Reconstructive techniques in musculoskeletal tumor surgery : management of pelvic and extremity bone tumors

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Issue Date: 2018-04-12

Chapter 1

General Introduction

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Historical Background & Aim of the Thesis

Primary bone tumors are rare, accounting for only 0.2% of the total human tumor burden[1]. In 1879, Samuel Weissel Gross published what was later referred to as the “first comprehensive work on bone sarcoma”[2, 3]. In this landmark paper, he advocated early amputation for high-grade sarcoma of bone and soft tissues, despite an overall operative mortality of 30%. Amputations at that time were also frequently performed to control local tumor growth, for palliation, because sarcomas often grew to enormous sizes before diagnosis[4] (figures 1 and 2).

Figure 1: A tumor of the humerus in a 16-year-old woman, four years after onset (from William Gibson, The Institutes and Practice of Surgery [Philadelphia: Carey & Lea, 1832], volume 1, facing page 248.)

Amputation long remained the principal treatment for bone sarcoma[5]. In 1940, Dallas Burton Phemister noted that “the proper treatment of bone sarcomas of the limbs without demonstrable metastases in the great majority of cases is amputation”[6]. Despite the aggressive and mutilating surgical approach at that time, the 1938 statistics of the Registry of Bone Sarcoma of the American College of Surgeons showed a mere 13% recurrence-free survival at a minimum follow-up of five years in patients with osteosarcoma[6].

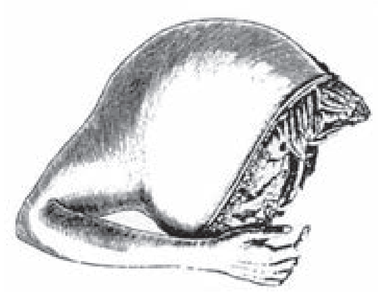

Figure 2: Specimen of a forequarter amputation carried out by George McClellan in 1838 (from George McClellan, Principles and Practice of Surgery [Philadelphia: Grigg & Elliot, 1848], page 412, figure 15).

During the late 19th and early 20th centuries, the first incidental reports on limb-salvaging procedures were published[7-10]. The advent of effective chemotherapeutic agents in the early 1970s caused an increase of five-year survival rates to approximately 55% to 70% for many types of primary sarcoma[11-19]. Concomitant sophistication of imaging and surgical techniques reduced the need for ablative procedures. Limb-salvage surgery was soon popularized and is now the treatment of choice for over 90% of patients with a primary malignant bone tumor[5, 20-25] (figure 3).

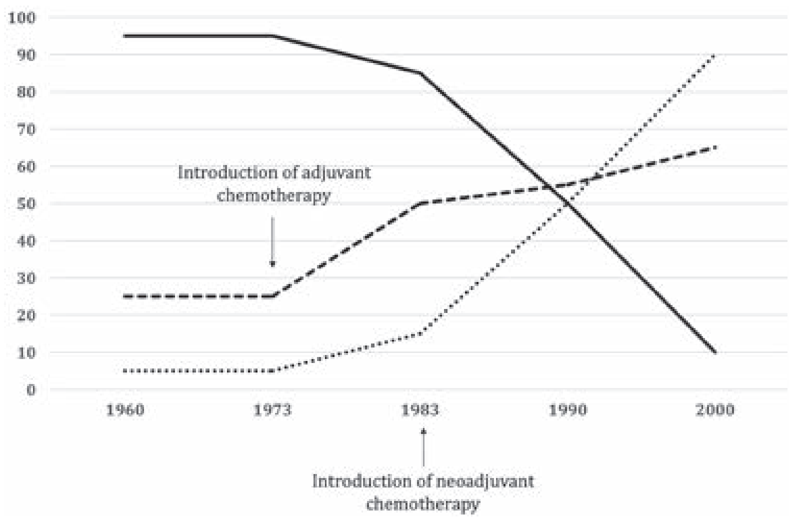

Figure 3: Graph illustrating the trends in the percentages of amputations, limb-salvage procedures, and survival for patients with primary bone sarcomas (solid line, amputations; round dot line, limb salvage procedures; square dot line, survival).

If applicable for the type of tumor, patients are first treated with neoadjuvant chemotherapy and/or radiotherapy. The subsequent limb-salvaging surgical procedure consists of three phases: (1) tumor resection, usually with the aim to obtain clear surgical margins, (2) skeletal reconstruction, and (3) soft tissue reconstruction[25, 26]. The techniques of reconstruction vary and are dictated by surgeon preferences, tumor localization, extent of the defect, and the availability of implants. A large variety of techniques are employed at present, each having its specific advantages and disadvantages; unfortunately, these large reconstructions do not come without complications. Many techniques have not been reviewed properly and therefore, it is difficult to make an evidence-based decision when having to choose the optimal reconstructive technique for the individual patient. Reasons for the paucity of solid evidence include the low incidence of primary musculoskeletal tumors, the heterogeneity in presentation, and significant loss to follow-up due to mortality, as a result of metastases.

The aim of this thesis is to evaluate the outcomes of different reconstructive techniques in treatment of pelvic and extremity bone tumors, to identify risk factors for impaired clinical outcome, and ultimately to improve outcomes for patients with musculoskeletal tumors.

Part I: Management of Pelvic Bone Tumors

Pelvic bone tumors include primary malignancies and metastatic tumors[27]. The most common primary tumors of pelvic bone are central and peripheral chondrosarcomas, myeloma, Ewing's sarcoma and, to a lesser extent, osteosarcoma[1, 14, 15, 28-30]. The traditional treatment for malignant tumors of pelvic bone is hindquarter amputation[21, 31-33]. The term hindquarter amputation (or external hemipelvectomy) is used to designate the complete removal of the lower extremity, the corresponding buttock, and the entire innominate bone in one stage[34, 35] (figure 4). In 1959, Gordon-Taylor reported on his experiences with hindquarter amputations in a series of 41 patients[36]. He noted perioperative mortality in 25 patients (61%), and described the procedure as "one of the most colossal mutilations practiced on the human frame".

Internal hemipelvectomy, on the other hand, does not sacrifice the unaffected lower extremity (i.e. the leg on the affected side remains intact, although functionality may be impaired significantly). Internal hemipelvectomies were first performed for treatment of tumors of the ilium and pubis, and were later presented as an alternative treatment for tumors of the (peri-)acetabulum[37, 38]. In

1978, Enneking and Dunham proposed a classification system for pelvic tumor resections: type 1, involving the iliac wing; type 2, the periacetabular region; type 3, the pubic rami; and type 4, the sacrum (figure 5)[39, 40]. Isolated type 1 or type 3 resections are relatively easy and reconstruction is generally not needed because the acetabulum and weight-bearing axis are preserved[38]. Type 2 resections however require reconstruction in order to restore force transmission along anatomic axes, and therefore pose unique surgical challenges[27, 41].

Figure 4: Photograph of specimen immediately after removal by hindquarter amputation (from Gordon Gordon-Taylor and Philip Wiles, Interinnomino-abdominal [hind-quarter] amputation [The British Journal of Surgery: volume XXII – No. 88, 1935]).

Although most patients with a periacetabular bone tumor can at present be treated by internal hemipelvectomy, these procedures are considered some of the most challenging operations in musculoskeletal oncology[21, 41]. First, pelvic neoplasms often grow to immense proportions before diagnosis (figure 6). Second, the pelvic anatomy is complex, and tumors frequently grow close to vital neurovascular structures. As a result, it is often difficult to obtain clear resection margins[41, 42]. Treatment of pelvic metastases is generally less complicated because the procedure is usually intralesional and therefore requires less bone and soft tissue resection[38]. Third, reconstruction is difficult because of high loading forces, limited bone stock, and large soft-tissue defects[43-46]. This reflects an important dilemma in treatment of these tumors: the decision to obtain adequate surgical margins, while salvaging enough bone to preserve longevity and function of the affected limb[47].

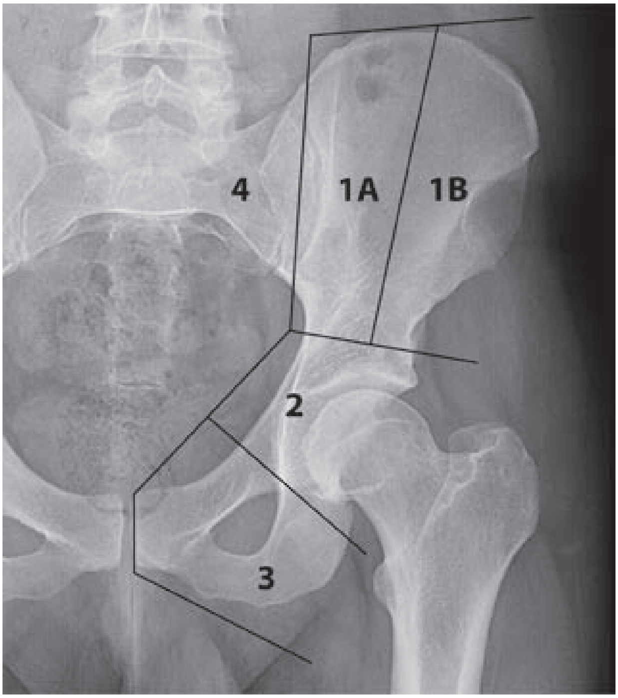

Figure 5: Conventional radiograph of the pelvis showing a modified version of Enneking's classification of pelvic resections. Resections of the ilium are further subdivided into types 1A (those involving the medial part of the ilium) and type 1B (those confined to the lateral portion of the iliac wing). The innermost line depicts the resection plane of a 'conventional' hindquarter amputation.

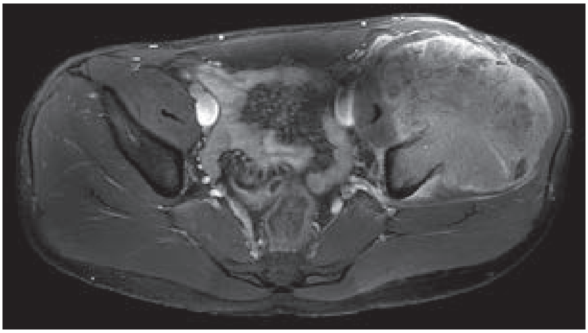

Figure 6: Transverse T1-weighted MR image with SPIR selective fat suppression, demonstrating a large telangiectatic osteosarcoma originating from the left iliac wing.

The most common primary tumor of the pelvic bones in adults is chondrosarcoma[38]. Pelvic chondrosarcomas are notorious for the high risk of (late) recurrence[48]. However, specific studies on this tumor type are lacking. Most previous studies focused on outcomes of resection and reconstructive techniques rather than on oncological outcome. However, to choose the optimal treatment and reconstructive technique, and to reduce the rate of unnecessary reoperations, it is important to identify patients with a poor prognosis in an early stage[49]. In chapter 2, we present a multicenter study on primary central chondrosarcoma of the pelvis. With this study, we aimed to gain insight in the outcome of treatment of this specific type of tumor, and to identify risk factors for impaired oncological outcome.

Following a type 2 internal hemipelvectomy, reconstruction can be achieved with metallic implants, biological transplants, or with techniques that utilize a combination of the two. Reconstructions with metallic implants include transposition of the center of the hip joint[50] and various types of endoprosthetic reconstructions[41, 51, 52]. Biological techniques include iliofemoral arthrodesis or pseudarthrosis[53], pelvic allografts[54], irradiated autografts (i.e., the resection specimen is irradiated and re-implanted)[55] and allograft-prosthetic composites[56]. Disadvantages of biological techniques include limited functional outcomes and a considerable risk of infection, nonunion, fracture, and graft resorption[50, 54-58].

The majority of surgeons focused on the use of endoprosthetic (metallic) implants during the last decades. Most of the implants that have been used had originally been developed for reconstruction of large acetabular defects in extended revision hip arthroplasty[41, 51]. The saddle prosthesis (Link, Hamburg, Germany), which was introduced in 1979, was the first implant to be used for pelvic reconstruction in musculoskeletal oncology on a regular basis[38, 51, 59, 60]. Although favorable short-term results have been published[38, 61], long-term clinical outcome and functional results were disappointing[51]. Apart from high rates of infection and implant breakage, saddle prostheses were associated with a substantial risk of cranial migration[51, 62].

In the quest for a successful implant for pelvic reconstruction, many designers have come up with a stemmed acetabular device. These often show similarities to the Ring prosthesis, which was introduced in 1968. He presented a device that consisted of a cup with a long, threaded stem, designed for reconstruction of acetabular defects[63] (figure 7). Ring described that "weight is transferred from the sacrum to the articular facet of the ilium, and thence through a thick bar of bone which extends down to the upper part of the acetabulum".

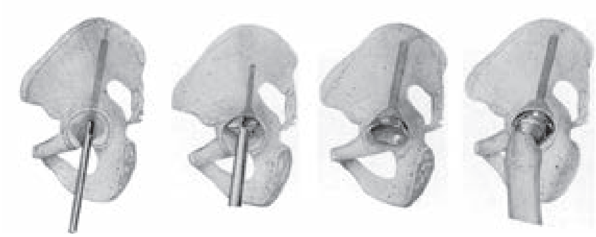

Figure 7: Drawings of the surgical procedure of reconstructing an acetabular defect with the "Ring prosthesis". First, a cannulated drill prepares the track for the prosthesis. Next, the cup is countersunk by using a conical reamer, and the implant is inserted (from P.A. Ring, Complete replacement arthroplasty of the hip by the ring prosthesis [Journal of Bone & Joint Surgery, British Volume: volume 50 – Issue 4, 720-731]).

The pedestal cup endoprosthesis (Schoellner cup; Zimmer, Freiburg, Germany) is one of the implant designs that follow this principle. In chapter 3, we evaluate clinical outcome of periacetabular reconstruction with the pedestal cup endoprosthesis in treatment of periacetabular tumors. Experiences with this implant in both revision hip arthroplasty and orthopaedic oncology had previously been described[64-66]. We were the first to report on its use in a consecutive series of patients with a pelvic malignancy[41].

Based on experiences with the pedestal cup endoprosthesis, the LUMiC prosthesis (implantcast GmbH, Buxtehude, Germany) was designed. Chapter 4 evaluates the short-term clinical results of periacetabular reconstruction with this novel device, and describes results from a retrospective multicenter study[52].

Part II: Management of Extremity Bone Tumors

In the history of orthopaedic surgery, there has always been a strong desire for successful reconstruction of diseased, deformed, or disabled limbs. This dream was presumably first described in the "Miracle of the Black Leg", in the third century AD[67]. In this folktale, the Saints Cosmas and Damian successfully amputated a cancerous lower limb of a church retainer, and replaced it with the leg of a Moor who had died that morning (figure 8). Over the centuries that followed, many authors reported on their attempts to successfully reconstruct a diseased (segment of) bone with an allograft – a transplant from a genetically non-identical donor of the same species. The first successful bone allograft transplantation is generally ascribed to Macewen, who reconstructed part of the humerus in a 3-year-old boy who had osteomyelitis with bone segments obtained from a rachitic patient[68].

Figure 8: Painting of the "Miracle of the Black Leg" by Pedro de Berreguete in the 15th century AD. The Saints removed the right leg of a church retainer, which was affected by a tumor, and replaced it with the leg of a Moor who had died that morning[67].

Various case reports were published in the years that followed. However, it was not before the early 1970s that the first series on patients with allograft reconstructions for bone tumors were published by groups led by Volkov (Moscow, Russia), Parrish (Houston, United States) and Ottolenghi (Buenos Aires, Argentina)[69-72]. Many advances in the field of allotransplantation had been made in the years before. These included techniques to freeze allografts following procurement and to thaw them during tumor resection, and resulted in an enormous decrease in the risk of allograft rejection[67]. The progress in the use of bone allograft can in part be attributed to efforts of the United States Navy, which became interested in preservation of human bone following the Second World War. Also, it has been claimed that the US navy founded the first 'bone bank'[67].

Around the same time, other groups experimented with major prosthetic reconstruction for large osseous defects, including those caused by tumor resections[22, 73]. The first known report on metallic hip replacement was published in 1942 by Austin T. Moore and Harold R. Bohlmann who replaced the proximal half of the femur in a patient with a recurrent giant cell tumor of bone with a vitallium endoprosthesis (figure 9)[74]. In 1949, in the United Kingdom, the first large endoprosthetic reconstruction was performed for a tumor of the distal femur, using an implant designed by professor Scales and manufactured by Stanmore (Stanmore Implants Worldwide, Elstree, United Kingdom)[75]. Endoprostheses at that time were custom-made, based on calculations made from radiographs of the affected bone(s), and it generally took six to eight weeks before the final endoprosthesis was ready for implantation (figure 10)[22, 74, 75].

Figure 9: Reconstruction of the proximal femur with a "metal hip joint", performed in 1942 by Moore and Bohlmann[74].

To ensure ready availability of endoprostheses and to allow for intraoperative flexibility, Kotz from Vienna (Austria) introduced the concept of a modular implant for reconstruction of large osseous defects in 1975. Professor Kotz later developed an entire modular implant system for reconstruction of various tumor sites, the Kotz Modular Femur and Tibia Reconstruction (KMFTR) system, which relied on uncemented stem fixation with two additional plates, and had a fixed hinge for reconstructions around the knee[76]. Despite several changes in endoprosthetic design over the years that followed, the basic idea behind the modern modular endoprosthetic systems is still comparable with the KMFTR system[73].

A few years later, Kotz and Salzer published on their early experiences with rotationplasty as an alternative method of reconstruction for patients with a tumor of the distal femur[77]. With this technique, that had earlier been described by Borggreve[78] and Van Nes[79] for treatment of femoral deformities, the ankle acts as a knee following resection of the knee and 180° rotation of the remaining lower limb[80]. Although patients have to use an external prosthesis and the cosmetic consequences are considerable, this technique allows patients to participate in unrestricted physical activity and may yield functional results that are comparable to endoprosthetic reconstructions. Moreover, these procedures are often definitive; the need for further surgical intervention is rare[80-83]. As opposed to limb-salvaging techniques, it may also be used in case the vessels are involved in the tumor.

Figure 10: Unassembled parts of the Kotz Modular Femur and Tibia Reconstruction System[76].

To understand and compare the various techniques used for reconstruction of osseous defects in the extremities, it is important to distinguish between joint replacements and intercalary (joint-preserving) reconstructions. Primary extremity bone tumors preferentially affect the meta-epiphyseal regions of the distal femur, proximal tibia, proximal humerus and proximal femur. Due to aggressive biological behavior, periarticular structures are frequently involved in the tumorous process, and partial or complete removal of the adjacent joint is commonly indicated[1,14,28,84]. Reconstruction can then be performed using an endoprosthesis[85], an osteoarticular allograft[86], or a combination of an allograft and a metallic implant – an allograft-prosthetic composite (APC)[87]. In other cases, however, it may be possible to salvage the joint and to perform an intercalary (segmental) resection. Several techniques have been described for reconstruction of segmental intercalary osseous defects, including allografts[88], vascularized fibular autografts[89], a combination of the two – the "Capanna technique"[90], extracorporeally irradiated autografts[91], segmental (metallic) prostheses[92], or bone transport with the Ilizarov technique[93].

Traditionally, massive allograft implantation was the most common technique for reconstruction of intercalary defects[94]. Ready availability of well-procured and well-preserved human grafts in the Netherlands was ensured by The Leiden Bone Bank Foundation, which was founded in 1988[95]. In chapter 5, we evaluate the results of intercalary allograft reconstructions in treatment of primary bone tumors from the four appointed centers for orthopaedic oncology in the Netherlands[84].

Orthopaedic surgeons later postulated that bone tumors with limited osseous and intramedullary involvement may be adequately treated by hemicortical (hemicylindrical) resection, leaving part of the cortical bone intact[96, 97]. Hemicortical defects may be reconstructed using allografts[96], autografts[98], or autologous iliac crest grafts[99]. Although autografts have favorable biological properties, allografts were the preferred technique in the Netherlands, because they allow for reconstruction of larger defects. Moreover, they avoid donor site morbidity, which occurrs in approximately 10% of patients and includes prolonged pain complaints, large hematomas, unsightly scars, and sensory loss[100]. In 2002, investigators from our center reported on the results of 22 hemicortical allograft reconstructions in treatment of low-grade malignant bone tumors[96]. The authors reported excellent results, with none of their patients experiencing local tumor relapse, fracture, or infection. Later, others reported comparable results, but all described small case series and most lacked long-term follow-up[97-99, 101-103]. In chapter 6, we present the results of a nationwide retrospective study on complications and oncological outcome after hemicortical resection of primary tumors of the musculoskeletal system[104].

In the early 1990s, allografts were also commonly used for (partial) joint replacement following tumor resection[105-107]. It soon appeared that specific problems of joint reconstruction with allografts were the high risks of joint instability, cartilage degeneration, and subchondral collapse[108-110]. However, large studies focusing on the long-term outcomes of these osteoarticular allografts were lacking. In chapter 7, we evaluate our own experiences with osteoarticular allograft reconstructions, and present a systematic review of the literature, in an attempt to quantify the risk of complications after osteoarticular allograft reconstruction.

One of the major complications of allograft reconstructions is nonunion of allograft-host junctions[111, 112]. Treatment of nonunion is often problematic because one side of the junction is comprised of nonvascular bone[111]. Nonunion is assumed to result from a complex interplay between biological and mechanical factors[111]. The influence of many factors, including the use of adjuvant chemotherapy, osteosynthesis type and location of the junction, has been thoroughly evaluated[84, 88, 111, 113]. On the other hand, it has been stated that construct stability and contact between host bone and the graft – presumably in combination with compression at the junction – are the principal determinants of union[114]. However, the influence of contact at the allograft-host junction had never been evaluated properly. In chapter 8, we present a study on the influence of contact between the allograft and host bone in intercalary reconstructions of the femur and tibia.

During the early 1990s, endoprosthetic implants rapidly refined with respect to modularity and thus possibilities to reconstruct resected bone, consequently these implants popularised[84, 112, 115-117]. Endoprostheses have the advantage of providing a relatively easy and quick reconstructive technique which allows for early postoperative mobilisation and weight bearing[22]. Pioneering centers mainly used custom-made endoprosthetic devices during the 1970s and 1980s. An inherent but important disadvantage of custom-made implants is the lack of intraoperative flexibility (i.e. modularity)[118]. MUTARS® (implantcast, Buxtehude, Germany) was one of the first modular implant systems that were specifically designed for reconstruction after tumor resection or extended revision arthroplasty. As opposed to custom-made implants, modular endoprostheses allow for intraoperative adjustment, for example when greater resection is needed than was anticipated[118]. Moreover, modular implants are available off-the-shelf and are generally less expensive than custom-made implants[118, 119]. Key features of the MUTARS® system include its uncemented, hexagonal-shaped stem, saw teeth at the junctions of stems and extension pieces to allow rotational adjustment, and the attachment tube for soft-tissue reconstruction[120, 121]. Encouraging results of its use in orthopaedic oncology and revision arthroplasty surgery were documented[120, 122, 123]. However, studies focusing on the long-term results of MUTARS® reconstructions around the knee were lacking, while studies on other endoprosthetic systems demonstrated that late complications are of frequent occurrence[115, 116]. In chapter 9, we present a study on distal femoral and proximal tibial replacements from two Dutch tertiary referral centers[121].

Finally, in chapters 10, 11, and 12, we present a general summary, general discussion, and summary in Dutch.

References

1. Fletcher CDM, Unni KK, Mertens F, Organization WH, Cancer IAfRo. WHO classification of tumours of soft tissue and bone: IARC press; 2013.
2. Gross SW. Sarcoma of the Long Bones; Based upon a Study of One Hundred and Sixty-five Cases. The American Journal of the Medical Sciences. 1879;78(156):338-77.
3. Gross SW. The classic. Sarcoma of the long bones: based upon a study of one hundred and sixty-five cases. 1879. Clinical orthopaedics and related research. 2005 Sep;438:9-14. Epub 2005/09/01.
4. Peltier LF. Orthopedics: a history and iconography: Norman Publishing; 1993.
5. Enneking WF. An abbreviated history of orthopaedic oncology in North America. Clinical orthopaedics and related research. 2000 May(374):115-24. Epub 2000/05/20.
6. Phemister DB. The classic. Conservative bone surgery in the treatment of bone tumors. 1940. Clinical orthopaedics and related research. 1986 Mar(204):4-8. Epub 1986/03/01.
7. Morris H. Conservative surgery. Lancet. 1876;1:440.
8. Mikulicz J. Ueber Ausgedehnte Resectionen der langen Rohrenknochen Weten Maligner Geschwulste. Arch Klin Chir. 1895;50:60-75.
9. Lexer E. Die Verwendung der freien Knochenplastik nebst Versuchen über Gelenkversteifung und Gelenktransplantation. Langenbecks Arch Klin Chir Ver Dtsch Z Chir. 1908;86:939-54.
10. Linberg BE. Interscapulo-thoracic resection for malignant tumors of the shoulder joint region. The Journal of Bone & Joint Surgery. 1928;10(2):344-9.
11. Friedman MA, Carter SK. The therapy of osteogenic sarcoma: current status and thoughts for the future. Journal of surgical oncology. 1972;4(5):482-510. Epub 1972/01/01.
12. Link MP, Goorin AM, Miser AW, Green AA, Pratt CB, Belasco JB, et al. The effect of adjuvant chemotherapy on relapse-free survival in patients with osteosarcoma of the extremity. The New England journal of medicine. 1986 Jun 19;314(25):1600-6. Epub 1986/06/19.
13. Eilber F, Giuliano A, Eckardt J, Patterson K, Moseley S, Goodnight J. Adjuvant chemotherapy for osteosarcoma: a randomized prospective trial. Journal of clinical oncology : official journal of the American Society of Clinical Oncology. 1987 Jan;5(1):21-6. Epub 1987/01/01.
14. Bielack SS, Kempf-Bielack B, Delling G, Exner GU, Flege S, Helmke K, et al. Prognostic factors in high-grade osteosarcoma of the extremities or trunk: an analysis of 1,702 patients treated on neoadjuvant cooperative osteosarcoma study group protocols. Journal of clinical oncology : official journal of the American Society of Clinical Oncology. 2002 Feb 1;20(3):776-90. Epub 2002/02/01.
15. Bernstein M, Kovar H, Paulussen M, Randall RL, Schuck A, Teot LA, et al. Ewing's sarcoma family of tumors: current management. The oncologist. 2006 May;11(5):503-19. Epub 2006/05/25.
16. Rosen G. Preoperative (neoadjuvant) chemotherapy for osteogenic sarcoma: a ten year experience. Orthopedics. 1985 May;8(5):659-64. Epub 1985/05/01.
17. Bacci G, Longhi A, Ferrari S, Mercuri M, Versari M, Bertoni F. Prognostic factors in non-metastatic Ewing's sarcoma tumor of bone: an analysis of 579 patients treated at a single institution with adjuvant or neoadjuvant chemotherapy between 1972 and 1998. Acta oncologica (Stockholm, Sweden). 2006;45(4):469-75. Epub 2006/06/09.
18. Nesbit ME, Jr., Gehan EA, Burgert EO, Jr., Vietti TJ, Cangir A, Tefft M, et al. Multimodal therapy for the management of primary, nonmetastatic Ewing's sarcoma of bone: a long-term follow-up of the First Intergroup study. Journal of clinical oncology : official journal of the American Society of Clinical Oncology. 1990 Oct;8(10):1664-74. Epub 1990/10/01.
19. Bone sarcomas: ESMO Clinical Practice Guidelines for diagnosis, treatment and follow-up. Annals of oncology : official journal of the European Society for Medical Oncology / ESMO. 2014 Sep;25 Suppl 3:iii113-23. Epub 2014/09/12.
20. Simon MA, Aschliman MA, Thomas N, Mankin HJ. Limb-salvage treatment versus amputation for osteosarcoma of the distal end of the femur. The Journal of bone and joint surgery American volume. 1986 Dec;68(9):1331-7. Epub 1986/12/01.
21. Grimer RJ, Chandrasekar CR, Carter SR, Abudu A, Tillman RM, Jeys L. Hindquarter amputation: is it still needed and what are the outcomes? The bone & joint journal. 2013 Jan;95-b(1):127-31. Epub 2013/01/12.

22. Grimer RJ, Aydin BK, Wafa H, Carter SR, Jeys L, Abudu A, et al. Very long-term outcomes after endoprosthetic replacement for malignant tumours of bone. The bone & joint journal. 2016 Jun;98-B(6):857-64.
23. Grimer RJ, Taminiau AM, Cannon SR. Surgical outcomes in osteosarcoma. The Journal of bone and joint surgery British volume. 2002 Apr;84(3):395-400. Epub 2002/05/11.
24. Tunn PU. Treatment of bone and soft tissue sarcomas: Springer Science & Business Media; 2008.
25. Malawer MM, Wittig JC, Bickels J. Operative techniques in orthopaedic surgical oncology: Lippincott Williams & Wilkins; 2012.
26. Aboulafia AJ, Malawer MM. Surgical management of pelvic and extremity osteosarcoma. Cancer. 1993 May 15;71(10 Suppl):3358-66. Epub 1993/05/15.
27. Satcher Jr RL, O'Donnell RJ, Johnston JO. Reconstruction of the pelvis after resection of tumors about the acetabulum. Clinical orthopaedics and related research. 2003 Apr(409):209-17. Epub 2003/04/03.
28. Unni KK, Inwards CY. Dahlin's bone tumors: general aspects and data on 10,165 cases: Lippincott Williams & Wilkins; 2010.
29. Gelderblom H, Hogendoorn PC, Dijkstra SD, van Rijswijk CS, Krol AD, Taminiau AH, et al. The clinical approach towards chondrosarcoma. The oncologist. 2008 Mar;13(3):320-9. Epub 2008/04/02.
30. Bloem JL, Reidsma II. Bone and soft tissue tumors of hip and pelvis. Eur J Radiol. 2012 Dec;81(12):3793-801.
31. Carter SR, Eastwood DM, Grimer RJ, Sneath RS. Hindquarter amputation for tumours of the musculoskeletal system. The Journal of bone and joint surgery British volume. 1990 May;72(3):490-3. Epub 1990/05/01.
32. Masterson EL, Davis AM, Wunder JS, Bell RS. Hindquarter amputation for pelvic tumors. The importance of patient selection. Clinical orthopaedics and related research. 1998 May(350):187-94. Epub 1998/05/29.
33. Apffelstaedt JP, Driscoll DL, Spellman JE, Velez AF, Gibbs JF, Karakousis CP. Complications and outcome of external hemipelvectomy in the management of pelvic tumors. Annals of surgical oncology. 1996 May;3(3):304-9. Epub 1996/05/01.
34. Pack GT, Miller TR. Exarticulation of the innominate bone and corresponding lower extremity (hemipelvectomy) for primary and metastatic cancer. A report of one hundred and one cases with analysis of the end results. The Journal of bone and joint surgery American volume. 1964 Jan;46:91-5. Epub 1964/01/01.
35. Gordon-Taylor G, Wiles P. Interinnomino-abdominal (hind-quarter) amputation. British Journal of Surgery. 1935;22(88):671-95.
36. Gordon-Taylor G. On malignant disease in the region of the hip-joint. Journal of the Royal College of Surgeons of Edinburgh. 1959 Oct;5:1-21. Epub 1959/10/01.
37. Steel HH. Partial or complete resection of the hemipelvis. An alternative to hindquarter amputation for periacetabular chondrosarcoma of the pelvis. The Journal of bone and joint surgery American volume. 1978 Sep;60(6):719-30. Epub 1978/09/01.
38. Aboulafia AJ, Buch R, Mathews J, Li W, Malawer MM. Reconstruction using the saddle prosthesis following excision of primary and metastatic periacetabular tumors. Clinical orthopaedics and related research. 1995 May(314):203-13. Epub 1995/05/01.
39. Enneking WF, Dunham WK. Resection and reconstruction for primary neoplasms involving the innominate bone. The Journal of bone and joint surgery American volume. 1978 Sep;60(6):731-46. Epub 1978/09/01.
40. Aponte-Tinao L. CORR Insights: Reconstruction After Hemipelvectomy With the Ice-Cream Cone Prosthesis: What Are the Short-term Clinical Results? Clinical orthopaedics and related research. 2016 Mar 28. Epub 2016/03/30.
41. Bus MP, Boerhout EJ, Bramer JA, Dijkstra PD. Clinical outcome of pedestal cup endoprosthetic reconstruction after resection of a peri-acetabular tumour. The bone & joint journal. 2014 Dec;96-b(12):1706-12. Epub 2014/12/03.
42. Fisher NE, Patton JT, Grimer RJ, Porter D, Jeys L, Tillman RM, et al. Ice-cream cone reconstruction of the pelvis: a new type of pelvic replacement: early results. The Journal of bone and joint surgery British volume. 2011 May;93(5):684-8. Epub 2011/04/23.

43. Angelini A, Calabro T, Pala E, Trovarelli G, Maraldi M, Ruggieri P. Resection and reconstruction of pelvic bone tumors. Orthopedics. 2015 Feb 1;38(2):87-93. Epub 2015/02/11.
44. Campanacci M, Capanna R. Pelvic resections: the Rizzoli Institute experience. The Orthopedic clinics of North America. 1991 Jan;22(1):65-86. Epub 1991/01/01.
45. Capanna R, van Horn JR, Guernelli N, Briccoli A, Ruggieri P, Biagini R, et al. Complications of pelvic resections. Archives of orthopaedic and trauma surgery. 1987;106(2):71-7. Epub 1987/01/01.
46. Mavrogenis AF, Soultanis K, Patapis P, Guerra G, Fabbri N, Ruggieri P, et al. Pelvic resections. Orthopedics. 2012 Feb;35(2):e232-43. Epub 2012/02/09.
47. Zimel MN, Cizik AM, Rapp TB, Weisstein JS, Conrad EU, 3rd. Megaprosthesis versus Condyle-sparing intercalary allograft: distal femoral sarcoma. Clinical orthopaedics and related research. 2009 Nov;467(11):2813-24. Epub 2009/08/08.
48. Sherman CE, O'Connor MI, Sim FH. Survival, local recurrence, and function after pelvic limb salvage at 23 to 38 years of followup. Clinical orthopaedics and related research. 2012 Mar;470(3):712-27. Epub 2011/07/13.
49. Wedin R. Surgical treatment for pathologic fracture. Acta Orthop Scand Suppl. 2001 Jun;72(302):2p , 1-29.
50. Hoffmann C, Gosheger G, Gebert C, Jurgens H, Winkelmann W. Functional results and quality of life after treatment of pelvic sarcomas involving the acetabulum. The Journal of bone and joint surgery American volume. 2006 Mar;88(3):575-82. Epub 2006/03/03.
51. Jansen JA, van de Sande MA, Dijkstra PD. Poor long-term clinical results of saddle prosthesis after resection of periacetabular tumors. Clinical orthopaedics and related research. 2013 Jan;471(1):324-31. Epub 2012/10/12.
52. Bus MP, Szafranski A, Sellevold S, Goryn T, Jutte PC, Bramer JA, et al. LUMiC® Endoprosthetic Reconstruction After Periacetabular Tumor Resection: Short-term Results. Clinical orthopaedics and related research. 2016 Mar 28.
53. Fuchs B, O'Connor MI, Kaufman KR, Padgett DJ, Sim FH. Iliofemoral arthrodesis and pseudarthrosis: a long-term functional outcome evaluation. Clinical orthopaedics and related research. 2002 Apr(397):29-35. Epub 2002/04/16.
54. Delloye C, Banse X, Brichard B, Docquier PL, Cornu O. Pelvic reconstruction with a structural pelvic allograft after resection of a malignant bone tumor. The Journal of bone and joint surgery American volume. 2007 Mar;89(3):579-87. Epub 2007/03/03.
55. Sys G, Uyttendaele D, Poffyn B, Verdonk R, Verstraete L. Extracorporeally irradiated autografts in pelvic reconstruction after malignant tumour resection. International orthopaedics. 2002;26(3):174-8. Epub 2002/06/20.
56. Beadel GP, McLaughlin CE, Wunder JS, Griffin AM, Ferguson PC, Bell RS. Outcome in two groups of patients with allograft-prosthetic reconstruction of pelvic tumor defects. Clinical orthopaedics and related research. 2005 Sep;438:30-5. Epub 2005/09/01.
57. Ozaki T, Hillmann A, Bettin D, Wuisman P, Winkelmann W. High complication rates with pelvic allografts. Experience of 22 sarcoma resections. Acta orthopaedica Scandinavica. 1996 Aug;67(4):333-8. Epub 1996/08/01.
58. Bell RS, Davis AM, Wunder JS, Buconjic T, McGoveran B, Gross AE. Allograft reconstruction of the acetabulum after resection of stage-IIB sarcoma. Intermediate-term results. The Journal of bone and joint surgery American volume. 1997 Nov;79(11):1663-74. Epub 1997/12/31.
59. Aljassir F, Beadel GP, Turcotte RE, Griffin AM, Bell RS, Wunder JS, et al. Outcome after pelvic sarcoma resection reconstructed with saddle prosthesis. Clinical orthopaedics and related research. 2005 Sep;438:36-41. Epub 2005/09/01.
60. Cottias P, Jeanrot C, Vinh TS, Tomeno B, Anract P. Complications and functional evaluation of 17 saddle prostheses for resection of periacetabular tumors. Journal of surgical oncology. 2001 Oct;78(2):90-100. Epub 2001/10/02.
61. Renard AJ, Veth RP, Schreuder HW, Pruszczynski M, Keller A, van Hoesel Q, et al. The saddle prosthesis in pelvic primary and secondary musculoskeletal tumors: functional results at several postoperative intervals. Archives of orthopaedic and trauma surgery. 2000;120(3-4):188-94. Epub 2000/03/30.
62. Antoniades J, Pellegrini VD, Jr. Cross-sectional anatomy of the ilium: implications for acetabular component placement in total hip arthroplasty. Clinical orthopaedics and related research. 2012 Dec;470(12):3537-41.

63. Ring PA. Complete replacement arthroplasty of the hip by the ring prosthesis. The Journal of bone and joint surgery British volume. 1968 Nov;50(4):720-31. Epub 1968/11/01.

64. Schoellner C, Schoellner D. [Pedestal cup operation in acetabular defects after hip cup loosening. A progress report]. Zeitschrift fur Orthopadie und ihre Grenzgebiete. 2000 May-Jun;138(3):215-21. Epub 2000/08/10.

65. Perka C, Schneider F, Labs K. Revision acetabular arthroplasty using a pedestal cup in patients with previous congenital dislocation of the hip - four case reports and review of treatment. Archives of orthopaedic and trauma surgery. 2002 May;122(4):237-40. Epub 2002/05/25.

66. Dominkus M, Darwish E, Funovics P. Reconstruction of the pelvis after resection of malignant bone tumours in children and adolescents. Recent results in cancer research Fortschritte der Krebsforschung Progres dans les recherches sur le cancer. 2009;179:85-111. Epub 2009/02/24.

67. Mankin HJ, Hornicek FJ, Gebhardt MC, Tomford WW. Bone Allograft Transplantation. Bone Regeneration and Repair: Biology and Clinical Applications: Springer; 2005. p. 241-61.

68. Macewen W. Observations concerning transplantation of bone. Illustrated by a case of inter-human osseous transplantation, whereby over two-thirds of the shaft of a humerus was restored. Proceedings of the Royal Society of London. 1881;32(212-215):232-47.

69. Volkov M. Allotransplantation of joints. Bone & Joint Journal. 1970;52(1):49-53.

70. Parrish FF. Allograft replacement of all or part of the end of a long bone following excision of a tumor. The Journal of bone and joint surgery American volume. 1973 Jan;55(1):1-22. Epub 1973/01/01.

71. Ottolenghi C, Muscolo D, Maenza R. Bone defect reconstruction by massive allograft: technique and results of 51 cases followed for 5 to 32 years. Clinical trends in orthopedics New York: Thieme-Stratton. 1982;1982:171-83.

72. Ottolenghi CE. Massive osteoarticular bone grafts. Transplant of the whole femur. The Journal of bone and joint surgery British volume. 1966 Nov;48(4):646-59. Epub 1966/11/01.

73. Pala E, Trovarelli G, Angelini A, Maraldi M, Berizzi A, Ruggieri P. Megaprosthesis of the knee in tumor and revision surgery. Acta Bio Medica Atenei Parmensis. 2017;88(2-S):129-38.

74. Moore AT, Bohlman HR. Metal hip joint: a case report. 1942. Clinical orthopaedics and related research. 2006 Dec;453:22-4.

75. Unwin PS, Cobb JP, Walker PS. Distal femoral arthroplasty using custom-made prostheses. The first 218 cases. The Journal of arthroplasty. 1993 Jun;8(3):259-68.

76. Kotz RI. Progress in musculoskeletal oncology from 1922 - 2012. International orthopaedics. 2014 May;38(5):1113-22.

77. Kotz R, Salzer M. Rotation-plasty for childhood osteosarcoma of the distal part of the femur. The Journal of bone and joint surgery American volume. 1982 Sep;64(7):959-69.

78. Borggreve J. [Replacement of the knee joint by the rotated ankle] [in German]. Arch Orthop Unfall-Chir. 1930;28:175-8.

79. van Nes CP. Transplantation of the tibia and fibula to replace the femur following resection: turn-up-plasty of the leg. The Journal of bone and joint surgery American volume. 1948;30:854-8.

80. Agarwal M, Puri A, Anchan C, Shah M, Jambhekar N. Rotationplasty for bone tumors: is there still a role? Clinical orthopaedics and related research. 2007 Jun;459:76-81. Epub 2007/04/07.

81. Forni C, Gaudenzi N, Zoli M, Manfrini M, Benedetti MG, Pignotti E, et al. Living with rotationplasty--quality of life in rotationplasty patients from childhood to adulthood. Journal of surgical oncology. 2012 Mar 15;105(4):331-6. Epub 2012/02/09.

82. Merkel KD, Gebhardt M, Springfield DS. Rotationplasty as a reconstructive operation after tumor resection. Clinical orthopaedics and related research. 1991 Sep(270):231-6. Epub 1991/09/01.

83. Rodl RW, Pohlmann U, Gosheger G, Lindner NJ, Winkelmann W. Rotationplasty--quality of life after 10 years in 22 patients. Acta orthopaedica Scandinavica. 2002 Jan;73(1):85-8.

84. Bus MP, Dijkstra PD, van de Sande MA, Taminiau AH, Schreuder HW, Jutte PC, et al. Intercalary allograft reconstructions following resection of primary bone tumors: a nationwide multicenter study. The Journal of bone and joint surgery American volume. 2014 Feb 19;96(4):e26. Epub 2014/02/21.

85. Jeys LM, Kulkarni A, Grimer RJ, Carter SR, Tillman RM, Abudu A. Endoprosthetic reconstruction for the treatment of musculoskeletal tumors of the appendicular skeleton and pelvis. The Journal of bone and joint surgery American volume. 2008 Jun;90(6):1265-71. Epub 2008/06/04.

86. Muscolo DL, Ayerza MA, Aponte-Tinao LA, Ranalletta M. Use of distal femoral osteoarticular allografts in limb salvage surgery. The Journal of bone and joint surgery American volume. 2005 Nov;87(11):2449-55. Epub 2005/11/03.

87. Donati D, Colangeli M, Colangeli S, Di Bella C, Mercuri M. Allograft-prosthetic composite in the proximal tibia after bone tumor resection. Clinical orthopaedics and related research. 2008 Feb;466(2):459-65. Epub 2008/01/16.

88. Ortiz-Cruz E, Gebhardt MC, Jennings LC, Springfield DS, Mankin HJ. The results of transplantation of intercalary allografts after resection of tumors. A long-term follow-up study. The Journal of bone and joint surgery American volume. 1997 Jan;79(1):97-106. Epub 1997/01/01.

89. Hilven PH, Bayliss L, Cosker T, Dijkstra PD, Jutte PC, Lahoda LU, et al. The vascularised fibular graft for limb salvage after bone tumour surgery: a multicentre study. The bone & joint journal. 2015 Jun;97-b(6):853-61. Epub 2015/06/03.

90. Capanna R, Campanacci DA, Belot N, Beltrami G, Manfrini M, Innocenti M, et al. A new reconstructive technique for intercalary defects of long bones: the association of massive allograft with vascularized fibular autograft. Long-term results and comparison with alternative techniques. The Orthopedic clinics of North America. 2007 Jan;38(1):51-60, vi. Epub 2006/12/06.

91. Fuchs B, Ossendorf C, Leerapun T, Sim FH. Intercalary segmental reconstruction after bone tumor resection. European journal of surgical oncology : the journal of the European Society of Surgical Oncology and the British Association of Surgical Oncology. 2008 Dec;34(12):1271-6. Epub 2008/01/15.

92. Chao EY, Fuchs B, Rowland CM, Ilstrup DM, Pritchard DJ, Sim FH. Long-term results of segmental prosthesis fixation by extracortical bone-bridging and ingrowth. The Journal of bone and joint surgery American volume. 2004 May;86-a(5):948-55. Epub 2004/05/01.

93. McCoy TH, Jr., Kim HJ, Cross MB, Fragomen AT, Healey JH, Athanasian EA, et al. Bone tumor reconstruction with the Ilizarov method. Journal of surgical oncology. 2013 Mar;107(4):343-52. Epub 2012/07/19.

94. Deijkers RL. Massive deep-frozen bone allografts : contamination, immunogenicity and clinical use. Disseration, Leiden University, Leiden University Medical Center, Department of Orthopaedic Surgery. 2005.

95. Deijkers RL, Vehmeyer SB, Veen MR, Persijn GG, Bloem RM. [5-year experience with a central bone bank]. Nederlands tijdschrift voor geneeskunde. 1995 Mar 25;139(12):622-6. Epub 1995/03/25.

96. Deijkers RL, Bloem RM, Hogendoorn PC, Verlaan JJ, Kroon HM, Taminiau AH. Hemicortical allograft reconstruction after resection of low-grade malignant bone tumours. The Journal of bone and joint surgery British volume. 2002 Sep;84(7):1009-14. Epub 2002/10/03.

97. Agarwal M, Puri A, Anchan C, Shah M, Jambhekar N. Hemicortical excision for low-grade selected surface sarcomas of bone. Clinical orthopaedics and related research. 2007 Jun;459:161-6. Epub 2007/04/07.

98. Liu T, Liu ZY, Zhang Q, Zhang XS. Hemicortical resection and reconstruction using pasteurised autograft for parosteal osteosarcoma of the distal femur. The bone & joint journal. 2013 Sep;95-b(9):1275-9. Epub 2013/09/03.

99. Funovics PT, Bucher F, Toma CD, Kotz RI, Dominkus M. Treatment and outcome of parosteal osteosarcoma: biological versus endoprosthetic reconstruction. Journal of surgical oncology. 2011 Jun;103(8):782-9. Epub 2011/01/18.

100. Younger EM, Chapman MW. Morbidity at bone graft donor sites. Journal of orthopaedic trauma. 1989;3(3):192-5.

101. Lewis VO, Gebhardt MC, Springfield DS. Parosteal osteosarcoma of the posterior aspect of the distal part of the femur. Oncological and functional results following a new resection technique. The Journal of bone and joint surgery American volume. 2000 Aug;82-a(8):1083-8. Epub 2000/08/23.

102. Chen WM, Wu PK, Chen CF, Chung LH, Liu CL, Chen TH. High-grade osteosarcoma treated with hemicortical resection and biological reconstruction. Journal of surgical oncology. 2012 Jun 15;105(8):825-9. Epub 2012/01/04.

103. Lindner N, Ozaki T, Hillmann A, Blasius S, Winkelmann W. Adjuvant local treatment of parosteal osteosarcoma. International orthopaedics. 1996;20(4):233-6. Epub 1996/01/01.

104. Bus MP, Bramer JA, Schaap GR, Schreuder HW, Jutte PC, van der Geest IC, et al. Hemicortical resection and inlay allograft reconstruction for primary bone tumors: a retrospective evaluation in the Netherlands and review of the literature. The Journal of bone and joint surgery American volume. 2015 May 6;97(9):738-50.

105. Mankin HJ, Springfield DS, Gebhardt MC, Tomford WW. Current status of allografting for bone tumors. Orthopedics. 1992 Oct;15(10):1147-54. Epub 1992/10/01.
106. Gebhardt MC, Flugstad DI, Springfield DS, Mankin HJ. The use of bone allografts for limb salvage in high-grade extremity osteosarcoma. Clinical orthopaedics and related research. 1991 Sep(270):181-96. Epub 1991/09/01.
107. Muscolo DL, Ayerza MA, Aponte-Tinao LA. Survivorship and radiographic analysis of knee osteoarticular allografts. Clinical orthopaedics and related research. 2000 Apr(373):73-9. Epub 2000/05/16.
108. Hornicek FJ, Jr., Mnaymneh W, Lackman RD, Exner GU, Malinin TI. Limb salvage with osteoarticular allografts after resection of proximal tibia bone tumors. Clinical orthopaedics and related research. 1998 Jul(352):179-86. Epub 1998/07/25.
109. Rodl RW, Ozaki T, Hoffmann C, Bottner F, Lindner N, Winkelmann W. Osteoarticular allograft in surgery for high-grade malignant tumours of bone. The Journal of bone and joint surgery British volume. 2000 Sep;82(7):1006-10. Epub 2000/10/21.
110. Getty PJ, Peabody TD. Complications and functional outcomes of reconstruction with an osteoarticular allograft after intra-articular resection of the proximal aspect of the humerus. The Journal of bone and joint surgery American volume. 1999 Aug;81(8):1138-46. Epub 1999/08/31.
111. Hornicek FJ, Gebhardt MC, Tomford WW, Sorger JI, Zavatta M, Menzner JP, et al. Factors affecting nonunion of the allograft-host junction. Clinical orthopaedics and related research. 2001 Jan(382):87-98. Epub 2001/01/12.
112. Mankin HJ, Gebhardt MC, Jennings LC, Springfield DS, Tomford WW. Long-term results of allograft replacement in the management of bone tumors. Clinical orthopaedics and related research. 1996 Mar(324):86-97. Epub 1996/03/01.
113. Frisoni T, Cevolani L, Giorgini A, Dozza B, Donati DM. Factors affecting outcome of massive intercalary bone allografts in the treatment of tumours of the femur. The Journal of bone and joint surgery British volume. 2012 Jun;94(6):836-41. Epub 2012/05/26.
114. Stevenson S, Emery SE, Goldberg VM. Factors affecting bone graft incorporation. Clinical orthopaedics and related research. 1996 Mar(324):66-74.
115. Myers GJ, Abudu AT, Carter SR, Tillman RM, Grimer RJ. The long-term results of endoprosthetic replacement of the proximal tibia for bone tumours. The Journal of bone and joint surgery British volume. 2007 Dec;89(12):1632-7. Epub 2007/12/07.
116. Myers GJ, Abudu AT, Carter SR, Tillman RM, Grimer RJ. Endoprosthetic replacement of the distal femur for bone tumours: long-term results. The Journal of bone and joint surgery British volume. 2007 Apr;89(4):521-6. Epub 2007/04/28.
117. Aponte-Tinao LA, Ayerza MA, Muscolo DL, Farfalli GL. What Are the Risk Factors and Management Options for Infection After Reconstruction With Massive Bone Allografts? Clinical orthopaedics and related research. 2015 May 20. Epub 2015/05/21.
118. Menendez LR, Ahlmann ER, Kermani C, Gotha H. Endoprosthetic reconstruction for neoplasms of the proximal femur. Clinical orthopaedics and related research. 2006 Sep;450:46-51. Epub 2006/08/15.
119. Chandrasekar CR, Grimer RJ, Carter SR, Tillman RM, Abudu A, Buckley L. Modular endoprosthetic replacement for tumours of the proximal femur. The Journal of bone and joint surgery British volume. 2009 Jan;91(1):108-12. Epub 2008/12/19.
120. Gosheger G, Gebert C, Ahrens H, Streitbuerger A, Winkelmann W, Hardes J. Endoprosthetic reconstruction in 250 patients with sarcoma. Clinical orthopaedics and related research. 2006 Sep;450:164-71. Epub 2006/05/13.
121. Bus MP, van de Sande MA, Fiocco M, Schaap GR, Bramer JA, Dijkstra PD. What Are the Long-term Results of MUTARS Modular Endoprostheses for Reconstruction of Tumor Resection of the Distal Femur and Proximal Tibia? Clinical orthopaedics and related research. 2015 Dec 9. Epub 2015/12/10.
122. Gebert C, Wessling M, Gotze C, Gosheger G, Hardes J. The Modular Universal Tumour And Revision System (MUTARS®) in endoprosthetic revision surgery. International orthopaedics. 2010 Dec;34(8):1261-5. Epub 2010/04/10.
123. Hardes J, Henrichs MP, Gosheger G, Gebert C, Holl S, Dieckmann R, et al. Endoprosthetic replacement after extra-articular resection of bone and soft-tissue tumours around the knee. The bone & joint journal. 2013 Oct;95-b(10):1425-31. Epub 2013/10/01.