Rehabilitation After Limb Salvage Surgery

Maurizio Lopresti
Lorenzo Panella
Editors

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Editors
Maurizio Lopresti
Physical Rehabilitation
Gaetano Pini – CTO Orthopedic Institute
Milan
Italy

Lorenzo Panella
Rehabilitation Department
Gaetano Pini – CTO Orthopedic Institute
Milano
Italy

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I'd love to dedicate this book to Loredana Maspes, one of the persons who more than anyone else believed in me and shaped my career.

Maurizio Lopresti

Foreword

In recent years, the development of drugs and advanced treatments has allowed to treat a large number of oncological conditions. The resulting improvement in survival, linked to the reduction of the effects of such diseases, has made it increasingly necessary to manage their long-term consequences. The impairment, the limitation of activities of daily living and the restriction of participation have made it essential to define a series of interventions aimed at improving the functional condition and quality of life. These areas of interventions are covered by rehabilitation. In past years, rehabilitation had somewhat neglected to focus on oncological pathology as a field of application. Currently, at a national level in several countries as well as within international organizations, this perspective is gaining increasing recognition; as a consequence, the techniques to address these pathologies have been constantly improving. The management of the consequences of neoplasia requires a multidisciplinary and multi-professional approach. This means that it is necessary to define an individual rehabilitation plan based on the available evidence, the professional experience and the perspective of the sick person, in the belief that the experience of illness plays a crucial role in functional recovery. Therefore, part of the rehabilitation project consists in defining goals and sharing these with the multi-professional team and the sick person. Rehabilitation is not just physical exercise, but a series of interventions aimed at achieving the defined goals. To this end, not only medical specialists in Physical and Rehabilitation Medicine but also Physiotherapists, Occupational Therapists, and Speech and Language Therapists are involved. On this basis, guidelines on cancer rehabilitation, position papers and best practice recommendations have been developed in a formal manner.

International organizations of physical medicine and rehabilitation are increasingly growing. The European Union of Physical and Rehabilitation Medical Specialists (UEMS) has provided space to identify the professional competencies needed in this field, in order to develop them through training strategies that integrate oncology rehabilitation in the training curriculum of physicians specialized in physical medicine and rehabilitation. Further cooperative actions are being taken in collaboration with the International Society of Physical and Rehabilitation Medicine (ISPRM) for the development of Oncology Rehabilitation.

Mauro Zampolini
UEMS—PRM Section
Foligno, Italy

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Part I

Primary Bone Tumors and Osteosarcoma

1 Classification of Primary Bone Tumors and of Osteosarcoma

A. Parafioriti, E. Armiraglio, and A. Di Bernardo

Although remarkable progress has been made in the histological typing and the molecular genotyping of bone tumors, their classification remains extremely complex; in some instances, the integration of histomorphological, phenotypic, and molecular features with the clinical appearance does not provide sufficient prognostic information to assess the clinical course and plan treatment.

Similarly to neoplasias affecting other body regions, musculoskeletal tumors can be classified as either benign or malignant based on their histological features.

At the present moment, the histogenetic classification of musculoskeletal tumors is not considered as reliable any longer, since there is not any sound evidence that tumor cells originate from their normal counterparts. The clinical reasoning is rather based on the differentiation patterns (lipogenic, smooth muscle, fibroblast, vascular, etc.) that determine the morphology of neoplastic cells variously resembling that of the normal counterpart [1]. In general, benign and low-grade malignant mesenchymal tumors are highly similar to their respective mature mesenchymal tissues, while intermediate and high-grade malignant tumors show morphological features that hardly match their normal counterpart. There are also a number of heterogeneous cases that include mesenchymal neoplasias—both benign and malignant—where a clear differentiation pattern and/or a normal counterpart cannot be identified.

The histological assessment and classification of musculoskeletal mesenchymal neoplasias are essentially based on the optical microscope analysis of the histomorphological features of the tumors [2].

Morphology often needs to be combined with immunocytochemical and molecular investigations for a correct diagnosis and classification of the lesions to be reached.

A. Parafioriti (✉) · E. Armiraglio · A. Di Bernardo
Pathology Unit, Gaetano Pini CTO Hospital, Milan, MI, Italy
e-mail: antonina.Parafioriti@asst-pini-cto.it; elisabetta.armiraglio@asst-pini-cto.it; andrea.dibernardo@asst-pini-cto.it

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Different malignancy grades can be identified in malignant tumors, depending on the risk of developing metastases and on the chances of survival.

The histological grading of malignant neoplasms consists in assessing a series of histomorphological parameters (mitotic activity, tumor necrosis, and tumor differentiation) that are believed to provide information on the biological behavior of the tumor.

For soft tissue sarcomas, the FNCLCC grading system—devised in France by the Federation *Nationale des Centres de Lutte Contre le Cancer*—is normally used; it identifies three malignancy grades based on the score obtained by summing the values assigned to the following evaluated parameters: mitotic count, tumor necrosis, and tumor differentiation.

For bone sarcomas, there is not any universally recognized grading system at the moment. The system that has always been in use identifies four malignancy grades and assesses the cellularity, nuclear features, mitotic count, and necrosis; this system is generally used to grade osteosarcoma. Ewing's sarcoma, dedifferentiated chondrosarcoma, and mesenchymal chondrosarcoma are considered as high-grade malignant tumors by definition.

For a correct, more accurate prognosis, the histological grading is later integrated with the local and distant spread of bone tumors in order to define the stage of the disease.

Purpose of the staging is to stratify tumors into different groups—sharing the same biological behavior and prognosis—so as to find a common language that enables to plan the most suitable therapeutic approach.

Staging is based on the three traditional parameters: G, T, and M. There are two staging systems:

1. The TNM system developed by the American Joint Committee on Cancer (AJCC).

   "G" describes the histological malignancy grading of the tumor: G1—well differentiated, low grade; G2—moderately differentiated, high grade; G3—poorly differentiated, high grade (on a four-grade malignancy scale: G1, G2—low malignancy; G3, G4—high malignancy).

   "T" describes the size of the tumor: T1—tumor ≤8 cm in diameter (Fig. 1.1); T2—tumor >8 cm in diameter (Fig. 1.2); T3—discontinuous spread (multifocal tumor within the bone segment).

   "M" indicates the presence of distant metastases: M0—no metastases; M1—evidence of metastases (M1a: lung metastases; M1b: distant bone metastases or metastases in different sites).

   "N" indicates the presence of locoregional lymph node metastases: N0—no metastases; N1—evidence of metastases.
2. The Enneking staging system [3, 4] adopted by the American Joint Committee Task Force on Bone Tumors, based on the concept of anatomic compartment.

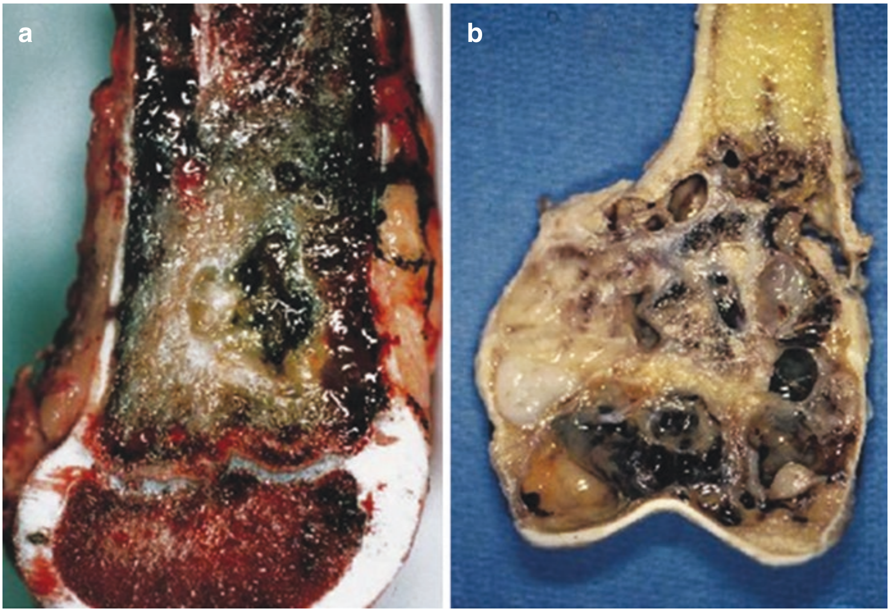


Fig. 1.1 T1 neoplasias: ≤8 cm

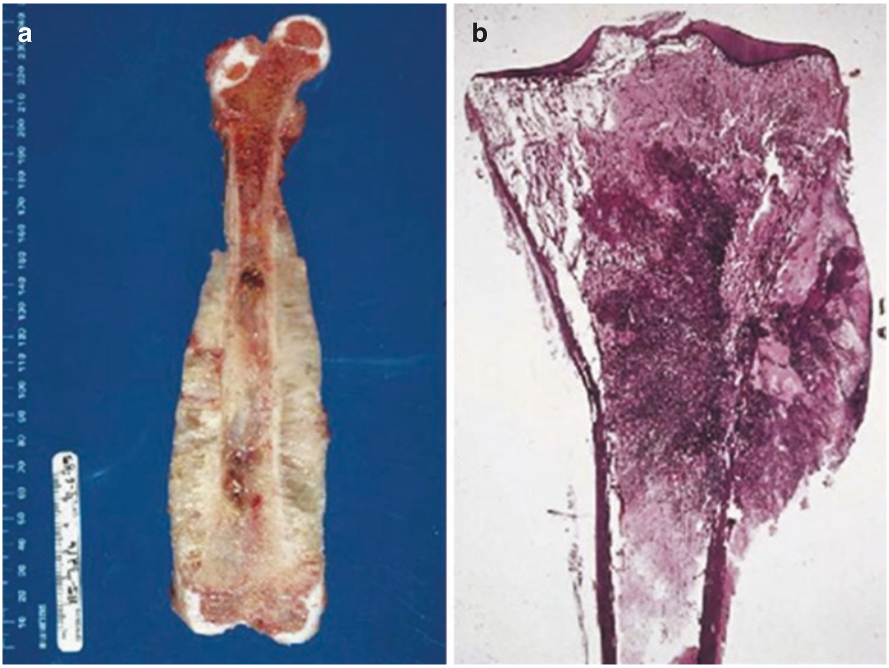


Fig. 1.2 T2 neoplasias: >8 cm

1.1 The Concept of "Anatomic Compartment"

A compartment is an anatomic structure or space limited by natural barriers that prevent the tumor from spreading, that is, cortical bone, fascia and fascial septa, articular cartilage, tendons and tendon sheaths, adipose tissue, and interstitial areolar tissue (Fig. 1.3). Neoplasias growing outside these regions are called extracompartmental.

Within this system, benign tumors are called G0 and classified as: (1) latent and inactive (Fig. 1.4), (2) active (Fig. 1.5), and (3) aggressive (Fig. 1.6), according to their intracompartmental and extracompartmental spread and to the presence of metastases (Table 1.1).

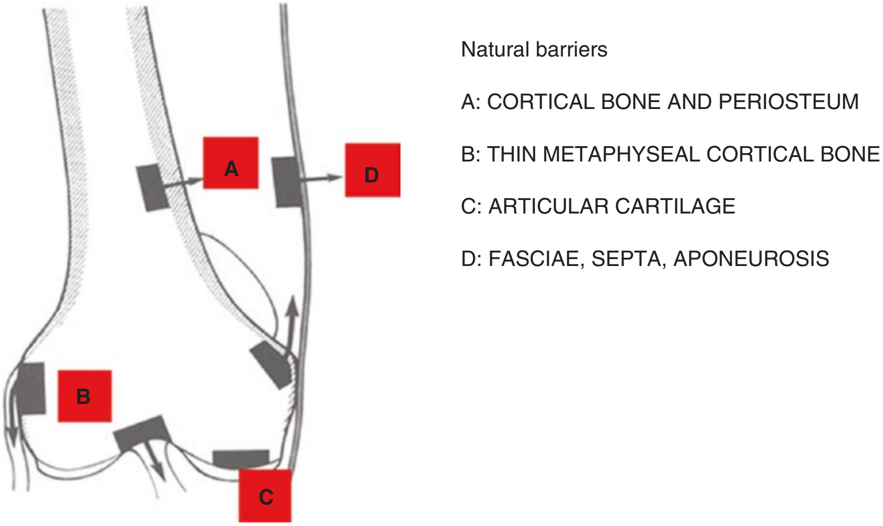
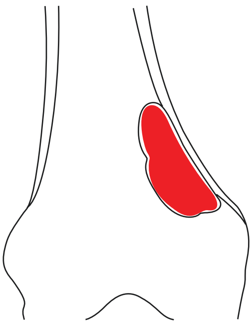


Fig. 1.3 Natural barriers. (**A**) Cortical bone and periosteum. (**B**) Thin metaphyseal cortical bone. (**C**) Articular cartilage. (**D**) Fasciae, Septa, Aponeurosis



GRADING	EXTENSION	METASTASIS
G0 (BENIGN)	**T0** INTRACAPSULAR	**M0** ABSENT

Fig. 1.4 Benign tumors. Latent and inactive stage

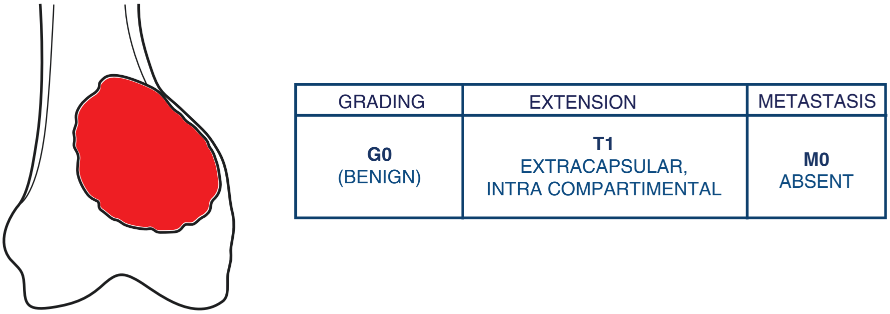


Fig. 1.5 Benign tumors. Active stage

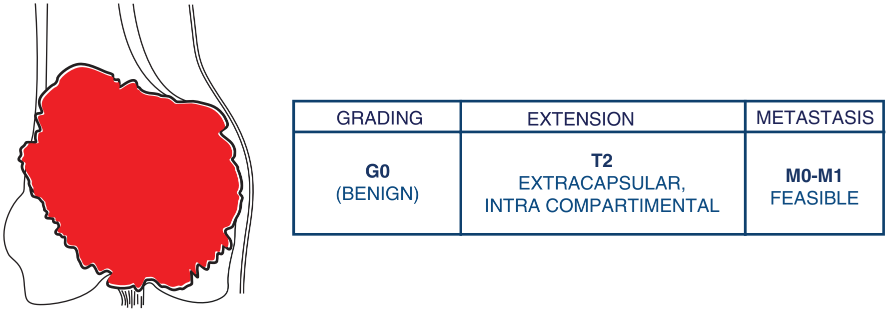


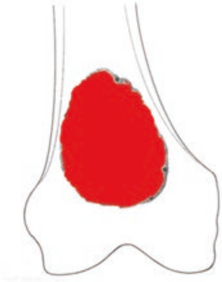
Fig. 1.6 Benign tumors. Aggressive stage

Table 1.1 Staging of malignant tumors

Stage	Definition
IA	Low grade, intracompartmental
IB	Low grade, extracompartmental
IIA	High grade, intracompartmental
IIB	High grade, extracompartmental
III	Any grade, metastatic

Malignant tumors (Table 1.1) are classified as G1 and G2 and, according to their sites, as T1 in case of intracompartmental spread (intraarticular spread, superficial spread through to the deep fascia, subperiosteal spread) and as T2 in case of extracompartmental spread (soft tissues, deep fascia, intraosseous or extrafascial spread) (Fig. 1.7).

Moreover, the tumor growth determines changes in the host tissue, both caused by the mechanical pressure of the tumor mass on the surrounding tissues and mediated by the proinflammatory factors and chemokines generated by the tumor cells, which induce a proliferation of mesenchymal cells and new vases, edemas, and the infiltration of inflammatory cells. On the edge between host tissue and tumor, a variable layer of tissue called "pseudocapsule" often grows, which might prevent the tumor growth and represents a cleavage plane for surgical resection.



LOW GRADE MALIGNANCY

STAGE 1 A

GRADING	EXTENSION	METASTASIS
G1 (MALIGN, LOW GRADE)	**T1** EXTRACAPSULAR, INTRA COMPARTIMENTAL	**M0** ABSENT

STAGE 1 B

GRADING	EXTENSION	METASTASIS
G1 (MALIGN, LOW GRADE)	**T2** EXTRACAPSULAR, EXTRA COMPARTIMENTAL	**M0** ABSENT

HIGH GRADE MALIGNANCY

STAGE 2 A

GRADING	EXTENSION	METASTASIS
G2 (MALIGN, HIGH GRADE)	**T1** EXTRACAPSULAR, INTRA COMPARTIMENTAL	**M0** ABSENT

STAGE 2 B

GRADING	EXTENSION	METASTASIS
G2 (MALIGN, HIGH GRADE)	**T2** EXTRACAPSULAR, EXTRA COMPARTIMENTAL	**M1** PRESENT

METASTATIC TUMORS

GRADING	EXTENSION	METASTASIS
G1 OR G2	**T1-T2** (INTRA OR EXTRA COMPARTIMENTAL)	**M1** (PRESENT)

Fig. 1.7 Representation of staging of malignant tumors

Malignant tumors are likely to show infiltrating behavior even when a pseudocapsule is present; the latter should, thus, be accurately examined, both macroscopically and microscopically.

Depending on the relationship of the tumor to the excision margin, the Musculoskeletal Tumor Society presented the following assessment system (Table 1.2 and Fig. 1.8).

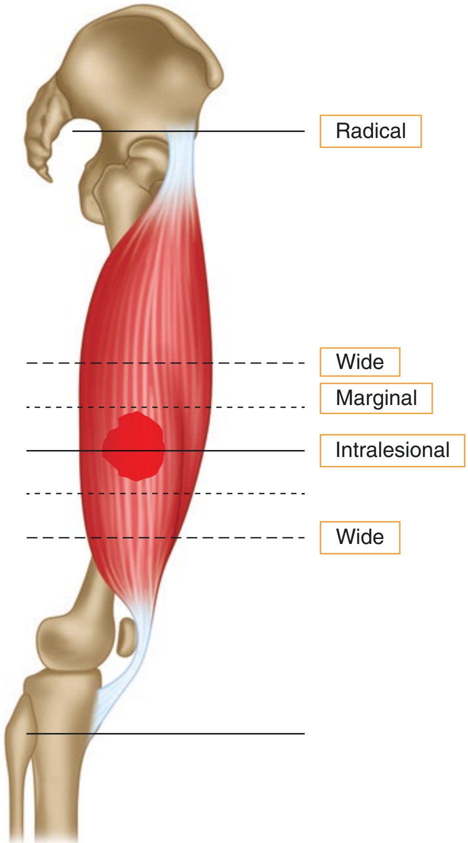


Fig. 1.8 The tumor should be resected with wide tumor-free margins

Table 1.2 Type of excision margin

Type of margin vs. plane of dissection:
Intralesional: within the lesion
Marginal: within the reactive/extracapsular zone
Wide: beyond the reactive zone of the healthy tissue within the compartment
Radical: extracompartmental healthy tissue

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Epidemiology

2

A. Parafioriti, E. Armiraglio, and A. Di Bernardo

Over 1,700,000 people living in Italy have been diagnosed with neoplasia, plus 250,000 new cases occurring annually [1].

The risk of being diagnosed with cancer rises with age, and 77% of all tumors are diagnosed in people aged over 55. In the United States, in children aged between 0 and 14 and teenagers aged between 15 and 19, the incidence rate of all types of cancer is 16.5 cases per 100,000 individuals per year with a growing trend. This is partly due to an improvement in diagnostic methods and partly due to an actual increase in new cases.

Primary bone tumors are quite rare. In Italy, slightly more than one case in 100,000 are reported on average every year, that is, around 350 new cases per year. The incidence rate is 0.9 per 100,000 individuals per year, and mortality rate is 0.4 per 100,000 individuals, with a survival rate at 5 years of 67.9%. The average age at diagnosis is around 39 years with the majority of cases (28.7%) under 20 years, and 50% of cases diagnosed before the age of 59 years. For children and teenagers aged between 0 and 19, the incidence rate is 0.9 per 100,000 individuals per year, while mortality is 0.4 per 100,000 individuals. Out of all the different types of tumor that can affect the under-20 population, malignant bone tumors account for 6% of cases. The two most frequent types of tumor in children and teenagers are osteosarcoma and Ewing's sarcoma.

Osteosarcoma has an annual incidence rate of 4.0 (3.5–4.6) per 1,000,000 individuals aged between 0 and 14, a rate of 5.0 (4.6–5.6) per 1,000,000 individuals aged between 0 and 19, and a rate of 3.0 cases (1.5–4.5) for people over 60 years of age. Data from tumor registers with regard to histological types show that osteosarcoma is the most common primary bone tumor at all ages, as it occurs in

A. Parafioriti (✉) · E. Armiraglio · A. Di Bernardo
Pathology Unit, Gaetano Pini CTO Hospital, Milan, MI, Italy
e-mail: antonina.Parafioriti@asst-pini-cto.it; elisabetta.armiraglio@asst-pini-cto.it; andrea.dibernardo@asst-pini-cto.it

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around 35% of cases, followed by chondrosarcoma in 25% of cases and Ewing's sarcoma in 16%. Among pediatric tumors, osteosarcoma ranks eighth for incidence.

Osteosarcoma has a bimodal distribution for age with two incidence peaks: the first is between 10 and 14 years of age, simultaneously with the pubertal growth peak, and the second appears in adults over 65 years (seventh and eighth decade), most likely as a malignant transformation of Paget's disease (1% of Paget patients develop osteosarcoma) or other benign bone lesions, or as a result from treatment of another tumor [2]. Osteosarcoma is extremely rare under 5 years of age with only 2% of cases.

Gender-based incidence has always been considered as higher in males than females, as it occurs with an average 5.4 cases per 1,000,000 individuals in males against 4.0 per 1,000,000 in females. This is true of teenagers aged between 15 and 19, but under 15 and over 65 years of age, incidence is higher for females [3].

All bone segments can be affected by osteosarcoma: in children and young adults, it mostly strikes rapidly growing bones, such as the terminal parts of long bones. The most common sites are the femur (42%, with 75% in the distal femur), tibia (19%, with 80% in proximal tibia), and humerus (10%, with 90% in the proximal humerus); other sites include the cranium and mandible (8%) and the pelvis (8%). In the elderly, osteosarcoma most frequently affects the axial skeleton or previously irradiated areas [4].

Mortality for primary bone tumors is 0.4 per 100,000 individuals per year. Mortality rate for osteosarcoma decreased by around 1.3% per year between 1990 and 2004. Survival at 5 years for osteosarcoma patients aged under 45 years is 68%, with no significant differences as to gender, while it remains under 45% in patients aged over 45 years. Patients' age is related to survival, with the oldest patients having the lowest life expectancy.

Complete surgical excision is critical to ensure an optimal outcome. The tumor stage, the presence of metastases, the local relapse, the chemotherapy regimen, the anatomical location, the tumor size, and the percentage of tumor cells destroyed by neoadjuvant chemotherapy are all factors that strongly impact the final outcome [5].

The tumor location has been associated with the outcome too: the lowest survival is registered in patients with tumors in the lumbar or pelvic areas (32%), in the scapula or shoulder (45%), and in the proximal femur (62%), while the highest survival rates are linked to tumors in the proximal tibia (78%) and distal femur (73%) [6].

With regard to histological subtypes, survival at 5 years is 52.6% for high-grade intramedullary osteosarcoma, 85.9% for parosteal osteosarcoma, 49.5% for small-cell osteosarcoma, and 17.8% for osteosarcoma secondary to Paget's disease.

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3 Clinical, Radiological, and Histological Diagnosis

M. B. Gallazzi, D. Coviello, A. Parafioriti, E. Armiraglio, and A. Di Bernardo

To diagnose a bone tumor, an analytical approach is required, as well as the use of clinical, histological, and radiological means.

3.1 Clinical Diagnosis

A. ParafioritiE. Armiraglio, and A. Di Bernardo

The clinical characteristics of osteosarcoma are aspecific; therefore, it might take a long time for the tumor to be diagnosed. The key symptoms leading to the diagnosis are pain, tumefaction, and overall discomfort. Limited mobility and spontaneous fractures might be present as well and might be important for the diagnosis.

In absence of spontaneous fractures (known as pathological), symptoms develop slowly and progressively.

Pain is the first and most common of all symptoms: being neuralgic, it is initially present at rest, with alternating quiescence and remission phases. It can subsequently grow more intense, to the point of disrupting the night sleep and spreading to the adjacent joints, which lead to it being wrongly interpreted as arthrosis or a posttraumatic phenomenon; for this reason, a differential diagnosis for rheumatic pain must be performed. Later on, pain tends to intensify and become persistent and sharp, and needs to be treated with opiates. If a nerve trunk or plexus is compressed,

M. B. Gallazzi (✉) · D. Coviello
Radiodiagnostic Operating Unit, Gaetano Pini CTO Hospital, Milan, MI, Italy
e-mail: mauro.gallazzi@asst-pini-cto.it

A. Parafioriti · E. Armiraglio · A. Di Bernardo
Pathology Unit, Gaetano Pini CTO Hospital, Milan, MI, Italy
e-mail: antonina.Parafioriti@asst-pini-cto.it; elisabetta.armiraglio@asst-pini-cto.it; andrea.dibernardo@asst-pini-cto.it

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pain can be irradiated; in case of nerve root or bone marrow compression suggesting spinal cord involvement, pain can be combined with motor and/or sensory deficits.

The most common sign is tumefaction, only detectable if the tumor has spread outside the bone or if the bone has expanded due to the tumor growth. In malignant tumors, the tumor mass rapidly increases in size (a physical or ultrasound measurement in centimeters might be helpful) and may have different consistencies (hard, soft, elastic). At advanced stages, any tumefaction due to neoplasia can cause changes in the skin surface, which may appear tense and shiny, translucent with visible veins, livid, hyperthermic, with stretch marks or ulcerations. The mobility of the dermis, the hypodermis, and the muscles over the tumor should be examined as well: a reduced mobility is yet another sign of a malignant neoplasm.

Limb mobility may be limited if the tumor is intraarticular and/or in case of advanced-stage lesions. Occasionally, mobility limitations are not due to the tumor, but to the reactive synovitis of the joint, which might mislead the diagnosis.

Another indicative sign is a volume increase in regional lymph nodes, usually due to a reactive hypertrophy rather than a metastasis.

Events that often lead to diagnosing neoplasia are pathological fractures. Rarely the first sign of a tumor, they often occur in advanced pathological stages due to the osteolytic effect of the disease.

General symptoms and signs are temperature, fatigue, and weight loss.

On a serological level, an increase in alkaline phosphatase, and less frequently in LDH, may be detected; both are poor prognostic factors. Their values tend to move back within the limits following tumor ablation (surgical or pharmacological) and to increase once again in case of a relapse.

3.2 Radiological Diagnosis

M. B. Gallazzi and D. Coviello

With its various diagnostic methods, radiology serves two primary functions: to diagnose and to assess the local and/or distant spread of neoplasms so that a suitable treatment plan can be built. Today, traditional radiology still remains the first diagnostic approach to skeletal neoplasms. It notably allows to identify a series of iconographic features suggestive of an aggressive lesion, and potentially the matrix of the lesion itself, as a guide for the etiological diagnosis. Although the radiographic appearance of bone tumors may sometimes be less typical or dubious, when they do not evidently spread beyond the cortical bone and thus mimic less aggressive or benign lesions, a malignant lesion generally presents irregular osteolysis with ill-defined margins that "fades" into the adjacent healthy bone without any frank evidence of demarcations, particularly in the form of sclerotic borders. As it rapidly grows, the tumor destroys the cortical bone and periosteum and extends beyond them to soft tissues. The periosteum attempts to limit the tumor spread by laying down new layers that form the so-called periosteal reaction, which will, however, be ill-defined and interrupted, with the formation of radiopaque strips perpendicular to the cortical bone surface (sunray periosteal reaction) and/or of irregular periosteal layers parallel to the cortex (onionskin periosteal reaction). In the most aggressive neoplasms, the neoplastic tissue grows between the periosteal reaction and cortical bones, thus detaching the periosteum and raising it away from surface of the cortex, which results in the formation of a triangular marginal area known as Codman's triangle (Fig. 3.1). In case of primary bone neoplasms forming a "matrix," radiology may identify it and allow for a first etiological diagnosis. In osteosarcomas in particular, radiographs will show calcified bone tissue, while in chondrosarcomas, pathologic osteolysis will show calcifications of lobular masses, either dispersed or arranged in popcorn-like or ring-shaped patterns. This bone or cartilage matrix may be found inside the bone only when neoplasia remains confined within the bone itself or within the adjacent soft tissues in case of extracompartmental tumors. In Ewing's sarcoma, whose neoplastic tissue presents an "amorphous" matrix (i.e., impossible to standardize based on its radiodensity), radiograms will show homogeneous nonspecific osteolysis, and it will obviously be impossible to identify any nonbone components of the tumor on the sole basis of traditional radiology. As lungs are the target organs of metastatic bone sarcomas, should any suspicions arise from traditional radiology, the examination must be complemented by a chest radiograph assessment to investigate the presence of any lung metastases.

In the past, bone scintigraphy with 99mTc-labeled diphosphonates was widely used both to diagnose skeletal sarcomas showing intense positivity even beyond the radiographic limits for neoplasia, and to identify metastases within the same bone

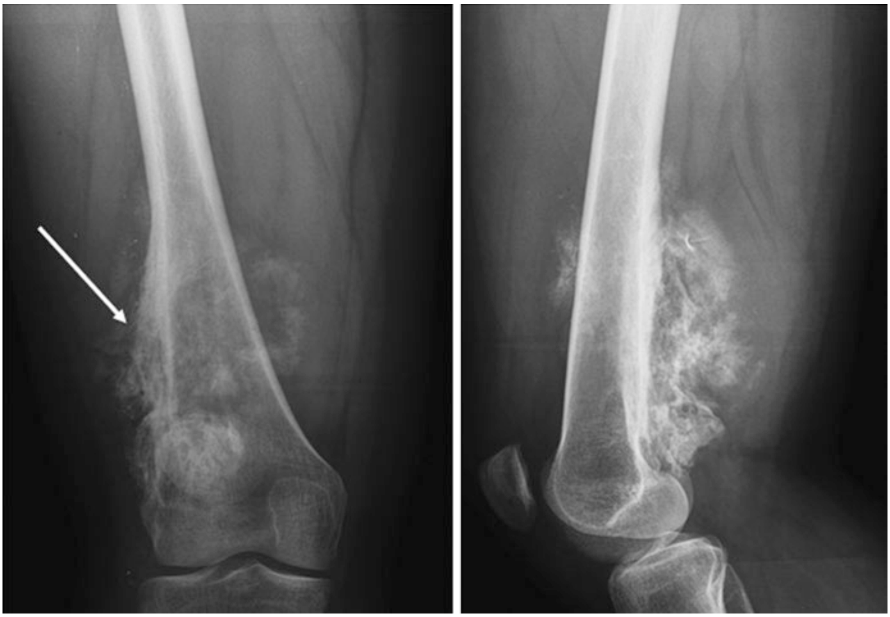

Fig. 3.1 Codman's triangle

(skip metastases) or in different bones (multifocal sarcomas). Today, its use has remarkably reduced, and it has mostly been replaced by MRI (Figs. 3.2 and 3.3).

CT still plays a leading role and integrates MRI. Especially with the new multilayer machines allowing for multiplanar reconstructions, CT provides valuable

Fig. 3.2 Bone sarcoma: AP radiograph

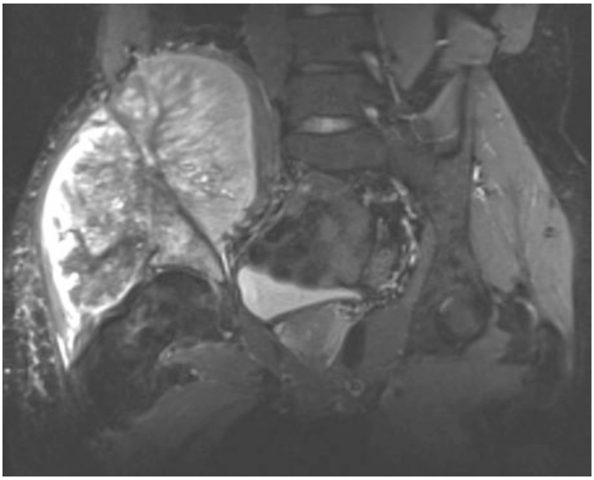

Fig. 3.3 Bone sarcoma: T2w MRI

information on the nature of the tumor and its spread within and outside the bone. In particular, CT currently represents the most accurate method available to study bones. In fact, it works on the same well-tested semeiological criteria formulated over the years in traditional radiology, and optimizes them by a higher contrast definition and multiplanar imaging, which allow to identify the smallest structural details of the lesion, and thus make an early diagnosis possible, as well as an efficient local staging (cortical infiltration with assessment of any impending fractures, minimal periosteal reactions not showing in the RT, fractures of the cortex with extracompartmental spread, penetration into metaphyseal cartilages, etc.) (Fig. 3.4). In some cases, basic CT already provides with comprehensive information; in others, post-contrastographic findings return substantial elements for a correct diagnosis and surgical planning (e.g., for what concerns the relationship between the neoplastic tissue and vascular-nerve bundles). Moreover, TC is the method of choice to guide needle biopsies of bone neoplasias. Nevertheless, performing a biopsy of the tumor still remains an essential diagnostic step. As a matter of fact, performing a histological or cytological test on the sample—to analyze it via immunohistochemical techniques, an electronic microscope, and molecular genetics—does not only provide definitive indications on the nature of the tumor, but also makes it possible to grade the tumor itself, with important consequences on the treatment choices and prognosis.

Last, CT is currently used for staging bone sarcomas, that is, for searching for their distant locations, particularly for what concerns lungs as elective target organs, as previously recalled (Fig. 3.5).

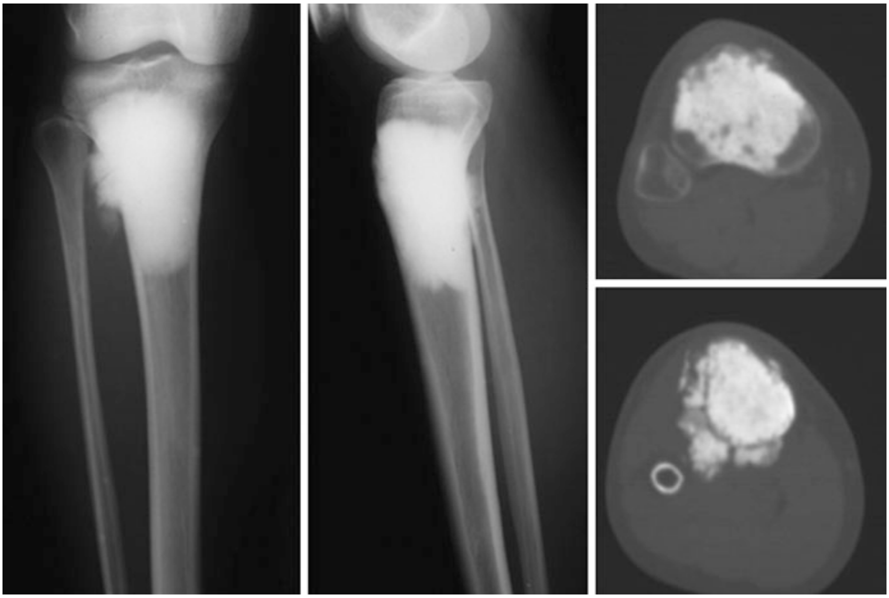

Fig. 3.4 Extracompartmental spread

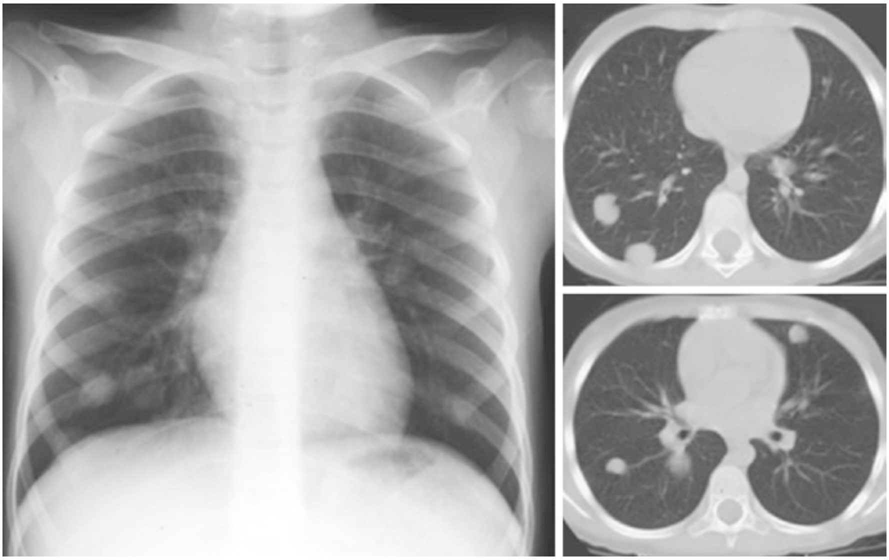

Fig. 3.5 Bone sarcoma's staging

In the MRI, sarcomas usually appear in a typical presentation pattern marked by low-intensity signals in T1-weighted sequences and high-intensity signals in T2-weighted sequences. The presence of an ossified osteoid matrix in the osteosarcoma shows in the MRI with low-signal intensity areas, both in T1 and T2 weighting. Similarly, in chondrosarcoma, the presence of calcified lobules will show in the form of hypointense spots in all weighting. In general, MRI remains the best method to investigate any intramedullary spread of the tumor as well as any spread beyond metaphyseal cartilage with invasion of the epiphysis skip metastases (Fig. 3.6). Moreover, thanks to its higher contrast definition for soft tissues compared to CT, MRI is the method that returns the most detailed information on the tumor spread outside the bone (Fig. 3.7).

Finally, a few considerations should be made on the role of radiology for patients with operated bone sarcomas. For these patients who often have joint prostheses, a radiological follow-up is crucial not just to monitor any local relapses, but also in terms of any periprosthetic complications that might arise (fractures, mobilizations, infections). As to fractures and mobilizations, traditional radiology is usually the basic diagnostic technique to use (Fig. 3.8). However, it should be noted that its diagnostic efficacy remarkably increases if previous serial radiographic examinations are available to be compared with the radiographs taken in case of painful prosthesis. Only in case the RT should be dubious, the technique of choice to explain periprosthetic pain may be a CT, with protocols for metal artifact reduction. Should an infection be suspected, an ultrasound may prove highly useful for seeking periprosthetic samples to collect via an eco-guided fine needle aspiration in search for any possible bacteria.

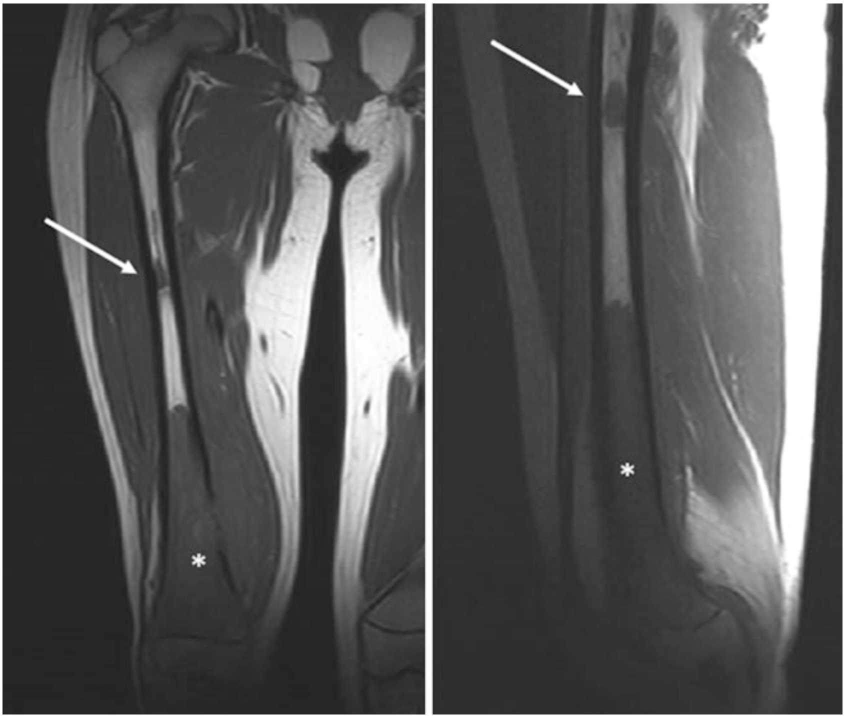

Fig. 3.6 Skip metastases

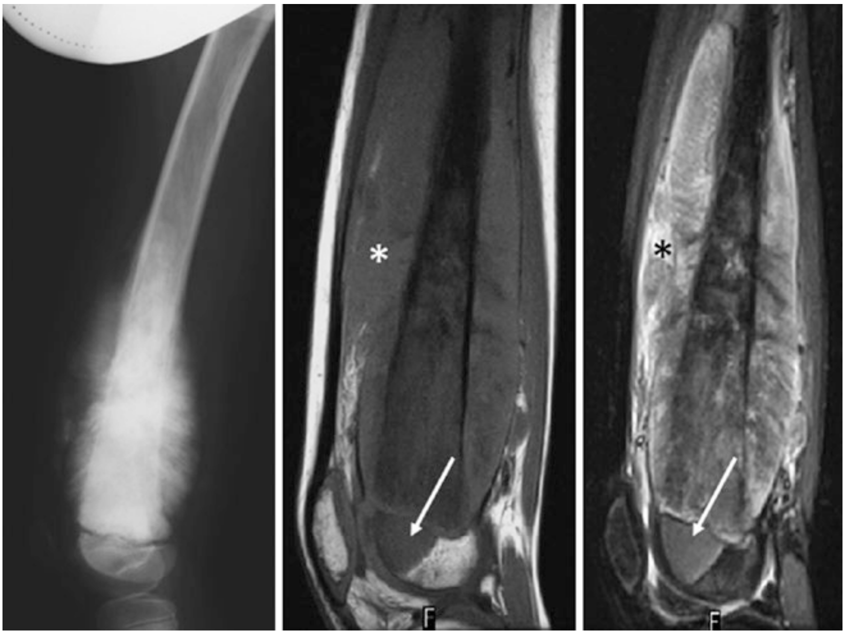

Fig. 3.7 MRI: Sarcoma's spread

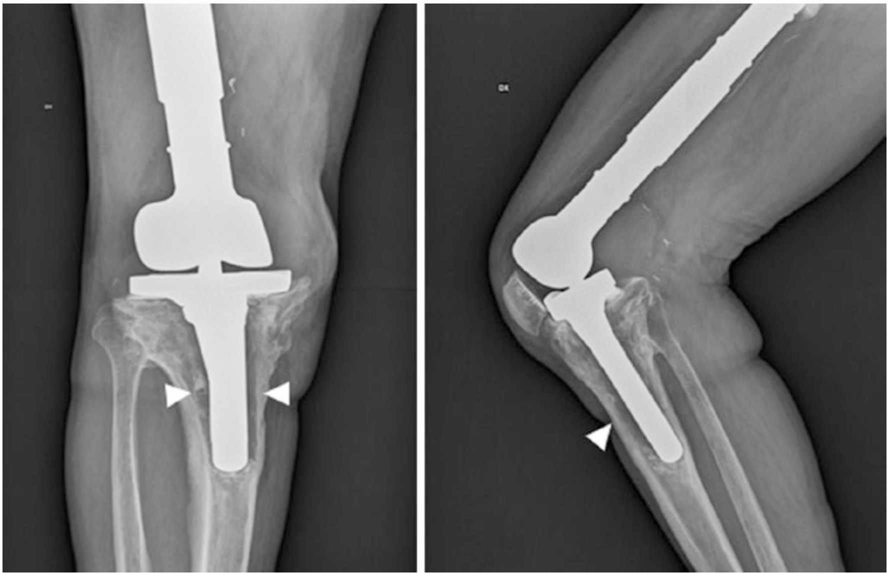

Fig. 3.8 RT: Prosthetic mobilization

3.3 Histological Diagnosis [1]

A. ParafioritiE. Armiraglio, and A. Di Bernardo

Histological diagnosis cannot be disregarded and is performed on fine-needle aspiration samples or an incisional biopsy.

Based on its histological features and clinical appearance, osteosarcoma can be classified as:

- Conventional (osteoblastic, chondroblastic, or fibroblastic) osteosarcoma
- Telangiectatic osteosarcoma
- Small-cell osteosarcoma
- Intraosseous well-differentiated osteosarcoma
- Intracortical osteosarcoma
- Periosteal osteosarcoma
- Parosteal osteosarcoma
- High-grade surface osteosarcoma
- Multifocal osteosarcoma
- Extraosseous osteosarcoma

Conventional osteosarcoma is a high-grade malignant sarcoma whose treatment consists in the following stages: biopsy-based histological diagnosis, neoadjuvant chemotherapy, surgery, histological assessment of chemotherapy-induced necrosis, adjuvant chemotherapy or radiotherapy.

Following surgical resection, the pathologist should examine the surgical site with special attention to the surgical margins, the presence of skip metastases, and postchemotherapy necrosis. Quantifying the necrosis is crucial to planning postoperative chemotherapy.

Among osteosarcomas, some forms have low malignancy grades like well-differentiated intramedullary osteosarcoma and parosteal osteosarcoma, which can only be treated surgically.

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Prognosis

4

Valentina Gariboldi, Maurizio Lopresti,
and Lorenzo Panella

Although further confirmation and clarifications are needed, the factors that seem to play a role in determining the prognosis of a disease are: age, tumor volume, site, increase in alkaline phosphatase and LDH in blood, histological grade, histological subtype, and ploidy.

Poor prognostic indicators include tumor arising from the axial skeleton, large tumor size, increased levels of alkaline phosphatase or lactate dehydrogenase, lymph node involvement, presence of metastases at presentation, and poor response to neoadjuvant chemotherapy [1].

Before chemotherapy was introduced, survival at 10 years was around 15%. With the advent of chemotherapy, it rose to 70% for nonmetastatic osteosarcomas at diagnosis (skip or distant osteosarcomas) affecting the appendicular skeleton.

With advances in diagnosis and therapies, limb salvage has replaced amputation as the cornerstone of treatment. Today, most of the patients receive limb salvage. Amputation is considered in case of infections, pathologic fractures, or when tumors surround neurovascular structures.

In 2–3% of cases, amputation is followed by a local relapse. Relapse is observed in 5–7% of cases with preoperative chemotherapy and conservative surgery. Nevertheless, both procedures have shown equivalent survival rates. The incidence

V. Gariboldi (✉)
Complex Operative Unit, Neurological, Sub-Intensive, Orthopedic-Vascular, General Geriatric Rehabilitation Unit, Department of Medicine and Rehabilitation, G. Salvini Hospital, Garbagnate Milanese, Italy
e-mail: vgariboldi@asst-rhodense.it

M. Lopresti
Physical Rehabilitation, Gaetano Pini – CTO Orthopedic Institute, Milan, Italy

L. Panella (✉)
Rehabilitation Department, Gaetano Pini – CTO Orthopedic Institute, Milano, Italy
e-mail: lorenzo.panella@asst-pini-cto.it

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of local relapses is related to the observance of surgical margins and the response to preoperative chemotherapy. Local relapse is a fatal event, as often synchronous with or followed by a metastatic spread.

Metastases of osteosarcoma usually occur in the first 2–3 years; this is why, disease-free survival at 3 years is significant, although secondary locations (or local relapses) might rarely be observed even at 5–10 years from treatment. The most frequent metastatic site is lung, followed by the skeleton.

Different studies have shown that, if properly selected, patients who have undergone limb salvage report better functional outcomes [2, 3]. Moreover, patients treated with limb salvage have reported superior quality of life, in comparison to those treated with amputation [4]. These findings demonstrate the strong link between perceived self-identity and the integrity of the physical body, and the importance of considering social and psychological aspects in defining quality of life.

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Treatment

5

P. Daolio and E. Marini

The treatment of osteosarcoma includes surgery on the primary tumor (as conservative as possible) and on any metastases, combined with preoperative and postoperative chemotherapy. Radiotherapy is used for inoperable cases.

5.1 Chemotherapy

Multidrug preoperative chemotherapy for osteosarcoma is started right after the final histological diagnosis and staging of the patient; also known as neoadjuvant chemotherapy, it was introduced in the late '70s by Rosen [1]. Chemotherapy helps to control the systemic phase of the disease by addressing potential micrometastases, which decisively increases the patient's survival rate (in up to 60–70% of cases). In addition, neoadjuvant chemotherapy acts on the peripheral reactive zone of the tumor to destroy the neoplastic microsites surrounding the main lesion and facilitate the excision [1, 2].

There is not any accurate method to evaluate the response to preoperative chemotherapy [1, 2]. After a short cycle of treatment (around 2 months), the tumor is restaged by assessing the following responses:

- The clinical response in terms of reduction of the pain and the tumor mass.
- The laboratory response via the serum reduction of the alkaline phosphatase.
- The radiological response, in terms of efficacy in halting the tumor growth, ossification and encapsulation of the tumor, regression of the vasculature and the edema, a reduced uptake of radioactive isotopes.

P. Daolio (✉) · E. Marini
Oncological Orthopedics Unit, Department of Orthopedics/Traumatology and Specialist Surgery, Gaetano Pini CTO Hospital, Milan, MI, Italy
e-mail: PrimoAndrea.Daolio@asst-pini-cto.it; Eleonora.Marini@asst-pini-cto.it

M. Lopresti, L. Panella (eds.), *Rehabilitation After Limb Salvage Surgery*,
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Tc-99m scintigraphy and MRI with contrast are good response indicators. On the basis of postchemotherapy staging, the suitability to surgery is then evaluated. In rare cases, preoperative chemotherapy cannot be completed due to the renal toxicity of the drugs—better tolerated by young than aged patients—and the related risks, or due to the tumor growth, if too rapid and dangerously progressive/aggressive despite treatment [2].

After surgery, the whole tumor mass is histologically examined to quantify the tumor cell necrosis: a necrosis in 90–100% of cells indicates a good response to treatment. Because of their reduced vasculature and the matrix protection, chondroblastic areas will respond less to treatment. It should be specified that not all malignant bone neoplasias (chondrosarcoma in particular) are chemosensitive [1].

Postoperative chemotherapy is started 1–2 weeks after surgery and carried on for 4–6 months; for good-responder patients, the same types of drugs selected as neoadjuvants are used, while for poor responders, molecules of different types are chosen, and the therapy duration is prolonged [2].

5.2 Radiotherapy

Radiotherapy currently plays a marginal role in the therapeutic routine of bone sarcomas. It is still indicated for particular cases, such as the local control of inoperable limb lesions, pelvic, and vertebral sarcomas, as an adjuvant therapy in the resection sites, where wide margins could not be obtained, and as a palliative treatment for metastatic sarcomas [3, 4].

5.3 Surgery

5.3.1 General Concepts

The surgical treatment of bone neoplasia varies considerably in relation to the tumor malignancy. Benign and low-grade malignant lesions may not need any treatment, since they either remain stable in time or tend to heal spontaneously, as in the case of hystiocytic fibroma. When a risk of fractures or actual fractures are present, a type of intralesional surgery may be used: curettage. The surgeon enters the lesion and removes it with metal curettes until macroscopically disease-free bone is exposed [5]. When surgery is indicated, this is the case for chondromas, juvenile bone cysts, aneurysmal bone cysts, intraosseous lipomas, bone angiomas, and osteoid osteomas that cannot be treated with radiofrequency. The residual cavity can be packed either with banked bone or bone substitutes if there is a residual risk of fracture. In such cases, rehabilitation issues are limited, as the articular physiology is preserved, and the rehabilitation therapist only intervenes to limit any damage caused by immobilization and postoperative pain while considering the time needed for the bone implant to integrate [5]. In locally aggressive benign lesions, such as the giant-cell tumor, osteoblastoma, and chondroblastoma, surgery remains conservative when possible; following curettage, though, adjuvants and chemical or physical local means like phenol, liquid nitrogen, or diathermy coagulation are used to reduce the risk of relapse. This does not impact the rest of the therapeutic plan, which radically changes in case the lesion—benign, but at a locally advanced stage (Enneking's stage 3)—requires resection and biological reconstruction, as in the cases further on examined for malignant neoplasia. In low-grade malignant tumors (Enneking's stage 1), most surgeons only accept curettage for chondrosarcomas (CSA G1). Almost everyone agrees on a conservative treatment based on accurate, thorough curettage, followed by the use of adjuvants [5]. Last, in high-grade malignant lesions, surgery is based on a wide-margin resection of the lesion, with reference to the margins examined and identified by Enneking as previously explained. In other words, the surgeon should remove the tumor and a portion of disease-free healthy tissue [5]. The quantity and quality of the healthy tissue have been the object of a long-standing debate among oncologists and surgeons. A margin is generally considered as adequate when muscle or fat tissue is around 1 cm thick or less in case of fascial or periosteal tissue if not involved. In the majority of cases, resection is followed by reconstruction, which can be performed via highly complex, varied techniques. Any considerations on rehabilitation will then be discussed with regard to the tumor location and the type of reconstruction. Separate considerations are obviously needed for cases where the tumor resection requires amputation due to the local involvement of vascular-nervous structures, which prevents any conservative treatment [5].

5.3.2 Resection Techniques

5.3.2.1 Metaepiphyseal Tumors

In this site, lesions without any neoplastic spread to the articular cavity require a resection of the epiphysis and/or metaphysis for variable length according to the tumor extent. Currently, the most frequent resections of osteosarcomas, Ewing's sarcomas, and chondrosarcomas are performed on the distal femur and the proximal tibia (around the knee), followed by proximal humerus and proximal femur [6]. As anticipated, the length of the resection depends on the tumor extension inside the diaphyseal channel. Conventionally, in order to obtain an oncologically adequate margin, the resection should be performed at around 2 cm upstream or downstream of the tumor. Consequently, for example, if a tumor is 10 cm long, the surgeon will perform resection of approximately a 12 cm. Besides resecting the bone, all soft parts affected by the tumor (muscles, fascia, tendons, and ligaments) need to be removed too. When the reconstruction requires a total joint knee or hip prosthesis, it will obviously be necessary to resect the articular surface of the other bone composing the joint too, so that the corresponding articular component can be inserted [7].

5.3.2.2 Joint Tumors

In case the articular cavity is involved because the tumor spreads beyond the cartilage shell or interrupted the articular surfaces of the joint, the surgeon should perform a “closed-“joint resection [8]. This means that both the articular extremities and the capsular structures should be resected without opening the joint in order to avoid spreading the neoplasia. The operation is naturally more complex, and functional outcomes are generally worse than normal [8].

5.3.2.3 Diaphyseal Tumors

In tumors that affect the diaphysis alone, an intercalary resection is performed: the diaphysis is resected upstream and downstream of the tumor at a safety distance of around 2 cm, while joints are preserved. When the tumor spreads beyond the bone surface and involves not just muscle-tendon structures, but also the main vascular-nervous fascia, the limb must necessarily be amputated [5].

5.3.3 Types of Reconstruction

Over the last few decades, limb salvage surgery has seen remarkable progress, making destructive surgery less and less frequent. Limb salvage is made possible by the wide range of new prosthetic models now available and team work. The collaboration of different specialists, namely the microsurgeon, plastic surgeon, neurosurgeon, general surgeon, and vascular surgeon, alongside the orthopedic surgeon, has broaden the possibilities of conservative surgery through combined interventions of resection and grafting, transpositions of muscular, fascial, and cutaneous structures, arteriovenous bypasses, and nerve transplants [5].

5.3.3.1 Prosthetic Reconstruction

Prosthetic reconstructions can be classified into:

1. *Traditional Prostheses*: the regular prostheses commonly used in orthopedics to treat articular arthrosis or the after-effects of complex fractures. However, this type of prosthesis is rarely used, since bone neoplasia is generally already so extended at diagnosis that it requires wide resections, which do not allow such limited reconstructions [6].
2. *Modular Prostheses*: much more frequently used; prostheses of this kind are made of several components of different lengths that can be interlocked and assembled until the desired length is reached. If for example a 12 cm resection is needed, instruments allow to use several prosthetic cylinders of different lengths—1 cm, 2 cm, 4 cm, etc.—until the exact length of the resected bone is reached. Modern prostheses are made in titanium alloys and the surface in contact with soft parts is polished, while intramedullary stems have a rough surface to facilitate the active fixation by the recipient bone [6]. The diaphyseal component is connected to the articular epiphysis, which will come in contact with the opposite articular surface. Modern modular prostheses are meant to be used both

in cemented and uncemented implants (in the latter ones, the stem is polished). In the majority of cases, however, prostheses with uncemented stems are used, as they reduce complications in case of implant removal or revision. On the other hand, cemented prostheses are almost always indicated for reconstruction in metastases, where, due to shorter time for recovery and allowance of weight bearing, they allow to restart patients on specific oncological treatments earlier [6].

3. *Composite Prostheses*: a particular type of modular prostheses. A metallic prosthesis is inserted into a donor bone, then implanted into the operated bone. The advantage of this technique is that it allows to insert the periarticular soft parts and muscle tendons in the allograft structures, which considerably improves the early functional outcome [7]. These prostheses are most frequently used for the reconstruction of proximal tibia, humerus, and proximal femur. As to the shoulder, for patients with high functional needs, a particular composite prosthesis is now used: a reverse prosthesis. As is well known, the shoulder reverse prosthesis works on an “inversion” of the components of the articular surface: the socket is fixated to the humerus and the ball to the glena. In this prosthesis, the humeral stem is cemented into the donor bone and its articular surface has the shape of a glena, while the scapular articular surface is replaced with a glenosphere. This way, the joint can work both via the cuff muscles reinserted on the allograft cuff and via the deltoid, which allows abduction and flexion in reverse prostheses [7, 8].
4. *3D-Printed Prostheses*: tailor-made prostheses based on an individualized project for each patient. The surgeon identifies the edges of the tumor on the CT or MRI images and marks the resection lines on the bone. The images containing this information are sent to an engineer who uses a 3D printer to create a first model made from a plastic material that closely reproduces the shape and size of the bone to be removed. After a last check on the project by the surgeon, the final metallic prosthesis is made (generally from titanium), which will replace the affected bone. This method is especially used for pelvic tumors or in case of complex reconstructions, such as the short bones in the foot [9, 10].

5.3.3.2 Graft Reconstruction

First introduced by Mankin around the ‘70s, organ transplantation is now widespread in all countries, except those where it is forbidden for religious reasons [11]. Once the graft has been taken from the donor, it is transferred to and stored in “bone banks-,“dedicated hospitals, where it is sterilized, catalogued, and stored in a sterile environment at −80 °C. The surgeon who decides to reconstruct a segment with banked bone should first measure the recipient bone and compare its size with those available at the “bank” in order to adapt them to the site to be reconstructed [8, 10, 11]. Once the tumor has been resected, the graft is placed in the recipient site, and after all needed adjustments in length and shape, it is fixed to bone portions by plates and/or screws [11]. Osteoarticular grafts are defined as grafts of an articular component that include the cartilage shell and the cartilage of the corresponding metaepiphyseal region. In this case, one of the two articular components of the joint will only consist of one allograft: proximal humerus, distal radius, proximal tibia, or distal femur. Today, this type of reconstruction is almost exclusively used for the distal radius, particularly after a giant-cell tumor resection, which—as is known—accounts for the majority of tumors at this stage [12]. In this case, the allograft works quite well and has a long life span, since the radius does not bear excessive weight at the wrist level. In other sites, however, osteoarticular grafts are rarely used: after the initial enthusiasm for their excellent functional outcomes, later complications led to abandoning this type of reconstruction. As a matter of fact, the mechanical or torsional stresses borne by the shoulder, hip, and knee rapidly wear the cartilage surface and fragment the allograft until it gradually collapses, to be mostly reabsorbed by the epiphysis [12]. Grafts replacing intercalary diaphyseal resections are much more frequently used. In these cases, the resected diaphyseal cylinder is replaced by the allograft and fixed by plate and screws. In children and young adults, the allograft is combined with a vascularized fibula graft [10, 11]. This technique consists in inserting the autologous fibula (i.e., taken from the patient themselves) in the allograft, so that the arteriovenous pedicle protrudes out of the fibula from an opening into the cortical allograft. The arteriovenous pedicle is later connected to an artery and a vein from the surgical site with a termino-terminal anastomosis. This creates an implant made of an inert mechanical support (the allograft is a cadaver bone, i.e., lifeless) and of a vital bone fixed inside it. In time, as the fibula is nourished by the vascular pedicle, it tends to at least partially attach to the allograft and to hypertrophy, especially in younger patients [11]. The result is a more resistant structure that is more durable in time and may represent the final treatment. The vascular fibula may also be used alone without being connected to banked bone, especially in the upper limb. It is used, for example, in proximal humerus or distal radius replacements. For patients in the growth phase, in prepubertal children, it may be used by removing the proximal epiphysis with the corresponding vascular pedicle. This technique is called vascularized fibula augmentation graft, as the fibula includes the cartilage in proximal growth, and the bone will be able to lengthen and hypertrophy with highly satisfying aesthetical and functional outcomes [11, 12].

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Part II

Rehabilitation

Comprehensive Oncology Rehabilitation and Its Goals

6

Valentina Gariboldi, Maurizio Lopresti, and Lorenzo Panella

In the past few years, the new effectiveness of treatments targeting neoplastic diseases has resulted in the increased survival of oncology patients faced with two possible options: either to recover from the disease or to long live with it. The rising number of people having suffered from such diseases has opened new scenarios with multiple implications as to the needs related to the improvement of the quality of life, which was previously considered as secondary to the life-or-death possible outcome, but has now made the role of rehabilitation medicine crucial to the care of patients affected by neoplasia [1, 2].

The World Health Organization defines rehabilitation medicine as "*a set of interventions aimed at the development of a person to its fullest physical, psychological, social, vocational, and educational potential consistent with their physiological or anatomical impairment, and their environment.*" [3]. Therefore, oncology rehabilitation meets the demanding challenge of comprehensively caring for the person as a whole, as an individual with their own complexities [4].

While rehabilitation goals have been traditionally set and classified into prevention, reeducation, replacement, and palliative care, with a main focus on the physical sphere, the need has now risen to consider functional, social, and psychological

V. Gariboldi (✉)
Complex Operative Unit, Neurological, Sub-Intensive, Orthopedic-Vascular, General Geriatric Rehabilitation Unit, Department of Medicine and Rehabilitation, G. Salvini Hospital, Garbagnate Milanese, Italy
e-mail: vgariboldi@asst-rhodense.it

M. Lopresti
Physical Rehabilitation, Gaetano Pini – CTO Orthopedic Institute, Milan, Italy

L. Panella (✉)
Rehabilitation Department, Gaetano Pini – CTO Orthopedic Institute, Milano, Italy
e-mail: lorenzo.panella@asst-pini-cto.it

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implications too. The concept of quality of life, now broader than it was conceived in the past, covers physical as well as mental health [5].

In practice, therapists should consequently adjust their rehabilitation projects by adopting a relational approach based on inputs, feedbacks, communication, and willingness to listen in order to understand their patients' needs at best and enhance their compliance and trust.

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7 Team and Rehabilitation Team

Valentina Gariboldi, Maurizio Lopresti, and Lorenzo Panella

Planning an efficient rehabilitation program entails considering it from three different perspectives, namely: taking all aspects of a person's life into account, recognizing the individual as the core of the project, and ensuring continuity and coordinated interventions across all fields [1]. The wide, diversified range of possible interventions for the person's personal needs demands for several professionals to be involved, each of them at the appropriate stage of the disease and for specific issues.

According to the most recent evidence, a rehabilitation program can only be effective if implemented by a multidisciplinary team, defined as "a group of diverse clinicians who communicate with each other regularly about the care of a defined group of patients and participate in that care" [2, 3]. Effective team working produces better patient outcomes, including better survival rates, in a range of disorders [4].

For an optimal practice, the multidisciplinary team should promote a structured cooperation among all its members to achieve common goals, that is, the development of individualized therapeutic plans and the assessment and continuous monitoring of the processes undertaken to accomplish said goals [5–7].

The starting point for the multidisciplinary team's work is to identify the subject's rehabilitation needs, then to mutually share goals and results and communicate how

V. Gariboldi (✉)
Complex Operative Unit, Neurological, Sub-Intensive, Orthopedic-Vascular, General Geriatric Rehabilitation Unit, Department of Medicine and Rehabilitation, G. Salvini Hospital, Garbagnate Milanese, Italy
e-mail: vgariboldi@asst-rhodense.it

M. Lopresti
Physical Rehabilitation, Gaetano Pini – CTO Orthopedic Institute, Milan, Italy

L. Panella
Rehabilitation Department, Gaetano Pini – CTO Orthopedic Institute, Milano, Italy
e-mail: lorenzo.panella@asst-pini-cto.it

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these should be reached, while prioritizing the patient and their needs, the key rehabilitation players around which the multidisciplinary team revolves. It is absolutely critical for all team members involved in the patient's care to continuously communicate and coordinate with one another and with the patient's family, and for the rehabilitation therapist to be fully aware of the implications, in terms of how and to what extent their activities will be limited by the anatomical damage caused by the tumor and the treatments used against it. The rehabilitation therapist should also be willing to share their knowledge in order to build a relationship of mutual trust with their patient that allows for a smooth, sincere communication. Last, the team's work necessarily depends on monitoring the outcomes of the rehabilitation program; when consistent, this allows the team to continuously adjust their goals based on the patient's progression, so as to optimize their rehabilitation [3].

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Physiatric Evaluation

8

Valentina Gariboldi, Maurizio Lopresti, and Lorenzo Panella

Physiatric evaluation is a crucial moment to plan and manage a rehabilitative intervention. At this stage, the rehabilitation therapist in charge of oncology patients is called to accurately evaluate the anatomical and functional damage caused by the tumor and the therapies used to treat it, as well as all implications restricting the patient's activity and social participation. The therapist should also be able to outline a complete profile of the subject, so as to share a project that emphasizes their strengths and aims at improving their abilities and removing any environmental or personal factors that might be hindering their self-expression, thus promoting their social participation [1, 2] (see Tables 8.1 and 8.2).

A rehabilitation-oriented assessment has an interdisciplinary nature: a rehabilitation team is required both at the evaluation and the management stages. In order to understand the complex aspects that a person deals across the stages of the disease and all the related issues, multiple professionals must necessarily take part in the project [4].

The rehabilitation-oriented assessment of the patient should start from the symptoms reported by the patient themselves, and then include the present history of illness, the patient's functional history, past pathological history and family history, an

V. Gariboldi (✉)
Complex Operative Unit, Neurological, Sub-Intensive, Orthopedic-Vascular, General Geriatric Rehabilitation Unit, Department of Medicine and Rehabilitation, G. Salvini Hospital, Garbagnate Milanese, Italy
e-mail: vgariboldi@asst-rhodense.it

M. Lopresti
Physical Rehabilitation, Gaetano Pini – CTO Orthopedic Institute, Milan, Italy

L. Panella
Rehabilitation Department, Gaetano Pini – CTO Orthopedic Institute, Milano, Italy
e-mail: lorenzo.panella@asst-pini-cto.it

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Table 8.1 Proposal of body functions for a comprehensive functional evaluation of the person [3]

Body functions (Physiological functions of the body systems)
Energy and drive functions
Body image
Immunological system functions
Hematological system functions
Respiration functions
Digestive system functions
Sleep functions
Emotional functions
Perception of pain
Exercise tolerance
Protective functions of the skin
Urinary functions
Sexual functions
Functions related to joint mobility
Muscle strength

Table 8.2 Proposal of activity and participation for a comprehensive functional evaluation of the person [3]

Activity and participation (The subject's ability to carry out tasks and actions and to be involved in daily life situations)
Carrying out daily routine
Handling stress and other psychological demands
Maintaining a body position
Transferring oneself
Walking
Moving around
Moving around using equipment
Using transportation
Washing oneself
Caring for body parts
Toileting
Dressing
Eating
Looking after one's health
Doing housework
Assisting others
Basic interpersonal interactions
Intimate relationships
Remunerative employment
Recreation and leisure

accurate physical examination and an examination of the systems, a functional evaluation, and a patient profile [5].

In oncology, a functional rehabilitation-oriented assessment covers specific aspects related to the disease and the patient, and is carried out on two different levels:

1. Space. Addressing organ-specific issues related to the disease location and, if applicable, its spread:
   - Tissue damage (skin, muscles, bones)
   - Peripheral neurological damage (iatrogenic and/or tumor infiltration-related)
   - Circulatory damage (venous and lymphatic)
   - Locoregional pain
2. Time. Dynamic adjustment to the specific needs associated with the disease progression and to iatrogenic disorders:
   - Chemotherapy-related damage: peripheral neuropathies, cerebellar hemisyndrome, myopathies
   - Radiotherapy-related damage: fibrosis, skin and tissue retractions, algodystrophy, osteitis, osteoporosis, plexopathies and myelopathies, circulatory disorders
   - Metastasis
   - Fatigue, asthenia
   - Pain
   - Psychological disorders

As of now, the study of the specific determinants of life quality for patients affected by neoplasms has not led to the development of any measurement tool able to provide at once all the information on the patient's functional skills that are needed to outline their profile and determine the treatment effectiveness, so as to drive any changes might be necessary.

Conventional resources for a global function assessment of the person (Barthel Index, iADL e bADL [6, 7]) apply to populations affected by neoplasms with restrictions: the limitations already shown by these tools for the general population reduce their helpfulness and usability for the assessment of oncology patients.

The physical function section (PF-10) of the Medical Outcomes Study 36-Item Short Form Health Survey is an exception to the previously mentioned difficulties [8]. As a widely used tool, the PF-10 possesses normative data on the concerned populations and has been translated and validated in many languages. This scoring system is made of ten items, with each of them describing an activity. For every activity, three ordered levels are available, and describe difficulty to carry out said activity as the patient reported it.

The Karnofsky Performance Scale (KPS) [9] is widely used in oncology to assess the subject's overall performance and provides valuable information on the prognosis and the patient's ability to tolerate treatments. The KPS is an ordinal scale ranging from 0% (death) to 100% (normality, nondisorders, nonevidence of disease) by 10% steps. The scale scores are assigned by the physician according to their general impression of the patient's performance status during the examination, which does not require to question the patient directly. Although highly subjective, the KPS scores have proved prognostically valid and compliant with the patients' self-assessments in one-third of the cases. A score ranging from 70% (inability to care for oneself, carry out daily activities and work) to 40% (disability, qualified intervention required) suggests the need for a physiatrist's intervention.

The MTSS [10] is a tool that assesses functional damage in patients suffering from neoplastic diseases. The scale attributes a 0–5 score to each of the following six items: pain, carrying out ADL, emotional response, ability to use equipment, ability to walk, and gait alterations, and gives the final score in percentage. This tool has a low interobserver variability. A modified version exists for assessing upper limb function [4, 11].

The TESS evaluates specific disability in patients having undergone limb salvage surgery following neoplasia. The score assesses the overall functional outcome at the end of treatment and any need for healthcare support or changes to the environment. The TESS is a self-assessment survey made of 29 items, with scores ranging from 1—impossible to 5—no difficulties, related to the patient's experienced difficulty in carrying out ADL over the week that precedes the survey filling out. The final score is given in percentage. There are two existing TESS versions, one for the upper limb and one for the lower limb [12].

8.1 Fatigue

Out of all elements to be included in the functional evaluation of an oncology patient, a special mention should be reserved for fatigue.

Cancer-related fatigue—a subjective sense of physical and psychological tiredness, out of proportion to recent activity and interfering with the patient's regular function—differs from other types of fatigue as it cannot be relieved by sleep or rest. The underlying physiopathological mechanism depends on multiple factors; among them, some have suggested the suppression of the hypothalamus-pituitary-adrenal axis with a mild cortisol response [13], muscle alterations due to tumor necrosis factors,and anticancer treatments (radiations, chemotherapy, and glucocorticoids) [14].

Tools to evaluate fatigue are influenced by its subjective features and should include a review of the systems and medication in use in order to identify any reversible sources of fatigue, and tackle psychosocial factors, such as insomnia and depression. Guidelines by the National Comprehensive Cancer Network [15] strongly recommend using a numerical rating scale by verbally asking the patient to report the fatigue level that they experience. In addition, several specific measurement tools are available to assess fatigue, but there is not any universal consensus on their use: Brief Fatigue Inventory, Cancer Fatigue Scale, Fatigue Symptom

Inventory, Multidimensional Fatigue Inventory, Revised Piper Fatigue Scale and Revised Schwartz Cancer Fatigue Scale.

As far as rehabilitation is concerned, depending on the patient's general status and so far as possible, interventions should introduce training with progressive exercises against resistance and encourage a regular physical activity. Motor activity thus contributes to improve the physiological as well as the physical adaptation crucial to the patient's overall treatment.

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9 Rehabilitation Setting

Valentina Gariboldi, Maurizio Lopresti, and Lorenzo Panella

The rehabilitation project for patients affected by oncologic conditions can be carried out in two types of setting, either as inpatient rehabilitation or as outpatient rehabilitation. The choice of a setting that is suitable to the treatment project cannot exclude a functional evaluation and should consider the patient's overall function and the stage of the disease, so that it can dynamically adjust in time.

9.1 Inpatient Rehabilitation

Two factors influence the decision to opt for inpatient rehabilitation: the prognosis and the patient's tolerance to the rehabilitative treatment. Nevertheless, the low chance of long-term survival is not a contraindication to rehabilitation if a good therapeutic response is expected in terms of functional recovery (including the caregiver's education in case of patients with a terminal prognosis) [1].

In acute hospitalization, a rehabilitative treatment comprises two main phases, which differ for needs and care interventions: the preoperative rehabilitation phase and the postoperative rehabilitation phase.

V. Gariboldi (✉)
Complex Operative Unit, Neurological, Sub-Intensive, Orthopedic-Vascular, General Geriatric Rehabilitation Unit, Department of Medicine and Rehabilitation, G. Salvini Hospital, Garbagnate Milanese, Italy
e-mail: vgariboldi@asst-rhodense.it

M. Lopresti
Physical Rehabilitation, Gaetano Pini – CTO Orthopedic Institute, Milan, Italy

L. Panella
Rehabilitation Department, Gaetano Pini – CTO Orthopedic Institute, Milano, Italy
e-mail: lorenzo.panella@asst-pini-cto.it

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1. *Preoperative Phase*: In this phase, rehabilitation covers counseling and management with the purpose of evaluating and preventing any tertiary damage. The physiatrist should take care of assessing and planning interventions to guarantee the patient's proper mobility, meet their care needs, manage their cognitive status, communication and deglutition, provide them with the necessary prostheses and ortheses, and refer them to pain management services.

   At this stage, the major issues are related to the prolonged bed stay:

   - *Skin*: prevention of pressure sores. Considering that oncology patients often live in a cachectic state, it is necessary to change their positions in bed frequently, periodically check pressure points (occiput, sacrum, gluteus, heels, trochanters), provide them with antidecubitus equipment and mattresses, take extreme care of their personal hygiene, and massage pressure points daily.
   - *Musculoskeletal System*: Joints and muscles need to be preserved in order to prevent joint stiffness and muscle retractions; besides compromising future functional possibilities, any recurrent harmful habit might promote the arising of skin disorders. This may be prevented via active motion, if possible, or by passive motion, combined with muscle stretching and relaxing techniques [2, 3]. This articular and muscular prevention should be adjusted to the clinical conditions, particularly to any neuromotor deficits or to the onset of inflammatory syndromes (algoneurodystrophy).
   - *Osteopenia and Osteoporosis*: In case of prolonged immobilization in bed, controlled verticalizations may help to prevent bones from excessively weakening. If severe bone lesions and the related weakening are present, high caution should be exercised in motion and loading, which might be contraindicated at times. If the patient is at high-factor risk, the fragile bone may be protected with specific offloading braces or ortheses, which minimize risks related to verticalization.
   - *Cardiorespiratory System* [4, 5]: prevention of deconditioning and vascular complications. Deconditioning may be prevented by carrying out appropriate muscle exercises (active motion of the limbs). Vascular complications (phlebitis, pulmonary embolism) may be prevented too via mobilization, daily verticalization if possible, respiratory gymnastics, and the use of compression tools (compression stockings, elastic bandages, etc.).
   - *Urinary System*: prevention of recurring infections.
   - *Gastroenteric System*: prevention of intestinal stasis, regularization of the intestinal tract [6, 7].

     The physiatrist works within a multidisciplinary team with other specialists. Together, they should identify and provide the appropriate setting based on their care project for the person. This implies monitoring certain conditions, some of which iatrogenic, that negatively influence the patient's tolerance to the rehabilitative treatment: anemia, bone metastases, forms of electrolyte imbalance, temperature, bowel compression, and fluid accumulation.

2. *Outcome Phase*: Functional recovery may be achieved in two separate settings, either at a specialized rehabilitation unit or at an outpatient clinic.

   The physiatric evaluation of the impairments and the overall function via systemic, clinical instruments allows to define the rehabilitation goals and to identify the subject's care complexities in order to customize their treatment plan.

   Several scholarly studies have emphasized that neoplastic and non-neoplastic patients achieve comparable functional improvements, which substantially prove the effectiveness of inpatient rehabilitation treatments for patients affected by neoplastic conditions [8, 9].
3. *Terminal Phase of Life*: The caregiver should be educated so as to ensure a correct short-term management of the patient at home with hospice care support. At this stage, the team's goal is to improve the patient's quality of life and to maintain their maximum individual independence. Benefits from physical activity are increasingly recognized both in terms of increase in the chances of survival and decrease in impairment [10]. Particularly at this stage, the treatment of pain in all its forms (physical, psychical) and the psychological care of the patient are essential.

9.2 Outpatient Rehabilitation

1. *Outcome Phase*: Outpatient treatments address the management of specific problems affecting soft tissues, pain, mobility, and ADL. An outpatient clinical and functional monitoring of the patient may be needed, both when critical events occur (e.g., surgery) and over a long time span. Models for outpatient care are currently being thoroughly examined, especially as to survival treatment. The Institute of Medicine has recommended that, at the end of treatment, patients should receive a plan that summarizes treatments and anticipates future disorders, some of which might occur as late effects, for example, physical impairments, such as contractures and lymphoedema. Once again, noteworthy are the benefits of a regular physical activity.

Once treatment is over, it is advisable to build and supervise an exercise program for the patient to follow at home, to help them maintain the results achieved and promote a healthy lifestyle.

Since many bone tumors arise in childhood, rehabilitation should consider some specific aspects like the child's level of education, experience, and independence, as well as their relationship with the parents and the parents' ability to understand and support the young patients.

The clinical focus and structure of rehabilitation projects for patients having survived neoplastic conditions vary widely, but may be promptly accessed with the help of clinics or physiatrists specialized in treating these conditions.

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Rehabilitation Management Following Knee Replacement

10

Maurizio Lopresti, N. Ligabue, Valentina Gariboldi, and Lorenzo Panella

10.1 Joint Examination

The knee joint has 3 degrees of freedom [1]:

- Flexion and Extension: the main joint movement, occurring about the transverse axis in the sagittal plane.
- Rotation: only possible with the knee flexed, occurring about the vertical axis in the transverse plane.
- Lateral Translation: only possible with the knee flexed.

These movements serve two functions at once: ensuring stability in extension against the stress of body weight and allowing mobility in flexion to adjust to the ground surface. In addition to the shape of the bone extremities, joint stability is well known to be strongly influenced by the muscle-ligament system [2]. As a

M. Lopresti
Physical Rehabilitation, Gaetano Pini – CTO Orthopedic Institute, Milan, Italy

N. Ligabue
Complex Operative Unit, Physical Medicine and Rehabilitation, Physiatry and Rehabilitation Department, Gaetano Pini CTO Hospital, Milan, MI, Italy
e-mail: nicoletta.tagliabue@fastwebnet.it

V. Gariboldi (✉)
Complex Operative Unit, Neurological, Sub-Intensive, Orthopedic-Vascular, General Geriatric Rehabilitation Unit, Department of Medicine and Rehabilitation, G. Salvini Hospital, Garbagnate Milanese, Italy
e-mail: vgariboldi@asst-rhodense.it

L. Panella
Rehabilitation Department, Gaetano Pini – CTO Orthopedic Institute, Milano, Italy
e-mail: lorenzo.panella@asst-pini-cto.it

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consequence, the functional outcome of any surgical bone replacement also depends on the resection extent in terms of involved bone tissue and the adjacent soft tissues.

During a physical examination, the following parameters should be assessed:

- Skin: appearance of the surgical wound, formation of hematomas or edemas.
- Neurovascular system of the operated limb: absence of lesions.
- Posture: attitude of the lower limb when slightly flexed, guarding behaviors in the antalgic position.
- Lower limb length: presence of heterometries.
- Mobility of the knee, hip, and tibiotarsal joint: A reduction in ROM affecting all segments of the operated limb is frequently observed.
- Muscle trophism in the extensors and flexors (posterior and medial compartments).
- Static and dynamic efficiency of the agonist and antagonist muscles, as neuronal control systems are often disrupted by surgery.

10.2 Outcome Measures

The basic assessment of the condition should be combined with a physical examination by using assessment scales for measuring pain, joint insufficiency, and joint impairment, such as the VAS or NRS, the RMI or Knee Score, and the Barthel Index.

The Rivermead Mobility Index [3, 4] (RMI) is an assessment measure that examines the extent of the patient's mobility in carrying out ADL. The Lysholm knee scoring scale [5] combines a measure of the subject's function (walking, climbing up and down the stairs, needing equipment) with a separate measure of the knee function (pain level, ROM, muscle strength, ligament stability, alignment, flexion, defective contraction and extension).

Computerized gait analysis provides a quantitative evaluation of the gait parameters (see dedicated section).

10.3 Knee Megaprosthesis

A knee implant induces a decrease in the muscle strength and stability of the joint, and an alteration of gait.

There are a few differences depending on the tumor location and consequently on the joint extremity involved in the surgical resection:

- Distal Femur Resection: It generally entails the partial sacrifice of the vastus medialis and lateralis and the intermedial vastus, while the rectus femoris muscle is preserved. The partial resection of the quadriceps leads to an immobilization period that is necessary for the soft tissues to heal properly. When the extensor apparatus is preserved, functional recovery can be started early with positive outcomes.
- Proximal Tibia Resection: This type of resection entails the sacrifice of the popliteus muscle, plus part of the extensors and flexors. The patellar tendon is

detached from its distal insertion, which makes muscle transpositions necessary (medial gastrocnemius flap) in order to provide sufficient prosthetic coverage by healthy soft tissues, restore the continuity of the extensor system, and ensure that the patellar tendon is secured in the correct position by strengthening sutures on the transposed medial gastrocnemius muscle. After this type of surgery, an immobilization period is required, as well as the protection of the implant so as to observe the biological time frames needed for soft tissues to attach.

Once again, a rehabilitation project following the implant of a megaprosthesis after a wide surgical resection needs to be as personal and customized as possible, and to consider:

- The type of sarcoma and the site of the lesion
- The type of prosthesis implanted
- The type of surgery performed on muscles (which muscles were detached, reinserted, removed or transposed, presence or absence of the joint capsule, access site)
- The patient's general status
- The patient's age
- The patient's aptitudes
- Oncological treatments to follow (radiotherapy, chemotherapy)

10.4 Postoperative Rehabilitation Protocol [6]

The core elements of the rehabilitation project following a prosthetic implant for wide-knee resection are:

Long-term goals:

- Manage pain.
- Maintain clinical stability.
- Prevent complications.
- Restore maximum independence in ADL: achieve postural passages and transfers and walk with a correct gait pattern, while adhering to the surgeon's indications as to weight-bearing allowance.

Short-term goals:

- Educate the patient with postural hygiene.
- Restore full knee, hip, and tibiotarsal ROM in the operated limb.
- Restore muscle trophism and strength in the operated limb, trunk, and pelvis.
- Adjust to the prosthesis and restore proprioception.
- Restore standing and postural control in static, dynamic, and proactive standing.
- Restore walking with a correct gait pattern.

These goals should be progressively pursued and the patient's progression through the phases constantly monitored by the operators.

10.5 IRP for Prosthetic Implants Following Wide-Knee Resections: Distal Femur Resection

10.5.1 Phase 1

10.5.1.1 Setting: Acute Care

1.a

Timing: days 0–4 postsurgery.

Goals:

- Protect the implant.
- Prevent respiratory complications.
- Prevent venous and lymph stasis.
- Prevent the onset of patellar adhesions.

Interventions:

- Prolonged bed rest.
- Limb elevation. Implementation: patient lying supine with pillows or wedges under the involved lower limb. Ensure that the patient maintains the posture so as to promote the venous return of the leg and to restore the knee extension whenever insufficient. Special attention should be paid to prevent the patient from rotating the lower limb to assume an antalgic position with a slight flexion of the knee.
- Cryotherapy (application of ice for 20 min, three times per day).
- Use of an incentive spirometer. Goal: prevent complications.
- Self-assisted motion of the triceps surae. Implementation: the patient lying supine with the limbs extended on the table performs a plantar flexion and a dorsal flexion alternatively; this exercise can be performed by using bands of various resistance placed under the metatarsal heads and held in hand by the patient themselves.
- Active-assisted motion of the tibiotarsal joint. Goal: prevent venous and lymph stasis. Implementation: patient lying supine with the involved limb extended on the table. Ask them to perform tibiotarsal flexion and extension throughout the whole ROM (Figs. 10.1 and 10.2).
- Passive patellar motion. Goal: prevent adhesions. Implementation: patient lying supine with the lower limbs extended on the table. The operator stands next to the bed on the side of the involved limb and places their hands cranial and caudal to the patella, which can thus be moved in a craniocaudal direction; if, on the other hand, the operator places their fingers medial and lateral to the patella, this can be moved in a laterolateral direction or be tilted. Ensure that the patient is not in pain and that they do not interfere by contracting the quadriceps, which would prevent sliding, and thus compress the patella against the femoral condyles (Figs. 10.3, 10.4, and 10.5).

Figs. 10.1 and 10.2 Active-assisted motion of the tibiotarsal joint

Figs. 10.3–10.5 Passive patellar motion

- Continuous passive motion (CPM) of the knee at a minimum speed with few degrees of flexion. Goal: maintain ROM. Implementation: patient lying supine with the involved limb extended on the table. Standing next to the involved leg, the operator holds the hindfoot in the palm of the caudal hand, so that the patient's foot plant adheres to their own forearm with the cranial hand placed inside the popliteal fossa to control the movements of the knee: perform a triple flexion and return. Ensure that the patient does not actively interfere in the movement (Figs. 10.6, 10.7, 10.8, and 10.9).
- Maintain limb alignment in extension while keeping the hip in a neutral position.
- Educate the patient to independently maintain postures in bed in order to promote the knee flexion (e.g., prone posture with elevated bed head, supine posture with the bed flexed at the level of the knee).

Figs. 10.6–10.9 Continuous passive motion (CPM) of the knee

1.b

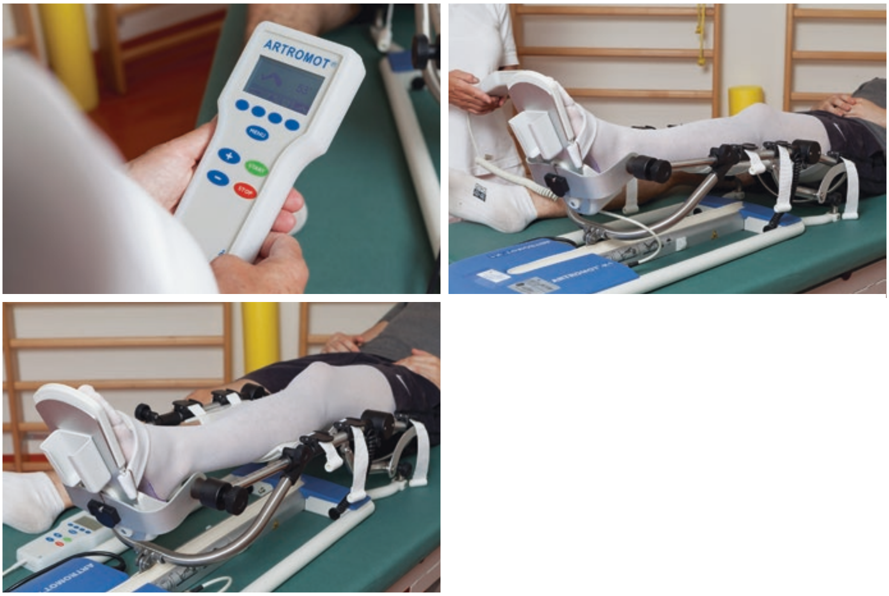
Timing: days 4–14 postsurgery.

Goals:

- Restore the knee ROM.
- Restore tone and trophism of the lower limb.
- Stand with assistance or supervision.
- Walk with the aid of a walker and with progressive weight bearing.

Interventions:

- CPM with hip flexion from 0° to 40–50° (as much as the painful symptoms allow). A Kinetec may also be used: adjust the joint flexion degrees before the session starts (Figs. 10.10, 10.11, and 10.12).
- Active-assisted knee motion (with the patient sitting and lying prone too). Goal: improve ROM. Implementation: patient lying supine with the limbs extended on the table; under the limbs, a wooden board allows for better sliding during motion. Ask the patient to actively flex the knee by using as much ROM as possible. Special attention should be paid to prevent the patient from making flexion or extension movements outside the physiological axis with consequent unwanted rotations (Figs. 10.13, 10.14, and 10.15).
- Strengthen the triceps surae via isometric and concentric contractions.



Figs. 10.10–10.12 Passive knee motion using Kinetic

Figs. 10.13–10.15 Active-assisted knee motion

- Progressively achieve standing. Goal: improve postural responses and control posture.
- Train walking with a walker and with progressive weight bearing (depending on the type of prosthesis). Goal: restore the gait pattern (Figs. 10.16, 10.17, 10.18, 10.19, 10.20, 10.21, 10.22, and 10.23).

Figs. 10.16–10.23 Gait training with walker

- Active-assisted strengthening of the quadriceps muscle. Warning: use isometric contraction exercises first, then move on to concentric contraction. Goal: strengthen the quadriceps and improve knee joint stability (Figs. 10.24 and 10.25).
- Simple SLR: patient lying supine with the lower limbs extended on the table. Ask the patient to flex the hip of the involved lower limb with the knee extended and the foot in dorsal flexion. Ensure that the knee is kept extended and that there are no uncontrolled rotations of the whole limb (Figs. 10.26 and 10.27).
- Facilitated SLR: patient lying supine with the involved lower limb extended on the table and the contralateral limb flexed with the foot placed at the level of the opposite knee. Ask the patient to flex the hip of the involved lower limb with the knee extended and the foot in dorsal flexion. Ensure that the knee is kept extended and that there are no uncontrolled rotations of the whole limb.
- Quadriceps contractions: patient sitting with the lower limbs hanging from the table. The operator sits next to the patient on a stool on the same side as the involved lower limb with their cranial hand placed cranial to the knee and their caudal hand under the calcaneus; ask the patient to extend their knee, while following the movement with the caudal hand. With the cranial hand, ensure that the quadriceps acts on the knee flexion, and not on the hip flexion (Fig. 10.28).

Figs. 10.24 and 10.25 Active-assisted strengthening of the quadriceps muscle

Figs. 10.26 and 10.27 Simple SLR

Fig. 10.28 Quadriceps contractions

Fig. 10.29 Extension posture with rolls

- Extension postures (with rolls progressively increasing in size). Goal: improve ROM. Implementation:
  - Patient lying supine on the table. Raise the heel by placing a pillow or wedge underneath it and let gravity extend the knee. Ensure that the patient is not keeping the knee semiflexed or fully rotating the lower limb (Fig. 10.29).
  - Patient sitting with the heel of the involved limb placed on a stool. A weight is placed on the knee, and the patient is positioned so that the weight and gravity extend the knee. Ensure that the patient is not keeping the knee semiflexed or fully rotating the lower limb.

Criteria to meet in order to move on to the next phase: good appearance of the surgical wound, good management of painful symptoms, and good ROM restoration with a 90° knee flexion.

10.5.2 Phase 2 (Intermediate)

10.5.2.1 Setting: Rehabilitation Unit

Timing: days 14–28 postsurgery.

Goals:

- Restore the knee ROM.
- Restore the tone and trophism of the lower limb.
- Walk with the aid of two forearm crutches.
- Improve the gait pattern.
- Plan exercises functional to discharge the patient home.

Interventions:

- Progressively increase the weight bearing within the muscle strengthening program.
  - Strengthen the quadriceps while sitting: patient sitting with the lower limbs hanging from the table. Ask the patient to extend the knee against the sole gravity resistance of the leg itself. Ensure that the motion is performed throughout the whole ROM and that it is continuous with no sudden movements.
  - Strengthen the extensors with a resistance band: patient sitting with the lower limbs hanging from the table. Tie a band to the involved ankle and secure it under the patient's seat. Ask the patient to extend their knee against the elastic resistance. Ensure that the resistance level of the band in use is ideal for the desired goal and that the movement is performed throughout the whole ROM (Figs. 10.30 and 10.31).
  - Strengthen the quadriceps with weights: patient lying supine on the table with a pillow under the popliteal fossa. Place a 1–2 kg weight on the ankle of the involved leg. Ask the patient to extend their knee and to subsequently pull it back. Ensure that the movement is controlled throughout the whole ROM (Figs. 10.32 and 10.33).

Figs. 10.30 and 10.31 Extensors strengthening with resistance band

Figs. 10.32 and 10.33 Quadriceps strengthening with weights

Fig. 10.34 SLR with weights

- – SLR with weights: patient lying supine with the lower limbs extended on the table. After placing a weight on the ankle of the involved lower limb, ask the patient to flex the hip of the involved lower limb with the knee extended and the foot in dorsal flexion. Ensure that the knee is kept extended and that there are no fully uncontrolled rotations of the limb (Fig. 10.34).
- – Squat: patient standing. Ask them to perform a half squat (that may also reach a full squat). Pay special attention to any uncontrolled deviations of the knee in the laterolateral plane [7] (Figs. 10.35, 10.36, and 10.37).

- Activation of the knee flexors (leg curl) with natural weight bearing. Goal: strengthen the flexors and the ischiocrural muscles. Please note: the knee should be flexed by bringing the heel to the gluteus; the movement should be slow and continuous. Ensure that the femur is not rotated throughout the whole ROM.
- To increase the exercise intensity, place some weight on the ankle of the involved limb.
- Static proprioceptive exercises. Goal: improve proprioception with no dynamic control (Figs. 10.38, 10.39, 10.40, 10.41, and 10.42).

Figs. 10.35–10.37 Squat

- Dynamic proprioceptive exercises with supported upper limbs. Goal: improve proprioception and postural stability. Patient standing on an instable surface, such as pillows, wobble boards, or mats, of different consistencies. Ask the patient to flex their knee by about 20° and to remain balanced while standing on one foot, then on two feet. The difficulty can later be increased by asking the patient to close their eyes. Special attention should be paid to any uncontrolled deviations of the knee in the laterolateral plane (Figs. 10.43, 10.44, 10.45, 10.46, and 10.47).
- Train the gait pattern between parallel bars. Goal: to resume walking in safe conditions. Implementation: ask the patient to walk between the bars by holding on to the handrail in order not to load the whole weight on the lower limbs; ensure that all phases of the gait cycle are performed correctly, without any kind of compensation (Figs. 10.48, 10.49, 10.50, and 10.51).
- Preparatory exercises to walking and walking with forearm crutches. Goal: restore the gait pattern. Implementation:
  - Walk with equipment: Walking equipment, such as a walker or crutches, allow to offload weight onto the ground without transferring it to the involved lower limb. A correct gait training will make it possible to reduce pain while walking and will promote a correct physiological pattern of neuromuscular activation (with walker: Figs. 10.52, 10.53, 10.54, 10.55, 10.56, 10.57, 10.58, 10.59, and 10.60) (with crutches: Figs. 10.61, 10.62, 10.63, 10.64, 10.65, and 10.66).
  - Walk forward and backward: patient standing. Ask the patient to walk for a few meters in a straight line, then to go back by walking backward, always in a straight line. Pay special attention to prevent the patient from performing uncontrolled knee movements and rotating the lower limb by loading it incorrectly.

Figs. 10.38–10.42 Examples of static proprioceptive exercises

Figs. 10.43–10.47 Examples of dynamic proprioceptive exercises

- Walk laterally: patient standing. Ask the patient to walk laterally for a few meters in a straight line, then to go back by walking in the opposite direction, always in a straight line. Pay special attention to prevent the patient from performing uncontrolled knee movements or rotating the lower limb, thus loading it incorrectly.

- Train stair climb and descent. Goal: improve independence in ADL and ensure a safe return home. Implementation:
  - Climb up steps: patient standing in front of a single- or double-height step. Ask the patient to climb up the steps while controlling the position of the knee throughout. Ensure that there are no uncontrolled laterolateral deviations.
  - Climb down steps: patient standing on a single- or double-height step. Ask the patient to climb down the steps while controlling the position of the knee throughout. Ensure that there are no uncontrolled laterolateral deviations.
  - Climb up and down the stairs: Ask the patient to climb up and down the stairs while holding on to the handrail so that lower limbs are not completely loaded. Ensure that all phases are performed correctly without any kind of compensation (Figs. 10.67, 10.68, 10.69, 10.70, 10.71, 10.72, 10.73, 10.74, and 10.75).
- Reeducate the patient to the other ADL.

Figs. 10.48–10.51 Gait training between parallel bars

Criteria to meet in order to move on to the next phase: stable general clinical status, good management of painful symptoms, healed surgical wounds, achieved ROM, checked and maintained between 0°–90°, and patient trained to perform exercises independently at home.

10.5.3 Phase 3 (Advanced)

10.5.3.1 Setting: Home-Based

Timing: after week 4 postsurgery.

Goals:

- Progressively improve the achieved locomotor and functional skills.
- Restore maximum independence in ADL.

Figs. 10.52–10.60 Preparatory exercises to walking (with walker)

Figs. 10.61–10.66 Walking with forearm crutches

Intervention:

- The patient may be discharged home.
- The rehabilitation plan is carried on at the outpatient clinic or with care support at home (with a frequency of three sessions per week at least).
- Introduce hydrokinesitherapy [8].

10.6 IRP for Prosthetic Implants Following Wide-Knee Resections: Proximal Tibia Resection

In the first 40 days after surgery, the knee should be immobilized in an articulated brace blocked in extension so as to allow the patellar tendon to scar at the new insertion site. This is a crucial step, as the tendon structure determines its ability to stand the strong traction forces that it is subject to during the functional use of the limb.

Figs. 10.67–10.71 Walking upstairs

During the first weeks following surgery, in order to allow the patient to be sufficiently independent in carrying out ADL, the physiotherapist will show them how to walk with touch weight-bearing on the operated knee. It is advisable to observe the required time frames in order to facilitate the scarring of the detached patellar tendon, subsequently reinserted into the megaprosthesis via supporting structures, on the transposed medial gastrocnemius. In order to improve the patient's perception and to promote weight bearing on the operated limb during gait training, the shoe worn by the contralateral limb may be raised (Fig. 10.76).

Figs. 10.72–10.75 Walking downstairs

Fig. 10.76 Raising of the contralateral shoe to promote weight bearing

10.6.1 Phase 1

10.6.1.1 Setting: Acute Care

1.a
Timing: days 0–4 postsurgery.
Goals:

- Protect the implant.
- Prevent respiratory complications.
- Prevent the venous and lymph stasis.
- Prevent the onset of patellar lesions.

Interventions:

- Extend the knee with the hip in a neutral position.
- Maintain the lower limb elevated.
- Self-assisted motion of the tibiotarsal joint.
- Passive motion of the patella.

1.b
Timing: days 4–7 postsurgery.
Goals:

- Strengthen the hip muscles. Implementation: patient lying on the side of the healthy limb. Abduct the hip while keeping the knee extended and the foot in dorsal flexion; pay special attention to ensure that the patient remains in axis without flexing or extending the hip. This exercise can also be performed with a flexed knee by abducting the hip and then by rotating it externally while keeping both feet in contact with each other.
- Restore standing.

Figs. 10.77–10.79 Operated knee immobilized in extension

- Walk with the operated limb in touch weight-bearing and with the aid of a walker.
- Control the load by using scales: this gives the operator a more accurate idea of the weight borne by the limb, and especially a visual feedback on weight-bearing allowance. Standard scales may be used by placing the foot of the healthy limb on the scales; the weight-bearing allowance can be accurately measured.

Interventions:

- Isometric strengthening of the hip extensors.
- Progressively verticalize the patient.
- Train locomotion with touch weight-bearing on the operated knee, which should be immobilized in extension (Figs. 10.77, 10.78, and 10.79).

Criteria to meet to move on to the next phase: good appearance of the surgical wounds, good management of painful symptoms, weight bearing progressively allowed on the basis of the surgeon's indications, and the types of prosthesis. Before moving on to the next rehabilitation phases, the patient should be educated and trained so that they can correctly manage the brace and adjust in order to be able care for themselves.

10.6.2 Phase 2 (Intermediate)

10.6.2.1 Setting: Rehabilitation Unit

Timing: weeks 2–6 postsurgery.

Goals:

- Start to restore the quadriceps strength.
- Restore independence in postural passages and transfers.
- Restore independence in ADL.
- Walk in touch weight-bearing on the operated limb and with the aid of two forearm crutches.
- Restore maximum independence in climbing and descending stairs.

Interventions:

- Low-intensity isometric activation of the femoral quadriceps, combined with a caudal contraction of the patella by the physiotherapist. This aims at preventing stresses on the new insertion site of the patellar tendon.
- Train walking with touch weight-bearing on the operated limb with the aid of two forearm crutches; the operated limb should be protected in extension.
- Educate the patient to perform postural passages and transfers and to carry out ADL with adjustments.
- Educate the patient to climb and descend stairs with the operated knee protected in extension.

Criteria to meet to move on the next phase: stable general clinical status, good management of painful symptoms, and healed surgical wounds. The patient should be educated and trained to carry on the planned exercises independently in safe conditions.

10.6.3 Phase 3 (Advanced)

10.6.3.1 Setting: Home-Based

Timing: after week 6 postsurgery.

Goals:

- Restore ROM with flexed knee.
- Restore the femoral quadriceps strength.
- Restore the knee flexor strength.

Interventions:

- Passive motion of the knee.

- Continuous passive motion (CPM), slow and progressive, of the operated limb knee.
- Careful active-assisted motion of the operated limb knee.
- Strengthen the femoral quadriceps with low-intensity muscular tension exercises.
- Strengthening. Goal: increase the joint stability in order to restore walking. Implementation:
  - Isometric ischiocrural contraction from a sitting position: patients sitting with their hips and knees flexed at 90° and feet not touching the floor. The operator sits in front of the patient and brings the involved lower limb to their thigh, then asks the patient to contract their ischiocrural muscles to press the heel on the operator's leg in order to obtain an isometric contraction of the ischiocrural muscles; with their cranial hand, the operator checks that the contraction is actually performed by the knee flexors, and not by other compensating muscle groups.
  - Concentric hamstring contraction from a prone position: patient lying prone. The operator stands next to the table on the same side as the operated limb, then places their cranial hand in the sacral region to stabilize the pelvis and the caudal hand in the calcaneal region. Flex the knee in order to produce enough resistance to make a concentric contraction happen; pay special attention to any compensating movements by the pelvis or unwanted contractions of the limb.
  - Eccentric hamstring contraction from a prone position: patient lying prone. The operator stands next to the table on the same side as the involved limb; flex the patient's knee, then place the cranial hand in the sacral region to stabilize the pelvis and the caudal hand in the calcaneal region. Ask the patient to resist the pressure applied to extend the knee. The patient must let the applied force "win" so that an eccentric contraction can happen; pay special attention to any compensating movements by the pelvis or unwanted rotations of the limb.
  - Eccentric hamstring contraction from a prone position against gravity: patient lying prone. The operator stands next to the table on the same side as the operated limb, and after flexing the patient's knee, the operator places their cranial hand in the sacral region to stabilize the pelvis. Subsequently, ask the patient to bring the knee back onto the table by slowing down the drop with an eccentric contraction of the ischiocrural muscles; pay special attention to ensure that the movement is not excessively slow or fast and to any compensating movements of the pelvis or unwanted rotations of the limb itself.

Starting from week 8 postsurgery:

- Walk with progressive weight bearing until full weight bearing is reached.
- Reintroduce the physiological gait pattern.

Interventions:

- Train walking with progressive weight bearing on the operated limb to gradually reach the full bearing.
- Correct the gait pattern in relation to the progressive joint and muscle restoration.

After allowing full weight bearing:
Goals:

- Improve the neuromotor control of the operated limb.
- Restore the maximum independence in ADL and discharge the patient home.

Interventions:

- Proprioceptive exercises even on destabilizing, irregular, or uneven surfaces.
- Hydrokinesitherapy.
- The patient may be discharged home.
- The rehabilitation program may be carried on at the outpatient clinic or with care support at home (with a frequency of three sessions per week at least).

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Rehabilitation Management Following Hip Replacement

11

Maurizio Lopresti, N. Ligabue, Valentina Gariboldi, and Lorenzo Panella

11.1 Joint Examination

The hip is the ball-and-socket proximal joint of the lower limb and has 3 degrees of freedom:

1. Transverse axis: horizontal, placed in a sagittal plane passing through the middle of the joint, about which flexion and extension occur.
2. Anteroposterior axis: horizontal, placed in a frontal plane passing through the middle of the joint, about which adduction and abduction occur.
3. Vertical axis: it virtually connects the femoral head to the middle of the malleoli; external and internal rotations occur about it.

During the physical examination, the following parameters should be assessed:

- Skin: appearance of the surgical wound, formation of hematomas or edemas.

M. Lopresti
Physical Rehabilitation, Gaetano Pini – CTO Orthopedic Institute, Milan, Italy

N. Ligabue
Complex Operative Unit, Physical Medicine and Rehabilitation, Physiatry and Rehabilitation Department, Gaetano Pini CTO Hospital, Milan, MI, Italy
e-mail: nicoletta.tagliabue@fastwebnet.it

V. Gariboldi (✉)
Complex Operative Unit, Neurological, Sub-Intensive, Orthopedic-Vascular, General Geriatric Rehabilitation Unit, Department of Medicine and Rehabilitation, G. Salvini Hospital, Garbagnate Milanese, Italy
e-mail: vgariboldi@asst-rhodense.it

L. Panella
Rehabilitation Department, Gaetano Pini – CTO Orthopedic Institute, Milano, Italy
e-mail: lorenzo.panella@asst-pini-cto.it

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- Neurovascular systems of the operated limb: absence of lesions.
- Posture: attitude of the lower limb in adduction, extra rotation and slight flexion, and guarding behaviors in the antalgic position to avoid the acute pain arising at every hint of motion.
- Lower limb length: presence of heterometries.
- Mobility of the knee, hip, and tibiotarsal joints: a decrease in ROM affecting all segments of the operated limb is frequently observed.
- Muscle trophism of the pelvic girdle, particularly of the gluteus medius and the femur quadriceps, and their antagonists.
- Static and kinetic efficiency of the agonist and antagonist muscles, as neural control system is constantly weakened by surgery.

Specific tests:

- Medius gluteus: Trendelenburg test. If positive, it indicates a drop of the nonsupported hip during walk due to weakness in the muscle.
- Iliopsoas: Thomas test. The patient lies supine on the examination table, so that when they flex the healthy hip, the back flattens on the table. If the contralateral hip tilts upward, a flexion deformity of the hip is identified (reduced muscle length).
- Sacroiliac joint: Patrick's test, also used to evaluate the hip. It tests the flexion, extension, abduction, and external rotation of the joint; the sacroiliac pain is elicited on the ipsilateral side, while the hip pain is elicited anteriorly on the femoral triangle.

11.2 Outcome Measures

The outcomes of the semeiological examination can be summed up and quantified via assessment scoring systems. The existing assessment scales include: the Harris Hip Score (HHS), the visual analogue scale (VAS), the short physical performance battery (SPPB), the SF-36, and the Barthel Index.

The *HSS* covers the domains of pain, function, range of motion, and deformity; it is used both in surgery and rehabilitation [1].

The *SPPB* is a tool for evaluating function that covers postural control, postural transfers, and a short-distance walk; the lower the score, the higher the risk of impairment [2].

The *VAS* is a reliable visual-analog scale, easy to apply and repeat that allows the patient to visually indicate the intensity of the pain they perceive on a segment [3].

11.3 Hip Megaprosthesis

Hip joint replacement implies: lower muscle strength, higher dislocation risk (this decreases for endoprostheses, which have dual mobility and their natural cotyle still in place), and gait alteration with lameness (Trendelenburg's sign).

The first factor conditioning recovery after replacement following wide hip resections is a tear of the gluteus muscles and their insertions. The gluteus muscles abduct and stabilize the joint and are reinserted during surgery by using tubular knit fabrics like Trevira.

The second factor impacting on rehabilitation is the structure of the rotation center and the lever arm (distance between the rotation center and the insertion of the muscles themselves, where the force vector acts), which determines the efficiency of the muscles, both in terms of thrust power to propel locomotion and of joint stabilization to reduce the risk of dislocation. An optimal structure is hard to achieve due to the massive resection of acetabular bone, despite the modular prostheses available.

A rehabilitation project following the implant of a megaprosthesis after wide surgical resection should be as personal and customized as possible, and consider:

- The type of sarcoma and the site of the lesion
- The type of prosthesis implanted
- The type of surgery performed on the muscles (which muscles were detached, reinserted, removed or transposed, presence or absence of the joint capsule, access site)
- Presence or absence of Trevira textile
- The patient's general status
- The patient's age
- The patient's aptitudes
- Oncological treatments to follow (radiotherapy, chemotherapy).

11.4 Postoperative Rehabilitation Protocol

Long-term goals:

- Manage pain.
- Maintain clinical stability.
- Prevent complications.
- Restore maximum independence in ADL: achieve postural passages and transfers and walk with a correct gait cycle while adhering to the surgeon's indications as to weight-bearing allowance.

Short- and medium-term goals:

- Educate the patient with postural hygiene.
- Restore full knee, hip, and tibiotarsal ROM in the operated limb.
- Restore muscle trophism and strength in the operated limb, trunk, and pelvis.
- Adjust to the prosthesis and restore proprioception.
- Restore standing and postural control in static and dynamic positions.
- Restore walking with a correct gait pattern.

11.5 Individual Rehabilitation Plan (IRP)

11.5.1 Phase 1

11.5.1.1 Setting: Surgery Unit

Timing: days 1–8/10 postsurgery.

After a prosthetic implant following wide resections, 8–10 days of bed stay are needed. The patient should maintain a supine position, with the limbs extended and slightly flexed and no rotation (Fig. 11.1 shows the correct position).

Goals:

- Manage pain with postural hygiene and pharmacotherapy.
- Develop a correct postural hygiene of the operated limb.
- Prevent complications arising from tertiary damage related to prolonged bed stay: pressure sores, venous or lymph damage due to stasis, respiratory disorders (bronchiectasis or lung atelectasis).
- Achieve isometric muscle activation of the femoral quadriceps and gluteus.

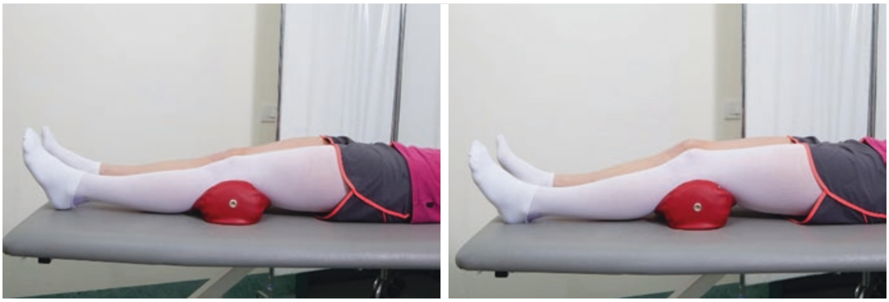
Compression tights are recommended to prevent the onset of circulatory disorders.

Interventions:

- Tibiotarsal flexion and extension. Goal: promote the venous and lymphatic return and prevent stasis-related disorders. Implementation: move the toes downward (as much as the immobilizer allows) and toward the patient themselves (Figs. 11.2 and 11.3).
- Quadriceps isometric contractions. Goal: reactivate muscles. Implementation: ask the patient to contract the quadriceps as if they were pressing something under the popliteal fossa. In order to promote the contraction of muscle fibers, a small wedge may be placed under the knee, such as a cylindrical pillow or a small, rolled-up towel. Ask the patient to keep the leg contracted for 5 s, then to

Fig. 11.1 Correct position of the limb by the use of an immobilizer

Figs. 11.2 and 11.3 Tibiotarsal flexion assuring limb's correct position with the immobilizer



Figs. 11.4 and 11.5 Quadriceps contractions

release for 10 s. Repeat ten times, and repeat the exercises several times throughout the day. Pay special attention to ensure that a selective contraction of the quadriceps occurs and that the gluteus is not compensating (Figs. 11.4 and 11.5).

- Gluteus isometric contractions (from day 4, as these muscles are involved in surgery). Goal: reactivate muscles. Implementation: ask the patient to contract their gluteus as if they had to hold back gas with their anal sphincter. Maintain the position for 5 s, then release for 10 s. Repeat ten times, and repeat the exercise several times throughout the day. Ensure that the patient is not emphasizing lumbar lordosis.
- Please note: The immobilizer limits movements that might compromise the implant stability.
- Breathing exercises. Goal: prevent tertiary damage due to immobilization. Implementation: show the patient how to breathe deeply with their diaphragm: stress that the abdomen needs to inflate when they inhale through their nose and to deflate when they exhale through their mouth. Peep and Coach systems may be used.
- Peep: Use a 1 L bottle containing 5–10 cm of water, and an 80 cm long rubber tube with a 1 cm diameter equipped with a mouthpiece. Show the patient how to exhale longer into the mouthpiece. Repeat for 4–5 times.
- Coach: Incentive spirometer.

Fig. 11.6 Active motion of the upper limb

In addition:

- Active motion of the healthy limb.
- Stretch the posterior muscles of the healthy limb.
- Active motion of the upper limbs (Fig. 11.6).

11.5.2 Phase 2

11.5.2.1 Setting: Rehabilitation Unit

Timing: from day 10 postsurgery.

Goal:

- Achieve a correct postural hygiene of the operated limb.
- Prevent complications arising from tertiary damage related to prolonged bed stay: pressure sores, venous or lymph damage due to stasis, respiratory disorders (bronchiectasis or lung atelectasis).
- Achieve isometric muscle activation of the femoral quadriceps and gluteus.
- Progressively restore independence in postural passages and transfers.
- Restore standing with supports.
- Start early gait training with the use of equipment.

Compression stockings are recommended to prevent the onset of circulatory disorders.

Interventions:

- Postural hygiene of the operated limb. Implementation: the immobilizer is gradually removed. The limb is placed in a Newport brace, and immobilized at a 0° flexion. The brace remains blocked at a 0° flexion until week 4 postsurgery, overnight too. The patient and/or caregiver are showed how to handle personal care and dressing. The brace may be worn over clothes as well. At this stage, special

Figs. 11.7 and 11.8 Positioning and blocking the Newport brace

attention should be paid to monitoring the skin function in the pressure points and preventing any pressure sores.

At this stage, hip flexion is not allowed yet, nor is sitting in a chair.

A pelvis cast may be used to avoid full hip rotations, which are poorly prevented by the hip brace (Figs. 11.7 and 11.8—the surgeon will advise on this after surgery).

With the patient lying on the table, postural hygiene maneuvers are performed. Goal: prevent any tertiary complications. The ROM is maintained via the early motion of the knee of the operated limb. At the gym, with the therapist's assistance, the knee is moved outside the table, with the hip extended (Fig. 11.9).

- Bed leave. Goal: vary postures and prevent tertiary complications. Implementation (Fig. 11.10): In order to guarantee the correct postural hygiene of the operated hip, the patient should directly pass from lying supine to standing, with the hip brace blocked at 0° (Figs. 11.11, 11.12, 11.13, and 11.14). Get out of bed from the side of the operated knee. The limb is supported by an operator and all rotations should be avoided, as the brace poorly controls them. The patient is transferred from the bed to the recliner—a wheelchair that allows to adjust the angle between the seat and the seatback until almost 180°—so that the patient may hold a position similar to lying down (Fig. 11.10).
- Restore standing and train walking. Goal: improve independence in ADL, postural transfers and independent transfers, and restore independence in transfers. At this stage, equipment may be used to increase the patient's postural stability during walk: a walker with underarm/forearm supports, four-point gait/two wheels, two-point gait/two forearm crutches (Figs. 11.15 and 11.16).

11.5.3 Phase 3

11.5.3.1 Setting: Rehabilitation Unit

Timing: from day 21 postsurgery.

Goals:

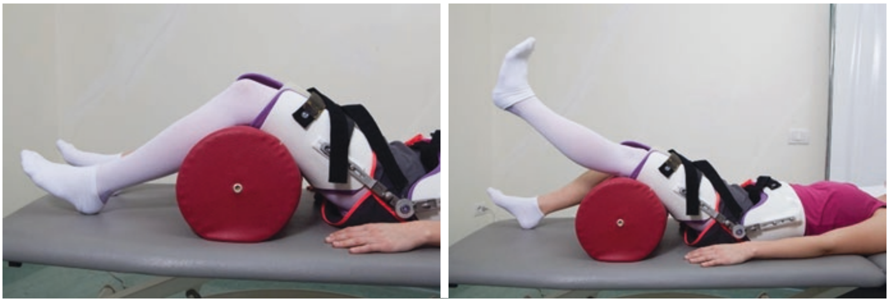
- Strengthen the previously restored abilities in postural transfers and transfers.

Fig. 11.9 Knee motion

Fig. 11.10 Recliner wheelchair with reclining seatback

Figs. 11.11–11.14 Sequence of a direct passage from lying supine to standing

Figs. 11.15 and 11.16 Restore standing (left) and postural training with walker (right)



Figs. 11.17 and 11.18 Quadriceps concentric contraction-operated side

- Strengthen the muscles of the operated lower limb, with particular attention to the femoral quadriceps.
- Introduce preparatory exercises to walk with a three-phase gait pattern.

Interventions:

- Achieve isometric contractions of the quadriceps on the operated side.
- Achieve concentric contraction of the quadriceps on the operated side: flexion and extension of the knee (Figs. 11.17 and 11.18).
- Reeducate locomotion with suitable equipment (walker or crutches) in three steps: push the aid forward, advance the operated limb, and advance the healthy limb so that it is in line with the operated limb (see Fig. 11.19).
- The advancement of the operated limb is initially compensated by swinging the trunk in the sagittal plane so as to avoid flexion and extension of the hip. If the patient finds it hard to swing the operated limb, a contralateral support may be used.
- Weight bearing is always set by the surgeon based on the type of prosthesis used, and it may be: touch weight-bearing (around 10 Kg), partial weight-bearing (20/25 kg), tolerable weight-bearing (based on the pain intensity), or full weight-bearing (usually not earlier than weeks 8–10 postsurgery).

11.5.4 Phase 4

11.5.4.1 Setting: Rehabilitation Unit

Timing: weeks 5–7 postsurgery.

Starting from week 5 postsurgery, the brace is released: for the first 3–4 days from 40° to 90°, then progressively for 7–10 days, to gradually restore the ROM.

Goals:

- Strengthen the previously restored skills.
- Maintain ROM and muscle tone of the healthy limb.

Fig. 11.19 (**a**–**d**) Three-phase gait pattern (clockwise)

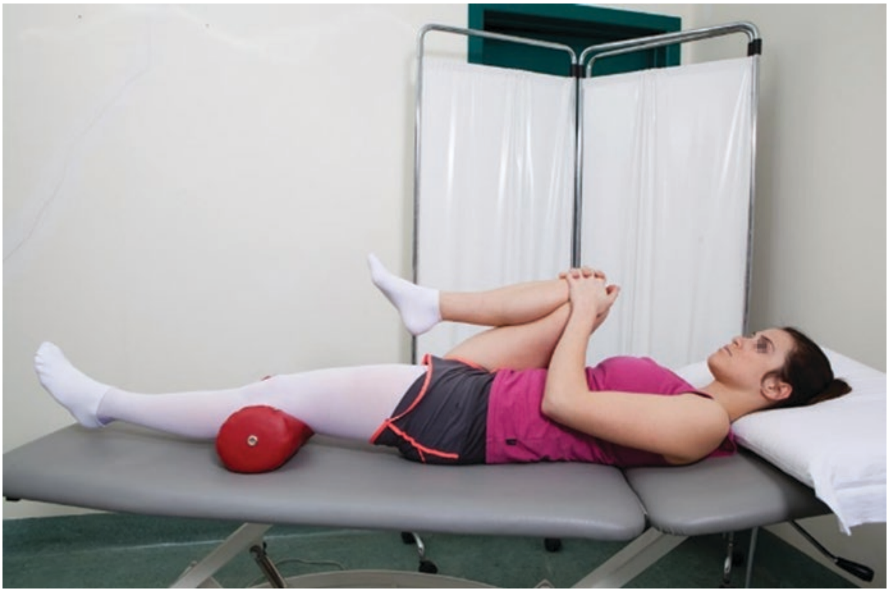


Fig. 11.20 Thompson maneuver

- Gradually recover the ROM of the hip and the operated knee.
- Strengthen the operated limb.
- Progressively improve independence in ADL.

Interventions:

During the rehabilitation session, the brace is removed so that hip flexion, and after a few days hip abduction, can be slowly, progressively restored.

Exercises should be performed slowly while controlling the execution of the movements.

- Strengthen and stretch the healthy limb muscles.
- Strengthen the flexors and extensors of the operated hip: hip flexion and extension on the table, first active-assisted, then active.
- Thompson maneuver (Fig. 11.20): restore hip extension on the operated side. Bring the healthy limb to the chest and simultaneously contract the quadriceps of the operated limb.
- Strengthen adductors and abductors (Fig. 11.21): mobilize the limb in adduction and abduction with hip and knee extended. Place a board under the heel to eliminate friction. Perform active-assisted motion first, then active motion. At an advanced stage, strengthening exercises may be carried out by applying weight (1–2 kg) to the ankles.
- Train gait. Progressively decrease the stance width during standing and walking, and gradually replace the walker with two forearm crutches.

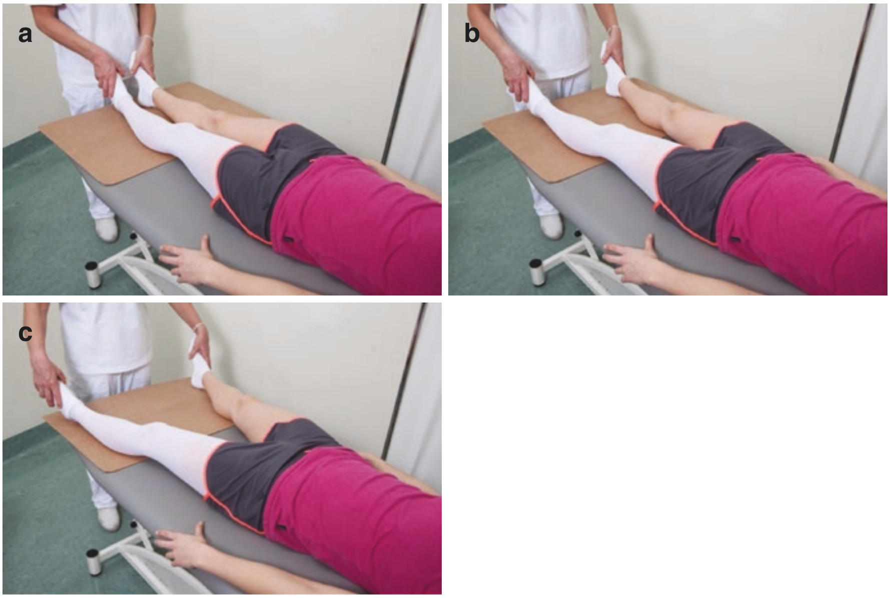


Fig. 11.21 (**a**–**c**) Strengthen hip adductors and abductors on the table

- Train stair climbing as per the following scheme:
  - Climb: place the healthy limb on the upper step, then the crutches, and last the operated limb (Figs. 11.22a–f)
  - Descent (Fig. 11.23a, b): place the crutches on the step to reach, then the operated limb, and last the healthy limb
- Train ADL: the patient may start sitting on the bed or in the wheelchair to eat, and using the toilet with a toilet seat riser, first under the physiotherapist and trained operators' supervision, then by reducing supervision and training the caregiver to perform the maneuvers correctly.

11.5.5 Phase 5

11.5.5.1 Setting: Hospital- or Home-Based

Timing: from week 8 postsurgery.

As per the rehabilitation plan, the brace should now be removed. A progressive removal is recommended, which should have already started in the previous phases, during physiokinesitherapy and under the physiotherapist's supervision, and should be carried on in this phase. Ultimately, the brace may be removed during sleep. In outdoor settings and on uneven surfaces, it is advisable to keep the brace on for better protection.

Upon removal of the brace, provided that the surgical wound status allows, it is possible to start the patient on hydrokinesitherapy exercises. The patient should be able to walk confidently and to climb the stairs with the aid of two forearm crutches (minimum requirements to access the pools).

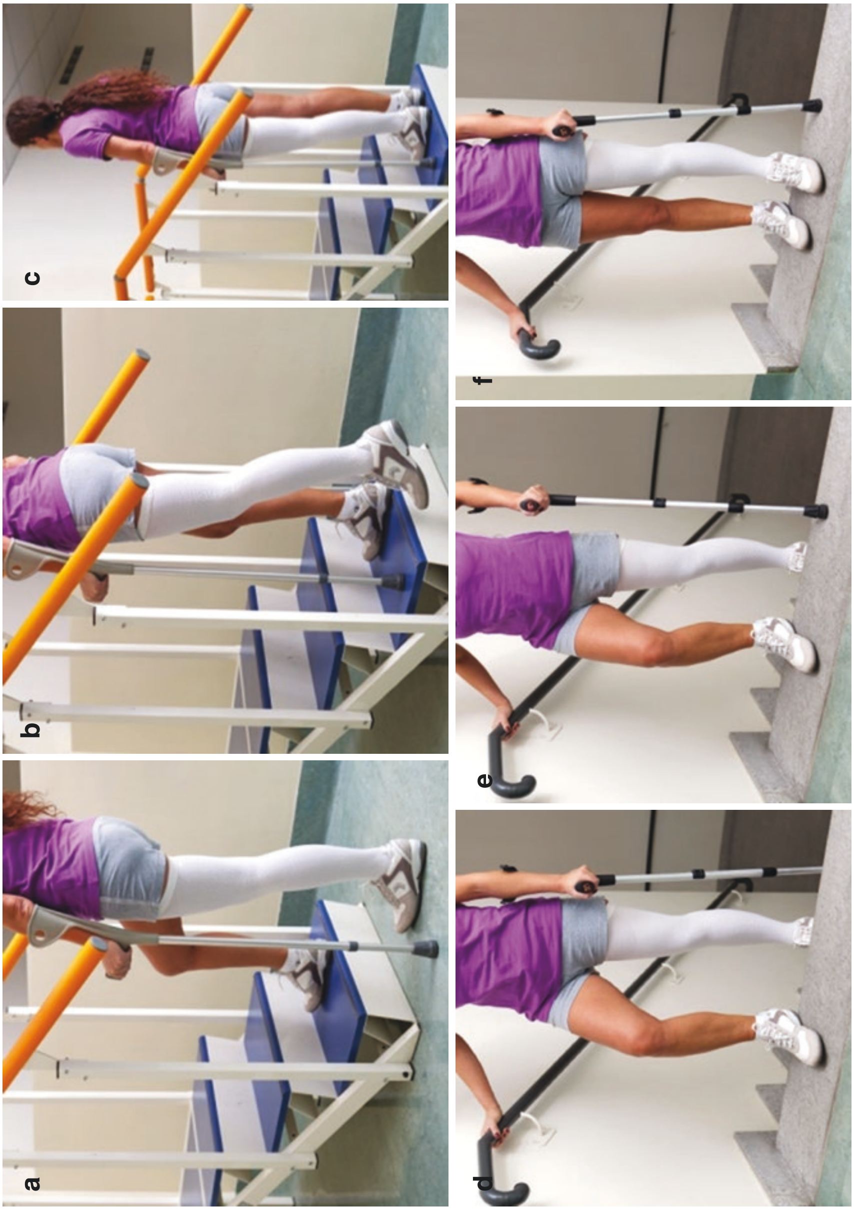


Fig. 11.22 (a–f) Climb up a step

Fig. 11.23 (**a**, **b**) Climb down a step

Fig. 11.24 Do not flex the hip over 90°

11.6 Notes

Full Weight-Bearing: Full weight-bearing is usually reached within 8–10 weeks of postsurgery. The use of equipment (forearm crutches) may be recommended for longer periods, depending on the joint stability.

Contraindications and Complications: Movements to be avoided are the same as for traditional hip implants, except for specific indications related to any loss of muscle mass, which should be evaluated case by case. The clinical course may significantly vary, should the patient be receiving radiotherapy or chemotherapy.

Movements and Postures to Avoid in order to Prevent Dislocation: Hip flexion over 90°, hip rotations (see Fig. 11.24, 11.25, 11.26, 11.27, 11.28, and 11.29).

Fig. 11.25 Do not pick up objects from the ground

Fig. 11.26 Do not rotate the trunk on the hip

Fig. 11.27 Do not tie shoes

Fig. 11.28 Do not cross legs

Fig. 11.29 Do not reach for blankets at the bottom of the bed

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12 Rehabilitation Management Following Shoulder Replacement

Valentina Gariboldi, Maurizio Lopresti,
and Lorenzo Panella

12.1 Joint Examination [1]

The shoulder connects the upper limb of the human body (the arm) to the trunk via a girdle made up of the scapula, the clavicle, and the humerus. The main function of the shoulder is to locate the hand in space in order to perform activities of daily living.

The shoulder complex is made up of several joints that are mechanically coordinated and can be grouped in two categories:

- The glenohumeral joint, covered by the deltoid muscle and stabilized by four ligaments: the three bands of the glenohumeral ligament (superior, middle, and inferior ligaments) and the coracohumeral ligament, comprising the joint capsule.
- The scapulothoracic, sternoclavicular, and acromioclavicular joints.

The shoulder has 6 degrees of freedom (three rotations and three translations), and thus allows a wide range of motion to the arm:

- *Flexion and Extension*: these movements occur about the frontal axis passing through the humeral head. The range of motion for flexion is 180°, whereas the range of motion for extension is 45–50°.

V. Gariboldi (✉)
Complex Operative Unit, Neurological, Sub-Intensive, Orthopedic-Vascular, General Geriatric Rehabilitation Unit, Department of Medicine and Rehabilitation, G. Salvini Hospital, Garbagnate Milanese, Italy
e-mail: vgariboldi@asst-rhodense.it

M. Lopresti
Physical Rehabilitation, Gaetano Pini – CTO Orthopedic Institute, Milan, Italy

L. Panella
Rehabilitation Department, Gaetano Pini – CTO Orthopedic Institute, Milano, Italy
e-mail: lorenzo.panella@asst-pini-cto.it

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- *Abduction and Adduction*: these movements occur about the sagittal axis passing through the humeral head. Adduction in the frontal plane, mechanically prevented by the trunk, occurs with a partial flexion or extension (the adduction range of motion during flexion can reach 40–45°). Abduction is the movement of the upper limb away from the trunk, and consists of four parts: an abduction from 0° to 90° controlled by the glenohumeral joint, limited by the contact of the humeral lesser tubercle with the glenoid labrum; an abduction from 90° to 180° controlled by the scapulothoracic joint, as the scapula glides and rotates along the chest wall.
- *Rotations*: these movements occur about the longitudinal axis; the range of motion for external rotations is 80°, whereas the range of motion for internal rotations is 100–110°.

The combination of these movements allows the arm to circumduct around the three axes of movement.

Shoulder stability is achieved by an interplay of structures, some of which have a dynamic role during movement: the insertion tendons of the supraspinatus, infraspinatus, teres minor, and subscapularis muscles that adhere to the surface of the capsule. Specifically:

- The deltoid acts to abduct the humerus up to 90° and allows internal and external rotations.
- The supraspinatus and infraspinatus muscles contribute to the external rotation of the arm, with the supraspinatus muscle also being involved in abductions.
- The subscapularis allows adductions and internal rotations.

Circumduction combines the previous movements around the three axes.

During the physical examination, the following elements should be assessed:

- Skin: appearance of the surgical wound, formation of hematomas or edemas.
- Neurovascular system of the operated limb: absence of lesions.
- Posture: attitude assumed by the upper limb.
- Mobility of the shoulder joint, as well as the elbow and the wrist: a decrease in the ROM of all segments of the operated limb is frequently observed.
- Muscle trophism of the stabilizer muscles.
- Static and dynamic efficiency of the muscles that contribute to and control the movements about the different axes, as neuronal control systems are usually disrupted by surgery.

12.2 Outcome Measures

Alongside functional outcome global measures (Barthel Index) and pain assessment (VAS o NRS), the joint function should be evaluated too. Functional outcomes are examined at three different timings (start of treatment, end of treatment, follow-up checkup) via internationally validated scales specific for the shoulder joint.

The constant shoulder score assesses the limb function after the treatment of shoulder conditions. It investigates various parameters that define the pain intensity and the impairment level in carrying out ADL: pain (0–15 points), ADL (0–20 points), ROM in forward elevation, abduction, internal rotation and external rotation of the shoulder (0–40 points), and strength (25 points). The higher the score, the higher the quality of the function.

12.3 Postoperative Rehabilitation Protocol

The rehabilitation program following replacement after wide resections of the humerus aims at achieving the following core goals:

- Manage pain and inflammation.
- Restore ROM.
- Restore muscle strength.
- Retrain proprioception.
- Restore neural control of locomotion.
- Achieve functional independence by restoring the use of the limb in ADL.

These goals should be progressively pursued while constantly monitoring the patient and their clinical course.

The primary goal is to return the patient having undergone this type of surgery to as much independence as possible before they leave hospital. In fact, contrary to the majority of postoperative patients, these patients are rarely referred to postacute care rehabilitation units, as they are most often discharged home to be started on radiotherapy or chemotherapy cycles.

Functional recovery is often impaired by the prolonged radiotherapy and chemotherapy cycles administered to these patients. Radiotherapy, in particular, may induce a decrease in ROM, an increase in the edema of the operated limb, and a decrease in muscle strength, whereas chemotherapy generally causes chronic weakness and fatigue, with a consequent decrease in muscle strength and resistance to effort.

Rehabilitation following replacement after wide resections of the humerus should be started early, so as to restore the patient to the highest possible level of function and to return them to their social environment at best while preventing the onset of incapacitating pain and the inability to use the limb in ADL.

Rehabilitation settings are standard inpatient admission, major outpatient services for complex care needs, and outpatient care.

The rehabilitation program includes physiotherapy and hydrokinesitherapy sessions in a rehabilitation pool.

12.4 Individual Rehabilitation Plan (IRP)

In the early postoperative phase, brace immobilization is needed (for approximately 40 days) in order to ensure that the implant is protected and soft tissues are attached to it. After this first period, the actual rehabilitation begins [2–4].

12.4.1 Phase 1

12.4.1.1 Setting: Surgery Unit and Home-Based

Timing: days 1–21 postsurgery.

In this first phase, the limb is immobilized in adduction, international rotation, and elbow flexion in an arm immobilizer.

Rehabilitation focuses on educating the patient and managing pain. Passive motion should carefully be started in order to prevent any adhesions, limit the edema, and restore shoulder mobility (Fig. 12.1).

In this phase, straightforward communication with the surgeon is essential, as immobilization timing and the imposed limitations to the ROM depend on the surgical technique used too (access site, detached muscles, complexity of the prosthetic implant).

Goals:

- Manage pain and inflammation.
- Prevent complications due to immobilization.
- Educate the patient.

Interventions:

- Use analgesic and anti-inflammatory medication as prescribed by the doctor.
- Use cryotherapy, especially after exercising.

Fig. 12.1 Immobilization of the shoulder with an arm immobilizer

Figs. 12.2 and 12.3 Prevention of complications due to immobilization of the operated limb

- Maintain good ROM and muscle tone of the healthy limb and of the uninvolved joints of the operated limb (Figs. 12.2 and 12.3).

12.4.2 Phase 2

12.4.2.1 Setting: Hospital-Based Outpatient Care at Rehabilitation Unit

Timing: week 3 postsurgery.

Goals:

- Manage pain.
- Restore joint mobility and scapulohumeral rhythm within the safety limits indicated by the surgeon.
- Treat the scar.
- Maintain a good ROM and muscle tone of the healthy limb and of the uninvolved joints of the operated limb.

Interventions:

- Passive and active-assisted motion of the operated limb within the pain threshold in elevation and abduction, with the patient lying supine and the humerus well centered in the glenoid fossa (Figs. 12.4 and 12.5).
- Passive and active-assisted motion of the operated limb within the pain threshold in elevation and abduction with the patient sitting in order to restore the right posterior gliding of the humerus during movement (concave-convex rule).
- Restore the correct scapulohumeral rhythm to avoid compensation or the early activation of the scapulothoracic joint. It is crucial to restore the strength-length ratio of the serratus anterior and the lower trapezius via scapular control exercises to be performed while standing or in quadrupedia, where the manipulation of the scapula by the physiotherapist enhances proprioceptive inputs and facilitates the correct movement.

Figs. 12.4 and 12.5 Passive motion to maintain the shoulder ROM

Figs. 12.6 and 12.7 Active motion from a sitting position

- Exercise to maintain the posture (following the physiotherapist's corrections).
- Treat the scar.
- Introduce exercises for overall muscle strengthening and postural control improvement (Figs. 12.6, 12.7, 12.8, 12.9, 12.10, 12.11, and 12.12).

Figs. 12.8–12.12 Exercises to restore the correct scapulohumeral rhythm: active-assisted, active

12.4.3 Phase 3

12.4.3.1 Setting: Hospital-Based Outpatient Care at Rehabilitation Unit

Timing: weeks 4–5 after surgery.

Goals:

- Strengthen the previously restored abilities.
- Maintain good ROM and muscle tone of the healthy limb.
- Increase the ROM of the operated shoulder.
- Reeducate the patient to use the limb in ADL.

Interventions:

- Restore muscle strength, initially via isometric contraction exercises for the various shoulder muscle groups, with the patient lying supine, sitting, or standing. Later, move on to concentric contraction exercises, first without gravity, then against gravity with the patient sitting on the floor. Last, integrate eccentric contraction exercises.
- Lengthen the various muscle groups with stretching exercises.
- Restore the physiological swinging of the upper limbs during walk and implement plyometric exercises with a ball to improve dexterity.
- Reeducate the patient to use the limb in ADL by planning organizational strategies, suggesting suitable changes to the home environment, and training them to use equipment that makes them independent in functional activities.
- Keep on treating the scar.
- Introduce exercise for overall muscle strengthening and postural control (Figs. 12.13, 12.14, 12.15, 12.16, 12.17, 12.18, 12.19, 12.20, 12.21, 12.22, 12.23, 12.24, 12.25, and 12.26).

12.4.4 Phase 4

12.4.4.1 Setting: Hospital-Based Outpatient Care at Rehabilitation Unit

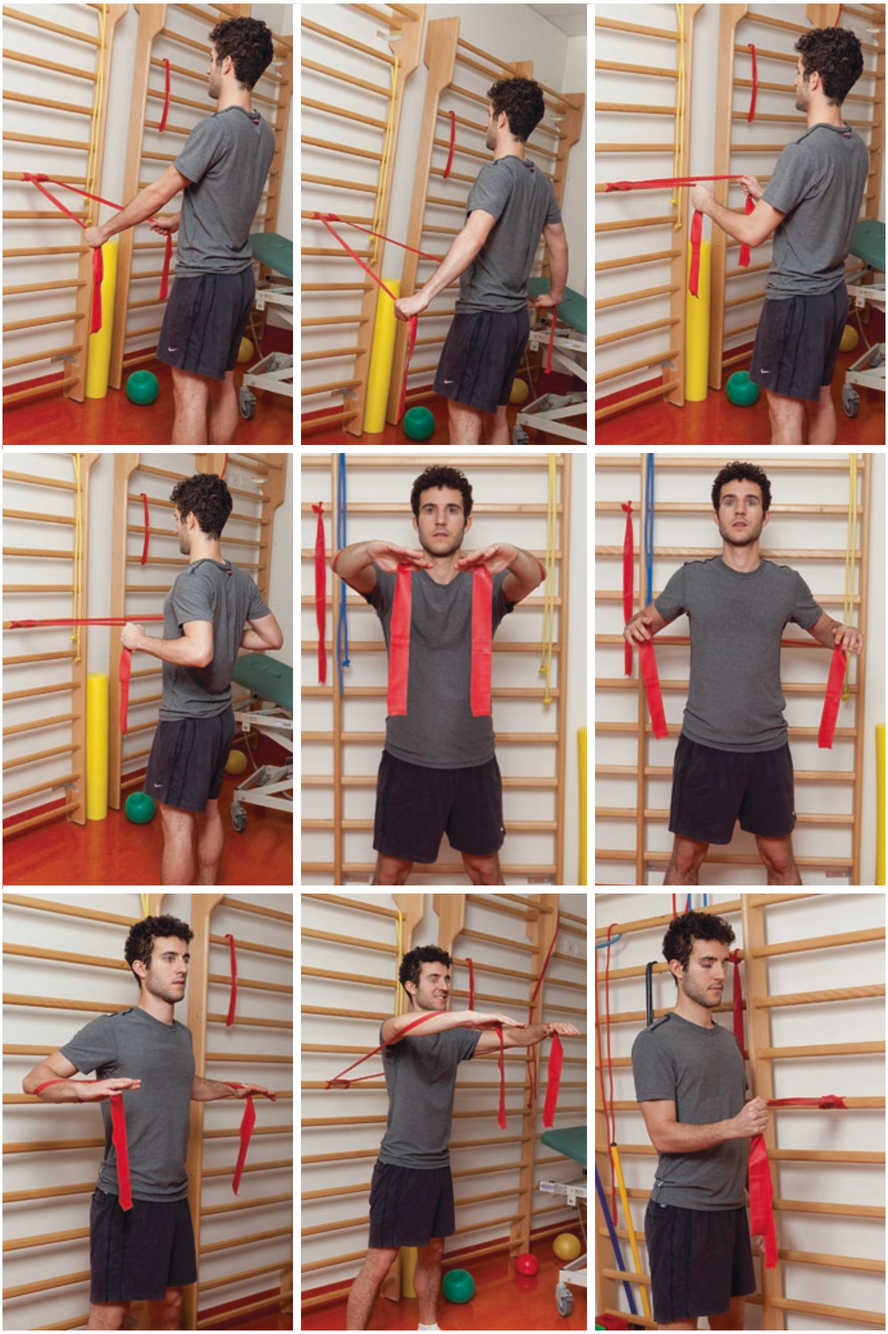
Timing: weeks 6–7 postsurgery.

Goals:

- Strengthen the previously restored abilities.
- Maintain good ROM and muscle tone of the healthy limb.
- Increase the ROM of the operated shoulder.
- Strengthen muscles in the operated limb.
- Develop neuromuscular control and proprioceptive abilities.
- Train ADL.

Interventions:

- Carry on all interventions listed in the previous phases.
- Plan an exercise program that the patient will independently follow at home.
- Adjust work and recreational activities that heavily engage and impact on the shoulder joint in order to preserve the glenohumeral joint from excessive forces that might lead to dislocation or early wear of the prosthetic implant.



Figs. 12.13–12.24 Sample muscle strengthening exercises with elastic resistance

Fig. 12.13–12.24 (continued)

Figs. 12.25 and 12.26 Stretching exercises

12.4.5 Phase 5

12.4.5.1 Setting: Home-Based

Timing: starting from week 8 postsurgery.

Goals:

Maintain, strengthen, and progressively improve the locomotor and functional skills restored during rehabilitation.

Interventions:

- Carry on home-based exercises: muscle strengthening exercises (especially for the rotator cuff), proprioceptive exercises to improve the execution of fine movements, and self-stretching.
- Fully return the patient to their work and recreational activities, as much as the progression of their condition and their age allow.

12.5 Hydrokinesitherapy [5]

Hydrokinesitherapy sessions integrate traditional physiokinesitherapy and may be implemented starting from week 3 postsurgery, once the immobilizer has been removed.

For hydrokinesitherapy to be introduced, it is necessary that the surgical wound is fully healed and that there are no contraindications to the patient being in the water.

Prior to the start of treatment, an assessment of the patients' swimming skills, adaptation to water stimuli and hydrostatic thrust is carried out.

Later, the patient is trained to attain the starting positions: standing, sitting, lying supine (supine floating), and lying prone (prone floating). Once the patient has mastered these positions, exercises are introduced depending on the rehabilitation stage and the previously described related goals for traditional physiokinesitherapy.

The first part of each sessions focuses on practicing walking at different gaits and in different directions, with the upper limbs swinging in order to restore the correct counter rotation of the girdles.

The middle part of the sessions focuses on reaching treatment goals by taking advantage of the benefits of water (a temperature of 33 °C and buoyancy) that promote the relaxation of the muscles and the periarticular structures, thus allowing a wider ROM in absence of pain, while the liquid resistance provides stress-free strengthening. Moreover, on a psychological level, exercising in water often helps patients to regain confidence in their abilities and recovery potential, as it gives immediate benefits in terms of pain relief and allows them to use the operated limb in several activities right from the start.

The last part of the session focuses on aerobic exercises for cardiovascular adaptation (e.g., stationary bicycle or water running) that help patients to keep the correct posture and stabilize the shoulder joint at the same time.

12.5.1 Phase 1

12.5.1.1 Setting: Hospital-Based Outpatient Care at Rehabilitation Unit

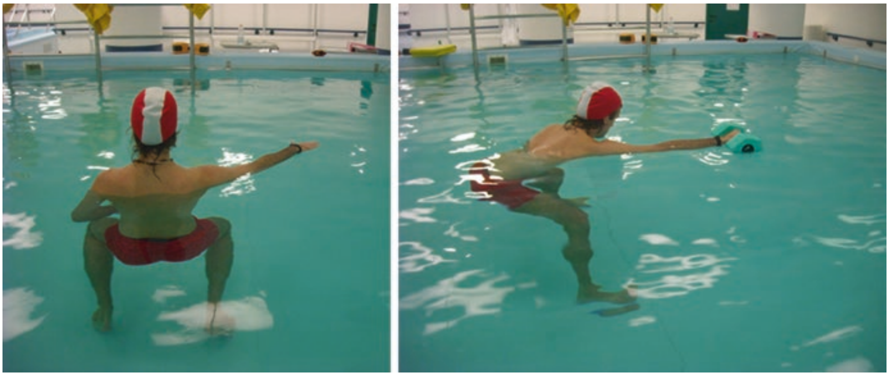
Timing: week 3 after surgery.

Goals:

- Restore full, pain-free ROM of the operated limb.

Interventions:

- Exercise flexion, abduction, and elevation movement in the scapular plane.
- Self-assisted motion in deep water at the shoulder level, floating with the therapist's support; rotations, abductions, and adductions in the horizontal plane.
- Stretch rotators by taking advantage of floating and the favorable water temperature (Figs. 12.27 and 12.28).



Figs. 12.27 and 12.28 Flexion and abduction exercises in the scapular plane

12.5.2 Phase 2

12.5.2.1 Setting: Hospital-Based Outpatient Activity at Rehabilitation Unit

Timing: weeks 4–5 postsurgery.

Goals:

- Strengthen previously restored abilities.
- Maintain good ROM and muscle tone of the healthy limb.
- Restore full ROM of the operated limb.
- Strengthen muscles in the operated limb.

Interventions:

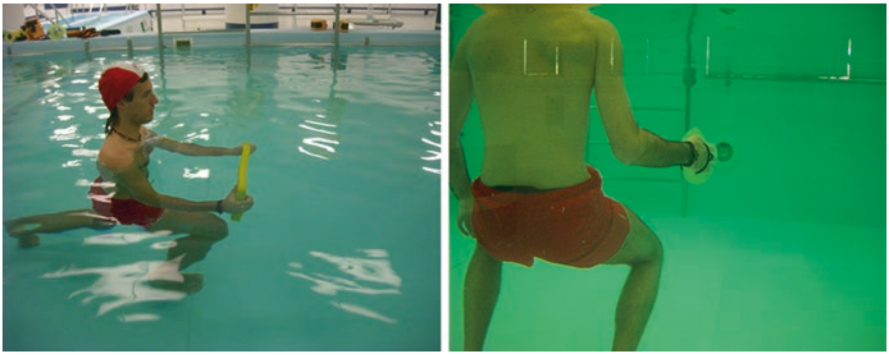
- Abduction control exercises on a wide floating surface.
- Rotator cuff muscle stabilization exercises by taking advantage of the water viscosity.
- Scapulothoracic retraining with strengthening exercises for the rhomboids, the serratus anterior, and the trapezius (scapular protraction and retraction exercises).
- Concentric contraction exercises against resistance, to be intensified by the use of equipment or by increasing movement speed.
- Eccentric contraction exercises by taking advantage of water turbulence; controlled high-speed movements, and short arc (Figs. 12.29 and 12.30).

12.5.3 Phase 3

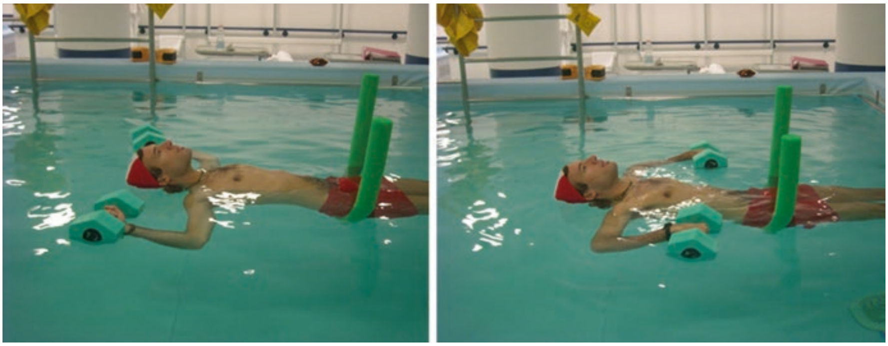
12.5.3.1 Setting: Hospital-Based Outpatient Activity at Rehabilitation Unit

Timing: weeks 6–7 post-surgery.

Goals:



Figs. 12.29 and 12.30 Concentric contraction exercises against water resistance with the use of equipment



Figs. 12.31 and 12.32 Rotator cuff strengthening exercises

- Strengthen previously restored abilities.
- Exercise to improve proprioceptive abilities.
- Educate the patient.

Interventions:

- Dynamically stabilize the shoulder by strengthening the rotator cuff in instable positions, performing closed kinetic chain movement, and using floating equipment in different postures.
- Retrain proprioception: facilitated movements in the orthogonal and diagonal planes, active repositioning exercises in a different gravity environment (Figs. 12.31, 12.32, and 12.33).

Fig. 12.33 Exercises to restore proprioception

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Gait Analysis in the Rehabilitation Process

13

N. Lovecchio, M. Zago, and C. Sforza

Gait analysis is the systematic and quantitative instrumental assessment of the biomechanical measures of locomotion [1], aimed at understanding the etiology of locomotor abnormalities and at assisting clinicians in their decisional process. Starting from the 1990s, gait analysis has turned from a purely academic discipline into a diagnostic tool, thus evolving into a process that embraces different operational methods and allowing for multiple applications.

13.1 History of Gait Analysis

As evidenced by frescoes and sculptures from classical Greece and Rome, humanity was already strongly interested in the observation and study of the movements involved in gait back in ancient times. The first attempts to grasp the basic biomechanics of gait date back to the Renaissance, thanks to the contributions of Leonardo da Vinci, Galileo Galilei, Newton, and Alfonso Borelli. However, the first modern biomechanical analyses were only carried out by the Weber brothers in Germany in the early nineteenth century.

The first significant example of the application of mathematical and engineering techniques to gait analysis can be found in Braune and Fischer's works (1890), which were the driving information for the well-known research carried out by

N. Lovecchio · C. Sforza (✉)
Laboratory of Functional Anatomy of the Locomotor System, Department of Biomedical Sciences for Health, University of Milan, Milan, Italy
e-mail: nicola.lovecchio@unimi.it; chiarella.sforza@unimi.it

M. Zago
Department of Electronics, Information and Bioengineering, Politecnico di Milano, Milan, Italy
e-mail: matteo2.zago@polimi.it

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Bernstein (1930s) and the University of California's College of Engineering and Medical School (1950s). From 1960 onward, several studies were conducted regarding the transmission of forces and moments and ways of storing, generating, and returning mechanical energy to initiate or continue gait phases [2, 3].

In healthcare, the 1960s only saw sporadic attempts at applying gait analysis to the planning of individualized treatments, as clinical and technical professionals had yet to properly master the use of the technology available at the time. For gait analysis to become routine, systems had first to be economically accessible and to run on user-friendly interfaces and procedures. This only happened in the late 1980s, thanks to work by four orthopedic surgeons: Jaquelin Perry, David Sutherland and Jim Gage in the United States, and Gordon Rose in England.

Nowadays, instrumental gait analysis is a widespread, duly recognized clinical tool that embraces multifactorial aspects of motion, such as kinematics, dynamics, and electromyography (EMG) [4–6].

Kinematics refers to the measurement of movement in terms of position, joint angles, speed, and acceleration of body segments. Although the earliest kinematic studies are attributed to Marey and Muybridge and coincided with the advent of photography in the late twentieth century, the first significant research was started by an extremely active group in California between 1940 and 1950 [7]. Limb positions were usually measured by manually digitizing hundreds of images on photographic film. It was only with the development of measurement systems based on television cameras between the 1960s and the 1970s that the process became faster and more efficient [8]. Several motion analysis systems were developed independently in different countries (including Canada, the United States, Scotland, Sweden, and Italy) and pioneered the commercial systems that are available today.

For their part, dynamic measurements cover the forces acting between the foot and the ground (ground reaction forces), as detected by force platforms. After the first one-dimensional devices [9, 10], starting from the late 1970s, new instrumentation appeared that was reasonably reliable for recording the three-dimensional effects of external forces. Today, integrated systems provide additional information on joint force moments and generated powers, based on the combination of force platform data and kinematic data. This process is called inverse dynamics and allows to calculate the torque (or joint moment), that is, the force applied to an arm resulting in a rotational movement.

EMG consists in measuring muscle electrical activity. This method emerged in the first half of the twentieth century. Since then, technological development has produced more and more sophisticated, accurate instrumentation up to modern wireless instruments that have made EMG examination a routine component of clinical gait analysis [11].

13.2 Gait Analysis in Clinical Settings

As far as terminology is concerned, it was Rose [12] who defined the boundaries of instrumental gait analysis and assessment. While the first is essentially related to the technical aspect of the process, the latter refers to the integration of an accurate visual inspection of gait with the relevant objective measurements (speed and cadence, joint angles, step length/width) and the synchronized EMG recording. As a result, in the clinical management of a patient, gait analysis is considered as one of the "special" examinations—like radiographies in orthopedics, biochemical examinations of the blood in hematology, and electrodiagnostic studies on nervous conduction in neurology.

The best-equipped gait analysis laboratories rely on a multidisciplinary team of professionals that can benefit from a considerably broad background of knowledge and skills. The core team usually consists of a physician, a physiotherapist, and a bioengineer. Figure 13.1 shows the layout of a typical motion analysis laboratory as well as photo-reflective markers—placed on a subject's body according to different standardized protocols—that allow to retrace the three-dimensional movement of body segments.

Most patients are referred to gait analysis from their physician and/or physiotherapist on the basis that under 8 years of age, gait patterns are still evolving, and the examination is logistically demanding, if not intrusive, for very young children. Gait analysis basically focuses on collecting five categories of information:

- Video recording: observation of macroscopic patterns of gait.
- Space-temporal parameters: step length/width, cadence, swing, stance and double support phases duration, and speed.
- Kinematics: articular angles and associated measures, such as range of motion, peak values, and plateau. This data is normally gathered via optoelectronic systems based on passive markers (still the gold standard in clinical data collection) although they have recently been sided by marker-free optical systems and systems based on wearable inertial units (accelerometers and gyroscopes), more and more appreciated.
- Dynamics: ground reaction forces, joint forces, and joint moments. These measures can be evaluated on the basis of data from force platforms placed on the ground.
- Electromyography: timing, phasing, and extent (frequency) of muscle contractions.

All this data contributes to define a patient's individual gait pattern, which will help therapists—the physician and physiotherapist, each with their own background—to formulate a comprehensive and objective clinical reasoning in order to plan tailored treatments so as to obtain the best step balance and symmetry [11, 13].

13.3 The Output of Gait Analysis in Rehabilitation

Walking is a periodic movement, and the gait cycle can be considered as its main period. Every gait cycle starts when the foot touches the ground (initial contact) and ends when the same foot strikes the ground again. The whole cycle consists of two main phases: a stance phase and a swing phase. The stance phase roughly accounts for 60% of the gait cycle: it begins when the foot strikes the ground (in physiological conditions, this contact is a heel strike) and ends when the foot leaves the ground

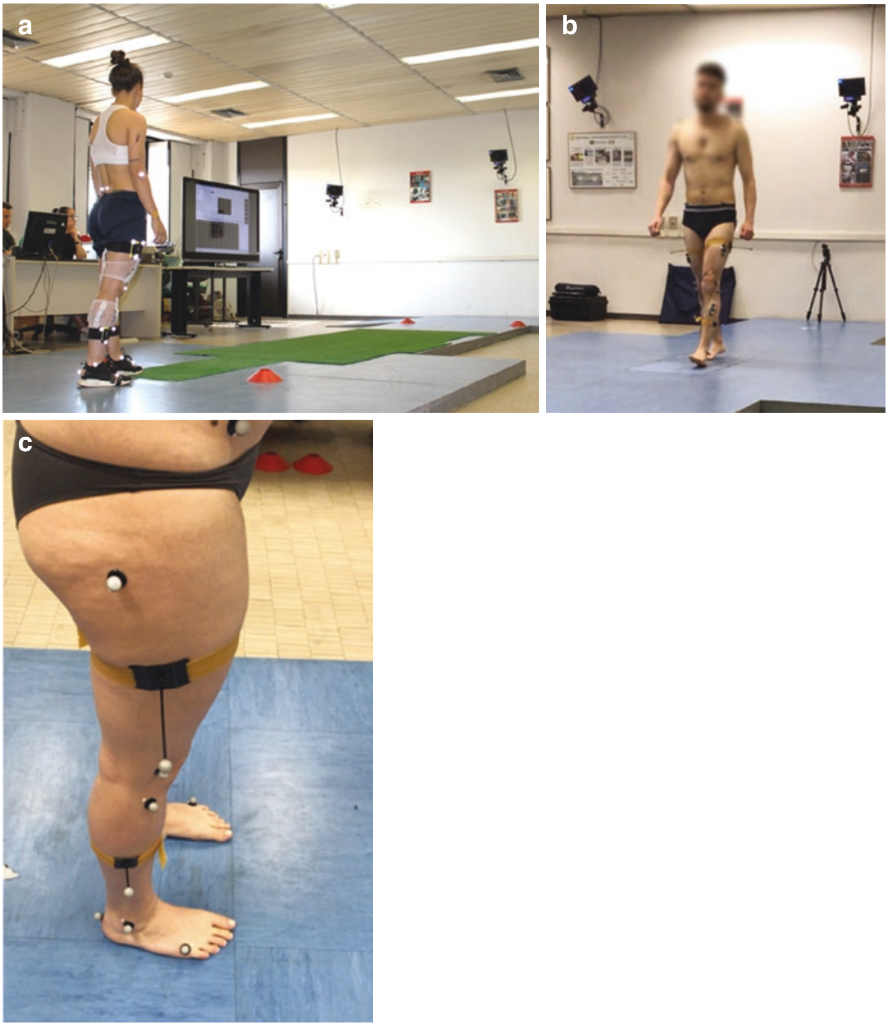

Fig. 13.1 (**a**–**c**) Setup of a multifactorial gait analysis laboratory. Picture (**a**) shows the placement of markers on the subject, which is based on clusters, that is, groups of joint markers, plus other markers placed in specific anatomical reference points. Pictures (**b**) and (**c**) show a different gait analysis model based on Davis protocol that works on specific sticks to be placed on mid-thigh and mid-leg of the subject

(toe-off); the swing phase represents around 40% of the gait cycle, starting from the toe-off and ending when the foot strikes the ground again.

The gait cycle can be alternatively divided in four subphases according to weight distribution on the lower limbs:

1. Initial Double Limb Stance or First Double Support: It represents the initial phase of the gait cycle (10%), where both lower limbs are in contact with the ground. Consequently, weight is shared by both limbs.
2. Single Limb Stance or Side Stance: Representing 40% of the gait cycle, this is the phase where the examined leg (conventionally the right) supports the whole body weight alone, while the other one is in swing phase.
3. Second Double Support or Terminal Double Limb Stance: Representing 10% of the gait cycle, it precedes the swing phase of the examined limb (right side). This is the phase where both feet are once again in contact with the ground, and it starts when the contralateral foot (conventionally the left side one) strikes the ground.
4. Swing: Accounting for 40% of the gait cycle, this is when the examined leg is in swing phase, which lasts from toe-off to heel strike. In this phase, the contralateral leg is the one supporting body weight.

Here, below are the main space-temporal parameters collected via an instrumental analysis of gait (on a side note, they coincide with the normal data of a healthy adult population):

- Step length, that is, the sagittal distance between the heel-strike point of one foot and the heel-strike point of the contralateral foot (0.62 ± 0.05 m).
- Stride length, that is, the sagittal distance between two successive placements of the same foot; stride consists of two step lengths (1.36 ± 0.11 m).
- Step width (right and left) is the frontal-plane distance between the heel and the median line (0.15 ± 0.05 m).
- Stance phase, defined as the time period when the foot is in contact with the ground, occupies around 60% of the whole gait cycle (60 ± 2%).
- Swing phase identifies the time period when the foot leaves the ground and allows the limb to advance. It roughly represents 40% of the cycle.
- Double support time, coinciding with the temporary contact of both feet with the ground (10 ± 3%).
- Step frequency is the number of steps in the time unit measured in steps per minute (114 ± 4 steps/min).
- Stride time (gait cycle duration) is the reciprocal of the previous parameter and coincides with the time taken to walk one step. In daily life, this usually takes around (1.1 ± 0.1 s).

These measures (Fig. 13.2 on the left) provide information on the nature and symmetry of the gait cycle and obviously depend on the subject's walking speed and age [14]. Assessing step lengths and swing times can help evaluate how a subject handles load: a long stance phase (and short swing phase), for example, indicates that the subject prefers to bear load—and handles the single support phase—on the examined limb rather than the other. Moreover, step width provides objective data

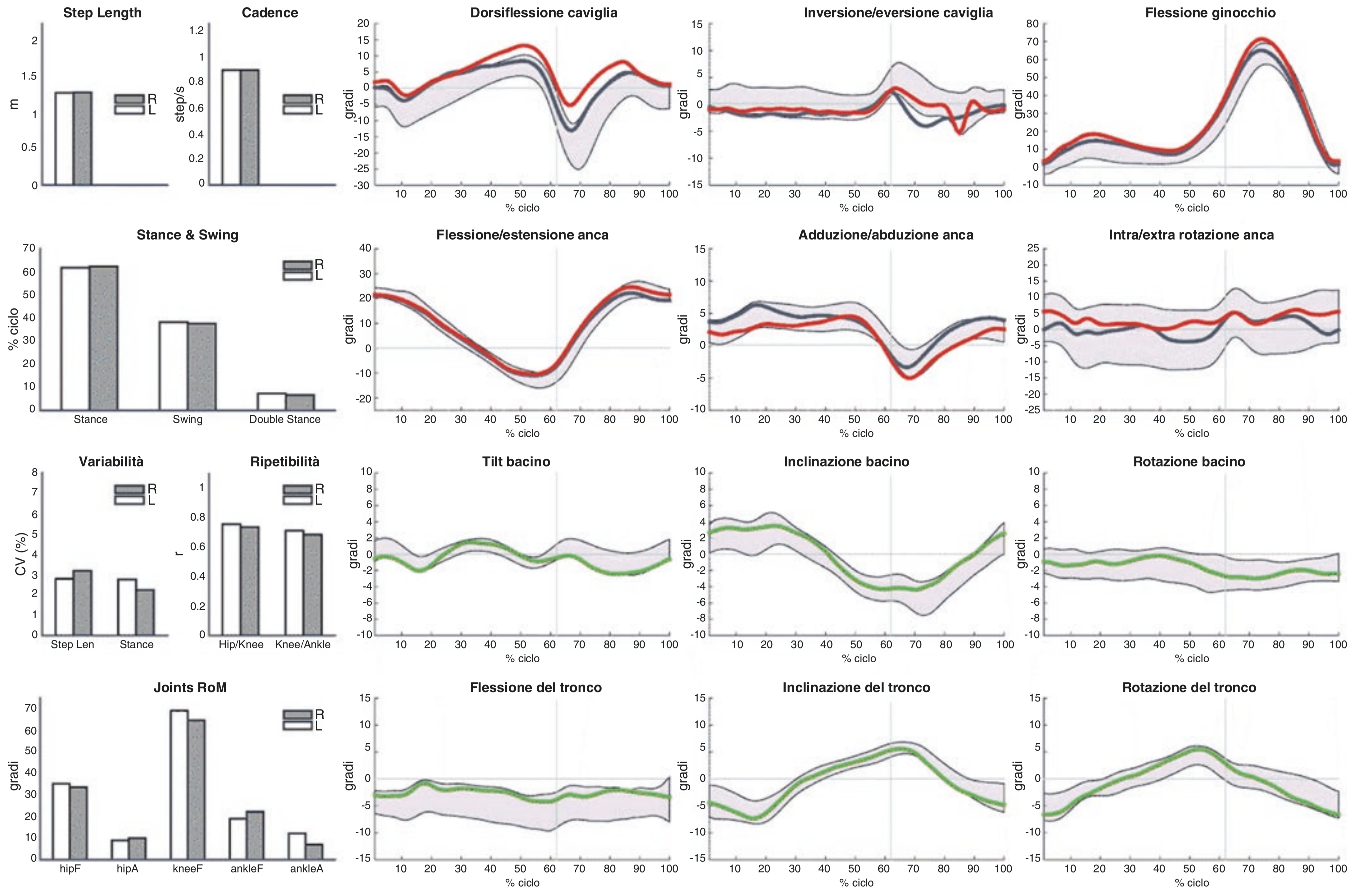

Fig. 13.2 A generic kinematic gait analysis report. It represents both cycle-derived parameters (on the left) and joint kinematics performance during the cycle itself (defined by two successive heel strikes, on the right). *R* right, *L* left, *RoM* range of motion

on the balance management based on the support base width, while gait timing can give indications on the walking speed (thus, indirectly assessing the gait control system) that, despite deficiencies, can be compensated for and reach values nearing normality.

Besides the data here described, a gait analysis report usually gives indications about joint kinetics (Fig. 13.2 on the right), allowing for a comprehensive overview of movement synchrony. As the figure shows, curves are traced for each examined joint and matched with reference confidence bands of a healthy population (represented by the green area). It is possible to note that between 0% and 10% of the gait cycle, the subject's ankle is in a dorsal flexion position (the heel is in contact with the ground), then assumes a plantar flexion position to gain full sole contact with the ground. Later on, a relative leg flexion on the foot shows a further increase in dorsal flexion values (between 10% and 55%): this indicates a shock-absorbing action as the subject enters the mid-stance phase, where the load is maximum. Subsequently (at 70% of the gait cycle), it is possible to observe a plantar flexion that matches with the so-called relative tibial flexion on the foot phase when the foot is pushed to promote advancement. This advancement is fairly synchronized with the peak of knee flexion (60–70°), occuring at around 70% of the cycle. It is noteworthy that at the beginning of the step (between 0% and 20%), the knee needs to flex to properly absorb body weight as it advances on the stance limb. This data, for instance, is highly significant of a patient's weight-bearing and strength management during rehabilitation.

Moving on to hip analysis, it is possible to note that after clearance, the foot is in an extended position (70% of the cycle). Said extension is actually due to the advancement of the trunk "dragged" by the contralateral limb that has meanwhile advanced.

The timings of these actions are essential, as they allow to understand the patient's whole gait pattern by considering the inclination of the pelvis, which should be lifted on the right side when the right heel contact occurs and vice versa. As a general rule, trunk movements in the three planes should be extremely limited and not exceed 15° as the sum of right/left, frontward/backward, and clockwise/counter-clockwise excursions.

13.4 Gait Analysis to the Aid of the Rehabilitation Program

Comprehensive data about the outcomes of total knee replacement surgery is scarce even in the international scientific community. This is often limited to surveys regarding the aesthetic self-perception of the limb and the quality of life achieved after this type of surgery, which in fact can be considered as lifesaving.

Our experience has enabled us to analyze a rehabilitation program purposely planned for the functional recovery after a megaprosthesis replacement, whose follow-up has also required two reviews and the reconstruction of the leg extension mechanism [15, 16]. This same case report, although brief as to the rehabilitation process itself, has required special efforts for the pre and postrehabilitation assessments in order to direct or adjust the functional needs of an intrusive, highly

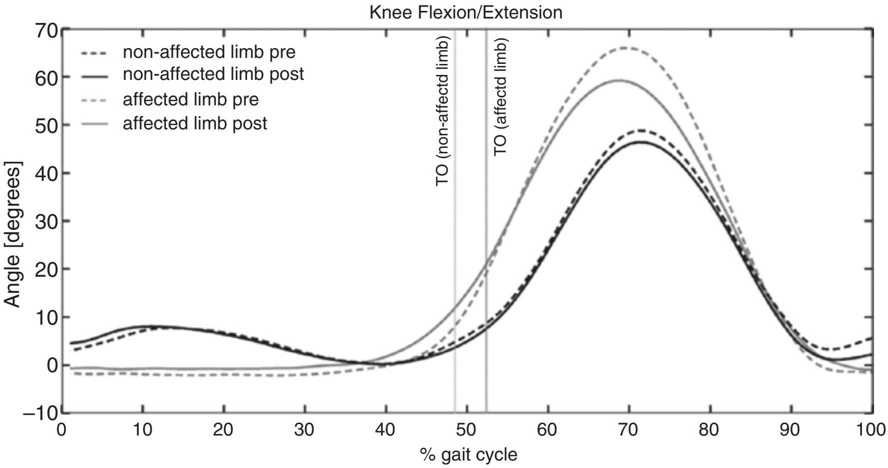

Fig. 13.3 Comparison of the joint kinematics performance (flexion/extension) of a healthy knee with a prosthetic knee

complex prosthesis via evidence-based criteria (i.e., based on factual data on the patient's gait).

Figure 13.3 shows knee ROM curves during gait cycle. The graph voluntarily includes healthy limb curves, to always be used as a first reference even before the assessment against normal population, and prerehabilitation curves in order to clearly identify which goals have been reached and which are still in progress.

The kinematics of the operated limb (gray curves) shows that at heel contact, the knee does not produce any loading response by absorbing weight (plateau around 10% of the gait cycle). This is the first signal that a gait analysis graph allows to identify in just a few instants. It is possible to observe that the knee hyperextension has minimally improved, but no flexion (shock-absorbing action) is actually performed by the patient at the beginning of the step taken with the operated limb. Hence, the first practical consequence, which leads to state that right from the beginning, it is not just necessary to restore the quadriceps strength, but mainly (perhaps, primarily) to more specifically address the shock-absorbing function (e.g., via eccentric training) and motor control (e.g., via weight transfer exercises).

Upon further analyzing the figures—here lies the efficacy of gait analysis reports—it is possible to note that the operated side starts flexing the knee (phasing) earlier than the healthy side (at 40% of the cycle), but in fact stops after ground contact (indicated as "toe-off" in the graph). This can be explained as a certain distress in keeping the limb hyperextended although it does not result in premature clearance, possibly because it is still unable to ensure stability during weight transfers. The second rehabilitative implication is easily recognizable: weight transfers, both frontal (promoting synergic work by the gluteal muscles as well) and sagittal (helpful for simulating steps) should be performed.

A third aspect is the wide-knee excursion during the swing phase. Despite showing improvements after the application of the rehabilitation protocol, the affected side still shows higher values than the healthy side. This is clinically attributable to a strategy activated by the patient to ease foot clearance in order to avoid falls (and handle the task by flexing the knee), as well as to a higher tendency to handle movement with the healthy limb (motor control). Clinical implications are immediately understandable: retrain gait with the aid of mirrors and enhance foot dorsiflexor strength in order to indirectly prevent the risk of developing a steppage gait.

Other examples of assessment of the rehabilitation process via gait analysis involve the study of gait in subjects having underwent fibula removal for mandible reconstruction, following destruction due to facial tumors. Recent studies [17, 18], for example, have evaluated ROM, gait parameters, and the movement of the body center of gravity during walking and when climbing/descending steps at a self-selected speed. In particular, after a 30-month followup, patients climbing/descending steps showed the same stride time (1.4 s) for the healthy limb and the operated limb—most importantly, the same stride time as healthy control samples. In this particular case, swing and support percentages (68% and 32%, respectively) did not present significant differences for the operated limb either. Moreover, the kinematic analysis proved that angular movements of the hip (flexion and abduction) and knee (flexion and extension) scored the same values as the contralateral limb and the control sample, while the pelvic inclination (operated side) during descent was lower than that of the healthy samples. This last observation, for instance, suggests that the rehabilitation process should focus on training motor control (i.e., fear of facing the task) rather than on restoring the ROM.

Moving on to examine younger patients (50 years of age) having underwent fibula removal, it is possible to infer that at 6 months postsurgery, ROM have been fully restored, and rehabilitation interventions do not require any passive actions for joint recovery. However, a 6% decrease in the double support phase of the nonoperated limb and the simultaneous increase (1.8%) in the double support phase of the operated limb indicate that the rehabilitation process needs to focus on weight transfers: confidence in transferring weight on the healthy limb (heel strike) and in the toe-off of the operated limb.

These are quick, functional, and crucial examples to drive rehabilitation in a realistic, evidence-based way, built on the basis of actual data about the subject and not conceived on logical criteria that have not been verified by experiential data. In the clinical and rehabilitative practice, analyses totally analogous to the one described above can be applied to several pathological conditions [19]. Besides the already mentioned postoperative evaluation [20], it is possible to determine the motor phenotype of specific populations, such as patients suffering from Down syndrome [21], diplegia [22], Parkinson's disease [23], respiratory diseases [23, 24], or elderly individuals—subjects where natural changes in gait are compromised and imply a higher risk of falls.

To conclude this brief journey through the world of gait analysis, we would like to point out that even the most sophisticated laboratory equipment is not the goal of rehabilitation, but a resource acting as a "magnifying glass" that helps to improve clinical evaluations by objectifying locomotor patterns, and thus excluding all personal interpretations. Mathematical precision allows for scientific rigor, which is always to be referred to with a wide-ranged vision. A graph shows the actual progression of a problem or impairment, but their biological interpretation is always in the hands of the physician and physiotherapist (clinical reasoning), who will contextualize figures in reality.

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