmental (T_2)	None (M_0)
III	Low (G_1) or High (G_2)	Intracompartmental (T_1) or Extracompartmental (T_2)	Regional or Distant (M_1)

Note: adapted from [12, 15]

The radiologist may be consulted to help establish all three staging characteristics by interpreting pre-operative imaging studies and performing the biopsy. Magnetic resonance imaging (MRI) is the imaging modality of choice in staging extremity neoplasms, due to its ability to image masses in multiple planes and provide excellent soft-tissue resolution [11]. In interpreting a pre-operative, pre-biopsy imaging study, the radiologist must make note of the size and location of the tumor, as well as its relationship to critical neurovascular structures. As surgical excision of any upper extremity neurovascular structures has great implications for the patient's overall function, it is important to inform the surgeon of possible involvement of or proximity to these critical structures [2]. Adequate pre-operative knowledge and planning may allow for microsurgical vascular or neural grafting or tendon-transfer procedures to minimize any ultimate loss of function for the patient.

The radiologist must also characterize the compartmental location of the tumor. Lesions staged as intracompartmental (T_1), or limited to within the compartment of origin, are surgically treated with wide local resection, whereas extracompartmental (T_2) lesions, or those that have spread beyond the compartment of origin, are generally treated with radical excision (excising the entire anatomic compartment), which often necessitates amputation to achieve a better functional outcome [16].

Anatomic compartments are defined as anatomic regions bounded by high-resistance barriers to tumor spread, such as fascial planes, articular cartilage, and cortical bone. Compartmental definition is possible for 95% of musculoskeletal tumors, with the remaining tumors occurring in extrafascial planes or poorly compartmentalized spaces [17]. Tumor spread may occur along neurovascular structures in the upper extremity, some of which pass between compartments [17]. A tumor which has spread beyond its compartment of origin through a high-resistance barrier will necessitate a more significant surgical procedure than one which is confined within one compartment. Therefore, identification of compartmental location and spread by the radiologist is helpful for surgical planning.

Arm Compartments

For purposes of tumor staging, the arm is regarded as composed of three anatomic compartments as well as the extracompartmental axillary space [17]. The humerus, with its strong layer of cortical bone, makes up one compartment, while the muscular anterior and posterior compartments comprise the other two. Extracompartmental spread occurs with extension through cortical bone of the humerus or outside of a muscular compartment.

Subcutaneously, both the arm and forearm are invested in a layer of fascia [18, 19]. The arm is divided into anterior and posterior anatomic compartments by fascial thickenings called the medial and lateral intermuscular septa, which pass from the humerus to the brachial fascia (Fig. 1). The most superficial muscles of the anterior compartment are the long and short heads of the biceps. Proximally, the coracobrachialis is located deep to the biceps along the medial aspect of the arm. The brachialis originates from the anterior humerus just proximal to the insertion of the coracobrachialis, and occupies a more lateral position in the mid-to-distal aspect of the anterior arm.

The posterior compartment of the arm is entirely occupied by the triceps. Superficially located are the long and lateral heads, while the medial head is found in a deeper location adjacent to the medial aspect of the humerus. The three heads of the triceps blend together in the distal arm before forming a tendon which inserts on the olecranon of the ulna.

The axillary artery passes deep to the clavicle as it enters the arm in close proximity to the cords of the brachial plexus. After crossing deep to the pectoralis major, the axillary artery and vein become the brachial artery and vein. These structures descend the arm medially in an extracompartmental location along with the median and ulnar nerves (Fig. 1). As these neurovascular structures pass into the distal arm, the brachial artery and veins along with the median nerve penetrate the anterior compartment and continue in a location between the biceps and brachialis muscles, while the ulnar nerve remains extracompartmental. The radial nerve occupies a position deep within the posterior compartment, in close proximity to the posterior humerus for most of the course of the arm before crossing into the anterior compartment proximal to the elbow.

Forearm Compartments

The forearm has been variably described as containing two, three, or four muscular compartments in addition to the osseous radial and ulnar compartments [17, 20–22]. In the two-compartment description, the forearm consists of a volar or flexor compartment and a dorsal or extensor compartment. The volar and dorsal compartments may each be further arbitrarily subdivided on the basis of function and anatomy into superficial and deep portions, yielding a four-compartment description. In the three-compartment classification commonly used by surgeons, three muscles (brachioradialis, extensor carpi radialis longus, and extensor carpi radialis brevis) are considered as the mobile wad of Henry or lateral compartment of the forearm. Yet another four-compartment classification divides the volar compartment into superficial and deep compartments in addition to the mobile wad and dorsal compartment.

With the exception of the strong interosseous membrane, forearm fascial planes often incompletely separate compartments, allowing some communication between muscle groups. For instance, in the setting of forearm compartment

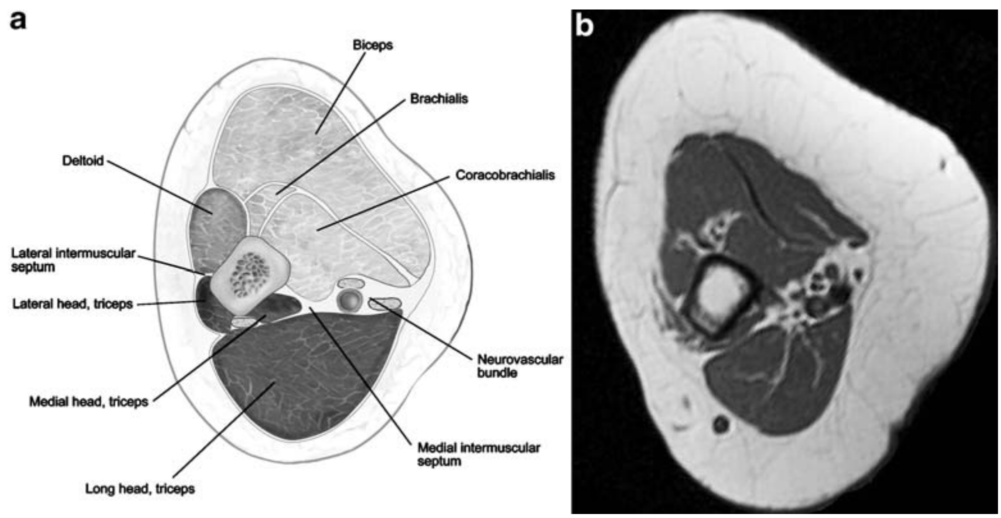

Fig. 1 **a** Axial diagram of the mid arm demonstrating compartmental anatomy. Anterior compartment musculature (*light shading*) is separated from posterior compartment musculature (*dark shading*) by the medial and lateral intermuscular septa and humerus. The deltoid is not considered to be within either arm compartment. **b** Axial spin echo T1-weighted MRI of the mid arm for comparison

syndrome, surgical fasciotomy of one muscular compartment may be sufficient to decompress another [21]. Therefore for purposes of tumor staging, division of musculature into dorsal and volar compartments is adequate and will serve as the basis for this discussion.

The volar and dorsal compartments are separated by the radius, ulna, and interosseous membrane connecting these two bones (Figs. 2 and 3). The retinacula of the wrist are the distal limits of these compartments. The superficial layer of the extensor compartment contains most of the extensors of the wrist and digits. From ulnar to radial, the superficial row of muscles consists of the extensor carpi ulnaris, extensor digiti minimi, extensor digitorum, and extensor carpi radialis brevis and longus. The brachioradialis may be considered a structure within the extensor compartment despite occupying a volar position. The deep extensor row contains the thumb and index finger extensor musculature. The abductor pollicis longus exists in close contact with the ulnar aspect of the radius, while the extensor pollicis brevis and longus and the extensor indicis reside closer to the ulna, from which they originate. Deep to the proximal extensor carpi radialis muscles and enveloping the radial aspect of the proximal radius is the supinator muscle.

The superficial flexor muscles, from radial to ulnar, include pronator teres, flexor carpi radialis, palmaris longus, flexor digitorum superficialis, and flexor carpi ulnaris. The deep flexor musculature includes the flexor digitorum profundus, which originates from the proximal part of the ulna, and the flexor pollicis longus muscle, which originates from the volar surface of the interosseous membrane. More distally, the pronator quadratus occupies a deep location adjacent to the interosseous membrane and attaches to both the radius and ulna.

Just distal to the elbow joint, the brachial artery splits into the ulnar and radial arteries which descend along the ulnar and radial aspects of the forearm, respectively. The radial artery is located superficial to the flexor digitorum superficialis and supinator and deep to the brachioradialis in the flexor compartment. More distally, as the musculature of the brachioradialis thins to its tendon, the radial artery attains a superficial location, where its pulse is easily palpable. The ulnar artery also resides within the flexor compartment, located deep to the flexor digitorum superficialis muscle and superficial to the flexor digitorum profundus muscle on the ulnar aspect of the forearm (Fig. 3).

The ulnar nerve passes posterior to the medial epicondyle before crossing into the flexor compartment distal to the wrist, where it is found between the flexor digitorum superficialis and flexor digitorum profundus, and just radial to the flexor carpi ulnaris (Fig. 2). The radial nerve passes anterior to the lateral epicondyle and splits into a deep and a superficial branch. The deep branch passes into the extensor compartment, while the superficial branch joins the radial artery in the flexor compartment. The median nerve enters the forearm accompanying the ulnar artery, and courses through the forearm in the flexor compartment in close association with the superficial surface of the flexor digitorum longus before reaching the carpal tunnel at the wrist.

Wrist and Hand Compartments

Both the volar and dorsal aspects of the wrist are poorly compartmentalized. Tumors originating in these areas spread along tendons and tendon sheaths, and into the carpal bones [17]. Likewise, the carpal bones, as well as the palmar and dorsal spaces of the hands represent poorly defined extracompartmental locations. Tumors arising in the metacarpals and digits, however, are regarded as intracompartmental [17]. The digital compartments contain the phalanges, digital soft tissues, extensor mechanism to

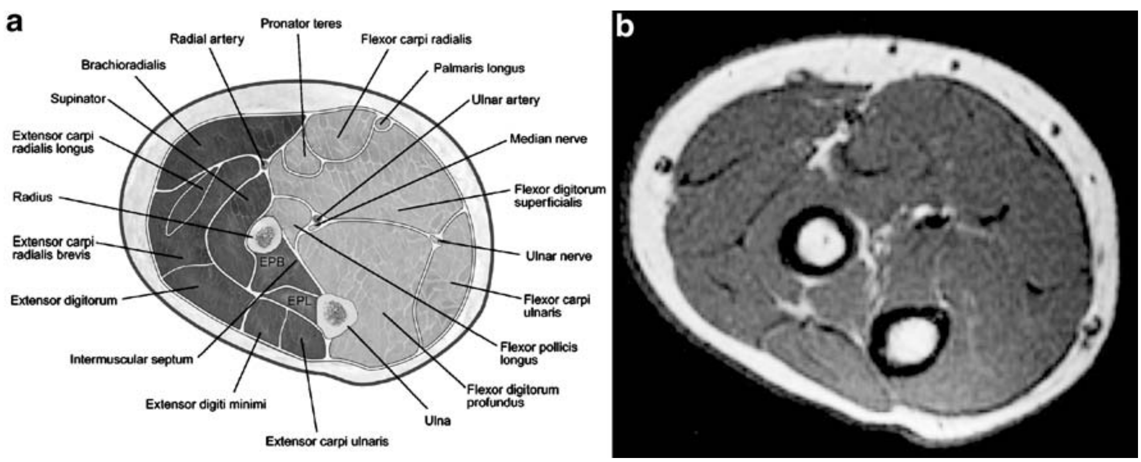

Fig. 2 **a** Axial diagram of the proximal forearm demonstrating compartmental anatomy. Volar compartment musculature (*light shading*) is separated from dorsal compartment musculature (*dark shading*) by the radius, ulna, and intermuscular septum. *EBP* = extensor pollicis brevis. *EPL* = extensor pollicis longus. **b** Axial spin echo T1-weighted MRI of the proximal forearm for comparison

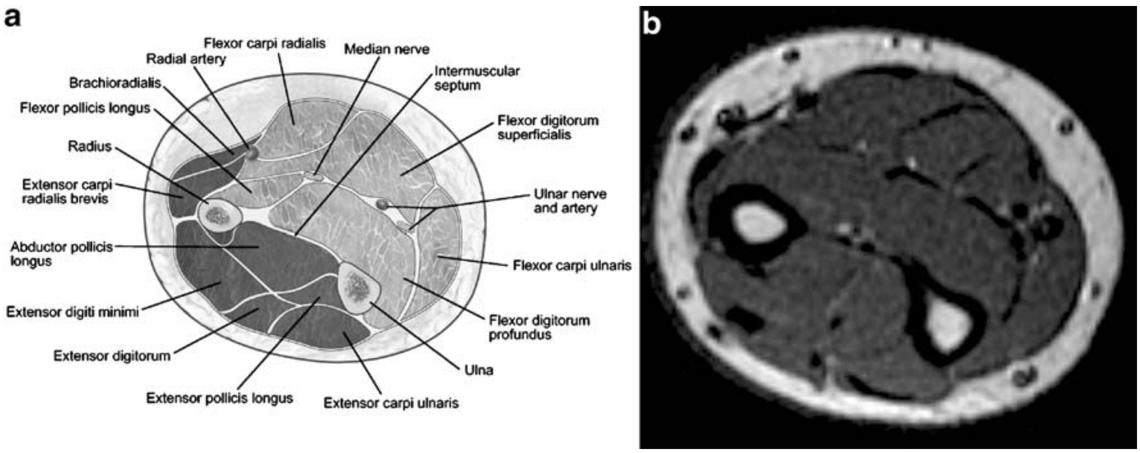

Fig. 3 **a**. Axial diagram of the distal forearm demonstrating compartmental anatomy. Volar compartment musculature (*light shading*) is separated from dorsal compartment musculature (*dark shading*) by the radius, ulna, and intermuscular septum. **b** Axial spin echo T1-weighted MRI of the distal forearm for comparison

the metacarpophalangeal hood, flexor tendons, and intrinsic musculature.

To illustrate these concepts, three cases of upper extremity tumors, both benign and malignant, are presented.

Case #1

A 21-year-old pregnant woman presented to orthopaedic oncology clinic complaining of a slowly enlarging, painful mass in the left upper arm. Physical exam revealed a tender 4-cm mass on the distal lateral aspect of the upper arm. MRI revealed a multi-loculated cystic-appearing mass in the subcutaneous tissues of the anterior arm, with no involvement of bone or neurovascular structures (Fig. 4). Differential considerations included a large sebaceous cyst, a neurogenic tumor, or a vascular tumor. Based on this report, the referring orthopaedic surgeon aspirated the mass, yielding 20 ml of dark liquid consistent with old blood. The mass disappeared immediately after aspiration. Cytology revealed necrotic debris and lymphocytes with no evidence of malignancy.

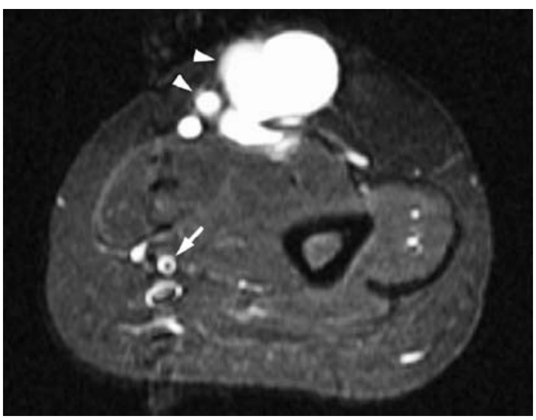

Fig. 4 Axial short tau inversion recovery image of the distal arm demonstrates a high-intensity multi-loculated mass (*arrowheads*) located in the subcutaneous tissues of the arm. The mass is entirely contained within the subcutaneous tissues of the anterior arm, with no extension into the anterior muscular compartment. The brachial artery, located medially, is uninvolved (*arrow*)

This patient presented with a painful mass, which by physical exam was not easily identified as a cystic lesion. MRI was helpful in identifying a lesion that was entirely subcutaneous, did not violate any compartmental boundaries, and was cystic in appearance. Based on this report, the referring orthopaedic surgeon attempted aspiration through an anterior approach, which provided easy access to the mass, did not cross any compartmental barriers, and allowed for an easily excisable needle tract should surgery be necessary. Aspiration demonstrated a benign cystic lesion, most consistent with a large sebaceous cyst. No further treatment was necessary.

Case #2

A 19-year-old right-hand-dominant man presented to orthopaedic oncology clinic with 1 year of worsening pain and swelling of the ulnar aspect of his right hand. MRI revealed an 18 mm × 22 mm × 27 mm homogeneous, lobar, high signal intensity mass on T2-weighted images located ulnar and deep to the flexor tendons (Fig. 5). Sarcoma was considered in the differential diagnosis. The referring surgeon performed fine-needle biopsy of this lesion through the palmar surface of the hand in clinic after receiving the MRI interpretation, which revealed malignant tumor cells consistent with a synovial sarcoma. Staging CT scans revealed no evidence of metastasis. The patient underwent neo-adjuvant radiation therapy followed by wide surgical resection. Negative margins were obtained. Seven years later, the patient has had no evidence of tumor recurrence.

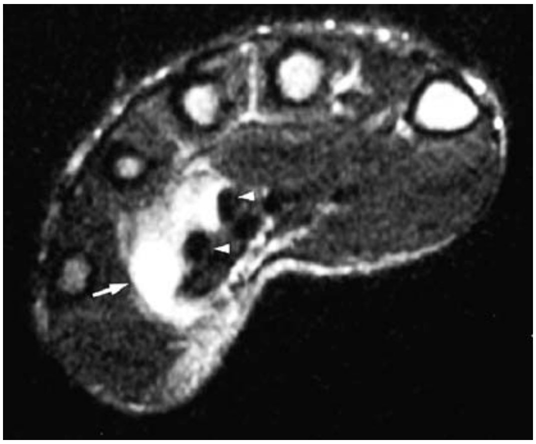

Fig. 5 Axial fast spin echo T2-weighted image of the hand showing a high intensity mass located in the ulnar aspect of the palmar space (*arrow*). The mass is located deep to the flexor tendons (*arrowheads*) and wraps around their ulnar aspect. Involvement of the ulnar nerve is suspected as well given this location. The underlying bone is not involved. Lack of high-resistance compartmental barriers makes this an extracompartmental (stage T_2) lesion

The role of the radiologist in this case was to identify and localize the mass, communicate involvement of neurovascular structures, and provide a differential diagnosis. The tumor was localized within the palmar tissues of the hand with no bony involvement. However, the mass did occupy the location of the ulnar nerve and wrap around the flexor tendons, indicating their likely involvement. The palmar tissues represent a poorly compartmentalized region of the hand, often allowing tumor to spread beyond the palm of the hand.

The surgeon elected to perform the biopsy. If the radiologist had been requested to do so, consultation with the referring surgeon would have helped to determine an appropriate biopsy tract to minimize later skin loss. To obtain a biopsy specimen, this tumor was approached through the palmar surface of the hand with a fine needle aspirate. The lesion was staged as a high grade (G_2), extracompartmental (T_2) synovial sarcoma without evidence of metastasis (stage IIB). Following neo-adjuvant radiation therapy, the tumor was identified at surgery within the ulnar aspect of the palmar space and adequate surgical margins were obtained, allowing for wide local resection.

As is often the case with resection of a tumor staged as T_2, resection resulted in a functional deficit for the patient. Involvement of the ulnar nerve and the superficial and deep flexor tendons of the small and ring fingers necessitated their resection. To obtain a deep margin, the periosteum of the metacarpals of the ring and small fingers was resected. An orthotic was crafted for the patient's small and ring fingers, which were rendered insensate on the volar aspect due to the ulnar nerve resection, and could not be flexed due to the absence of flexor tendons. Despite this functional deficit, neo-adjuvant radiation and wide local resection allowed this patient to remain tumor free for a period of greater than 5 years, which is considered curative for this lesion.

Case #3

A 54-year-old man was referred to the orthopaedic oncology clinic with a 3-year history of a painful, enlarging left forearm mass. MRI revealed a 3.5 cm × 3.5 cm × 3.5 cm elliptical mass located deep to the flexor digitorum superficialis within the proximal volar compartment (Fig. 6). The axial T2-weighted image demonstrated that the mass involved the median nerve. The differential diagnosis of this lesion included soft-tissue sarcoma and neurogenic tumor. The patient was taken to surgery for incisional biopsy. At surgery, the mass was found to be well-circumscribed and in continuity with the median nerve. Biopsy revealed a schwannoma and the lesion was subsequently resected without damage to the median nerve. The patient experienced no sequelae.

This case illustrates an example of a benign nerve-sheath tumor. Such benign diagnoses are more common than malignancies in the upper extremity. However, since a malignant lesion may be mistaken for a benign lesion preoperatively, caution must be undertaken to ensure that the patient's care is not compromised. In this case, the patient's orthopaedic surgeon referred the patient to an oncologic surgeon with greater experience managing both benign and malignant masses. Although the MRI could not exclude malignancy, it demonstrated that the mass was

Fig. 6 Axial fast spin echo T2-weighted image of the proximal forearm demonstrates a high intensity well-circumscribed mass (*arrow*) located in the volar forearm deep to the flexor digitorum superficialis (*arrowheads*). The median nerve, normally seen in the location of this mass within the volar compartment, is not identified, suggesting its involvement. There is no involvement of the radius, ulna, or interosseous membrane, indicating that this mass is confined to the volar compartment

limited to the flexor compartment, meaning wide local resection could be attempted safely if the lesion were found to be malignant. The surgeon elected to perform an incisional biopsy through a volar approach. The intraoperative diagnosis of a benign nerve sheath tumor afforded the opportunity for safe local resection without compromising the patient's functional status.

Conclusion

Malignant tumors of the upper extremity are uncommon. When a suspicious upper extremity lesion is encountered, it should always be approached as if it were a malignant lesion. Referral to a medical center with surgeons, radiologists, and pathologists experienced in managing musculoskeletal tumors is recommended. Staging with MRI allows localization of lesion to a compartment of origin. Identification of extracompartmental spread and invasion of neurovascular structures are important features that must be communicated to the surgeon preoperatively to ensure the patient receives appropriate therapy. If biopsy is to be performed by the radiologist, it should be planned in consultation with the referring surgeon to ensure the biopsy tract will be amenable to later resection. Adherence to these guidelines will help prevent unnecessary complications.

References

1. Trigg SD. Biopsy of hand, wrist, and forearm tumors. Hand Clin 2004; 20:131–135
2. Leit ME, Tomaino MM. Principles of limb salvage surgery of the upper extremity. Hand Clin 2004; 20: 167–179
3. Yaw KM, Leit ME. Tumors and amputations. In: Herndon JH, editor. Surgical reconstruction of the upper extremity. Appleton & Lange, Stamford, CT; 1999; pp 417–430
4. Simon MA, Biermann JS. Biopsy of bone and soft-tissue lesions. J Bone Joint Surg Am 1993;75:616–621
5. Toomayan GA, Robertson F, Major NM. Lower extremity compartmental anatomy: Clinical relevance to radiologists. Skeletal Radiol 2005;34: 307–313
6. Cancer Facts & Figures (2005) American Cancer Society website, http://www.cancer.org/downloads/STT/CAFF2005f4PWSecured.pdf
7. Pisters PW, Leung DH, Woodruff J, et al Analysis of prognostic factors in 1,041 patients with localized soft tissue sarcomas of the extremities. J Clin Oncol 1996;14:1679
8. Brennan MF. The surgeon as a leader in cancer care: Lessons learned from the study of soft tissue sarcomas. J Am Coll Surg 1996;182:520
9. Murray PM. Soft tissue neoplasms: Benign and malignant In: Trumble T (ed) Hand surgery. Update 3. American Society for Surgery of the Hand, Rosemont, IL; 2003; pp 569–581
10. Enneking WF, Spanier SS, Goodman MA. A system for the surgical staging of musculoskeletal sarcoma. Clin Orthop 2003;415:4–18
11. Parsons TW, Filzen TW. Evaluation and staging of musculoskeletal neoplasia. Hand Clin 2004;20:137–145
12. Enneking WF, Spanier SS, Goodman MA. A system for the surgical staging of musculoskeletal sarcoma. Clin Orthop 1980;153:106–120
13. Green FL, Page DL, Fleming ID, et al. AJCC cancer staging Handbook. 6th edition. Springer, Berlin Heidelberg New York; 2002; pp 213–215
14. Heare TC, Enneking WF, Heare MM. Staging techniques and biopsy of bone tumor. Orthop Clin North Am 1989;20:273–285
15. Anderson, MA, Temple HT, Dussault RG, Kaplan PA. Compartmental anatomy: Relevance to staging and biopsy of musculoskeletal tumors. AJR AM J Roentgenol 1999;173:1663–1671
16. Wolf RE, Enneking WF. The staging and surgery of musculoskeletal neoplasms. Orthop Clin North Am 1996;27:473–481
17. Rock MG, Wood MB, Fleegler EJ. Reconstruction for tumors of the upper limb. In : Bogumill GP, Fleegler CJ, (eds) Tumors of the hand and upper extremity. Churchill and Livingstone, Edinburgh; 1993; pp 413–434
18. Jenkins DB. Hollinshead's functional anatomy of the limbs and back. Saunders, Philadelphia 2002
19. Netter FH. Atlas of Human Anatomy. Icon Learning Systems, Teterboro, NJ; 2003
20. Boles CA, Kannam S, Cardwell AB. The forearm: anatomy of muscle compartments and nerves. AJR Am J Roentgenol 2000;174:151–159
21. Ronel DN, Mtui E, Nolan WB. Forearm compartment syndrome: anatomical analysis of surgical approaches to the deep space. Plast Reconstr Surg 2004;114(3):697–705
22. Frober R, Linss W. Anatomic basis of the forearm compartment syndrome. Surg Radiol Anat 1994;16:341–347