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ORIGINAL PAPER

Endoprosthetic reconstruction of the proximal humerus after tumour resection with polypropylene mesh

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Abstract
Purpose The purpose of this study was to evaluate the functional outcomes and complications of endoprosthesis-PPP mesh composite reconstruction after bone tumour resection of the proximal humerus.
Methods We retrospectively analysed 18 patients treated in our department with endoprosthesis-PPP mesh composite reconstruction after bone tumour resection of the proximal humerus between March 2005 and October 2010. Sixteen patients (16/18) were followed up for 56 months (range, 30–96 months). The pre- and post-operative pain severity was assessed according to a 10-cm visual analogue scale (VAS). The clinical results of functional improvement were assessed by Musculoskeletal Tumour Society (MSTS) score at the time of final follow-up. Moreover, we also analysed complications associated with the reconstruction procedure.
Results Most patients experienced some alleviation of pain two weeks after the reconstruction surgery. The mean MSTS upper extremity functional outcome score at the time of final follow-up was 20 (66.7 %, range, 16–27). Mean shoulder abduction was 36° (range, 18–125°) and mean shoulder flexion was 39° (range, 21–120°). Local recurrence occurred in only one patient (6.25 %), aseptic prosthesis loosening occurred in one patient (6.25 %) and anterior subluxation occurred in one patient (6.25 %).
Conclusions The capsule reconstruction on the basis of PPP mesh can significantly reduce the recurrence rate of glenohumeral joint instability, which may offer an alternative for the capsule reconstruction after bone tumour resection of the proximal humerus.

Keywords Proximal humerus tumours · Reconstruction · Endoprosthesis · Polypropylene mesh · Function

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Introduction

The proximal humerus is a common site of primary and metastatic tumours of bone [1, 2]. Advances in diagnostic imaging techniques and surgical interventions have allowed limb salvage in the treatment of bone tumours of the proximal humerus [2, 3]. However, functional reconstruction following tumour resection has been a surgical challenge because of surgical loss of functional soft tissues including shoulder joint capsule and rotator cuff tendons. The remaining rotator cuff tendons and capsule are usually functionless because their points of insertion on the humerus are resected. At present, the most commonly used functional reconstruction techniques following proximal humeral resection include osteoarticular allografts (OA) [4, 5], allograft-prosthesis composites (APC) [6, 7], and endoprosthesis (EP) reconstruction [2, 3, 8, 9]. Additional techniques such as Tikhoff-Linberg resection [10], fibular transplants [11] and shortening arthrodeses [12] were also used for shoulder construction. Of these commonly used techniques, EP reconstruction is considered more suitable for reconstruction of large bone defect after proximal humeral resection because of lower complication rates, higher implant survival and comparable functional results [13, 14]. Although the incidence of complications, such as infection, fracture and prosthesis loosening, is low, glenohumeral joint instability occurs in approximately 55 % of patients with EP reconstruction surgery [15].

To reduce the rate of joint instability and facilitate the remaining soft tissue reattachment, multiple biomaterials such as polyethylene terephthalate (PTT) tube [16] and expanded

polytetrafluoroethylene (ePTFE) tube [17] have been used to reconstruct destroyed capsule and promote soft tissue reattachment in previous clinical practice. However, these biomaterials have small pore sizes, which may prevent ingrowth of surrounding soft tissues and subsequent biomaterials–soft tissue incorporation [18, 19]. In this study, a macroporous biomaterial, a polypropylene (PPP) mesh widely used in general surgery as a patch for the treatment of ventral hernia [20], was used to reconstruct shoulder joint capsule and promote soft tissues reattachment after tumour resection. We here describe (a) a detailed shoulder joint capsule reconstruction procedure using a PPP mesh, (b) functional outcomes of patients who underwent this procedure and (c) the complications associated with the use of the device.

Patients and methods

Clinical data

Eighteen patients (eight men, ten women; mean age, 29.8 years; range 18–67 years) who underwent endoprosthetic replacement of the proximal humerus and capsule reconstruction using PPP meshes between March 2005 and October 2010 were enrolled in this study. All patients underwent preoperative plain radiography (PR), computerized tomography (CT) and magnetic resonance imaging (MRI) and/or electrical capacitance tomography (ECT) bone scan. Patients with soft tissue sarcomas or bone tumours of the clavicle, scapula, or only the humeral diaphysis were excluded. This study included only patients who had a bone lesion of the proximal aspect of the humerus. The pre- and post-operative (two weeks after reconstruction procedure) pain severity was assessed according to a 10-cm visual analogue scale (VAS), and functional improvement at the time of final follow-up was assessed using the Musculoskeletal Tumour Society (MSTS) function score.

The pathological diagnoses of all patients were obtained by pre-operative needle biopsy. These diagnoses included osteosarcoma (six patients), chondrosarcoma (five patients), Ewing sarcoma (two patients), multiple myeloma (one patient), malignant fibrous histiocytoma (one patient), large B cell lymphoma (one patient), and metastatic bone tumours involving the humerus (breast cancer, two patients). According to the Malawer classification of shoulder girdle resections, all patients enrolled in this study had type IA or IB resection. The surgical stage [21] was as follows: two patients stage IA, three patients stage IB, seven patients stage IIA and six patients stage IIB (Table 1). Of these 18 patients, the endoprosthesis-PPP mesh composite was used as the initial reconstructive technique following primary resection of the tumour in 12 patients (12/18) and as a revision procedure in six patients (6/18) (four patients underwent pure endoprosthesis reconstruction, two patients underwent osteoarticular allografts reconstruction).

To obtain a clear surgical margin and long-term survival prognosis, 13 patients (13/18, 72.2 %) with osteosarcoma, Ewing sarcoma, multiple myeloma, large B cell lymphoma, malignant fibrous histiocytoma and oligometastasis received pre-operative systemic neoadjuvant, adjuvant chemotherapy or chemotherapy. Two patients (2/18, 11.1 %) with Ewing sarcoma also received pre-operative adjuvant radiotherapy. Fifteen patients (15/18, 83.3 %; osteosarcoma, six patients; Ewing sarcoma, two patients; malignant fibrous histiocytoma, one patient; multiple myeloma, one patient; large B cell lymphoma, one patient; oligometastasis, two patients; chondrosarcoma, two patients) received postoperative chemotherapy. Although drug resistance often occurred in patients with chondrosarcoma, two patients received adjuvant chemotherapy according to the oncologist's suggestion in this study (Table 1).

Materials

The proximal humerus endoprostheses were customized and produced (LDK, Co., Ltd) according to the pre-operative design based on PR diagnostic imaging and MR imaging. The nonabsorbable PPP mesh and nonabsorbable sutures used for anchoring mesh are from Johnson & Johnson, Ltd.

The PPP mesh (PROLENE® light mesh) (Ethicon, USA) is a synthetic nonabsorbable porous mesh which is constructed of knitted filaments of extruded polypropylene. In previous studies, these nonabsorbable meshes were often used to repair ventral hernia and fascial truck defects [22]. The synthetic porous mesh used in this study was 15×15 cm^2 and 0.5 mm thick, and can be cut into any desired shape or size according to the intra-operative planning.

Surgical technique

The study was approved and monitored by the Human Research Ethical Committee of our hospital. All patients were allowed to weigh the risks and benefits of endoprosthesis-PPP mesh composites reconstruction as a new method before signing informed consent.

All reconstruction surgeries were performed by an experienced orthopaedic oncologist (Z.W.S.), and the surgical procedures were performed through an anterior approach as described by Marulanda et al. [17] and Neer et al. [23]. After general anaesthesia, an incision was made from the palpable landmark of the coracoid process to the skin overlying the deltopectoral interval, and extended distally depending on the expected level of humeral resection. Soft tissue dissection was dependent on the presence or absence of tumour compromise, and the previous biopsy track and haematoma were excised in continuity with removed soft tissues. A jigsaw was used to

Table 1 Summary data for all patients

Diagnosis	Number	Surgical stage				Pre-op therapy		Post-op therapy	
		IA	IB	IIA	IIB	CH	RAD	CH	RAD
Malignant									
Osteosarcoma	6	0	0	3	3[b]	Yes	No	Yes	No
Chondrosarcoma	5	2	3[b]	0	0	No	No	No[a]	No
Ewing sarcoma	2	0	0	1	1	Yes	Yes	Yes	Yes
MFH	1	0	0	1	0	Yes	No	Yes	Yes
Multiple myeloma	1	0	0	1	0	Yes	No	Yes	No
Large B lymphoma	1	0	0	0	1	Yes	No	Yes	No
Oligometastasis	2	0	0	1	1	Yes	No	Yes	No
Total	18	2	3	7	6				

MFH malignant fibrous histiocytoma, *CH* chemotherapy, *RAD* radiotherapy

[a] Two patients with chondrosarcoma received adjuvant chemotherapy according to the oncologist's suggestion

[b] Two patients were excluded in this study

make the osteotomy when the proposed level of humeral resection was identified. The remaining rotator cuff tendons and joint capsule were identified and tagged. For the patients who undergo type IA resection, protection of the axillary nerve is critical during the whole surgery. The resected specimens were sent for pathology analysis and confirmation of disease-free remaining bone.

A proper circular hole was prepared in the centre of the PPP mesh, and the whole edge of the central hole was reinforced by nonabsorbable suture (Fig. 1). As it shows in Fig. 2, the edge was then anchored and sutured to the remaining articular capsule and glenoid labrum of the glenohumeral joint. After proper location of the endoprosthesis, the endoprosthesis was cemented in place and wrapped by the free end of the PPP mesh (Figs. 3 and 4). Then the tagged rotator cuff tendons and surrounding soft tissues were reattached to the PPP sheath and fully covered the endoprosthesis. After successful hemostasis, the surgical incision was closed and large-bore suction catheter drainage was secured.

Postoperative treatment

All patients received intravenous cephalosporins for the duration of the hospital stay (mean, five days; range three to eight days), and the surgical incisions were carefully monitored. The patients with postoperative pain received the treatment of non-steroidal anti-inflammatory drugs (NSAIDs). Most patients (15/18, 83.3 %) received postoperative chemotherapy or radiotherapy (details listed in Table 1). All patients in this study received the same function exercise program. To facilitate the repair of soft tissues, the reconstructive limb was maintained on an abduction splint for four to five weeks (Fig. 5). Once the abduction splint was removed, continuous passive movements, starting from a small range and gradually

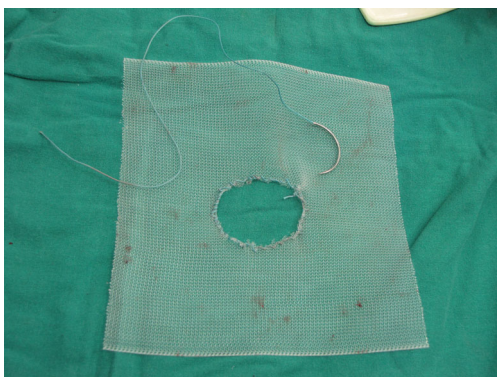

Fig. 1 The polypropylene (PPP) mesh used for shoulder joint capsule reconstruction. A proper circular hole was prepared according to the dimension of the glenoid, and the whole edge of the central hole was reinforced by nonabsorbable suture

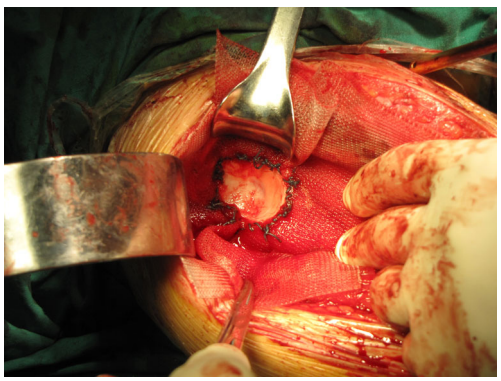

Fig. 2 Fixation of polypropylene (PPP) mesh. The reinforced edge was anchored and sutured to the remaining articular capsule and glenoid labrum of the glenohumeral joint

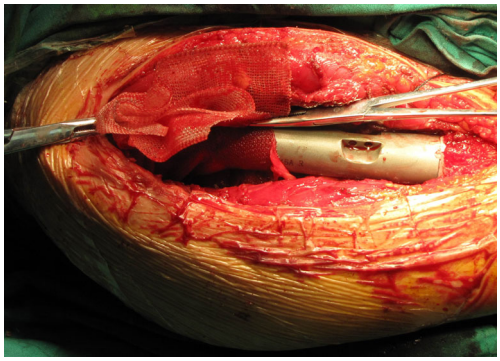

Fig. 3 Reconstruction of shoulder joint capsule. After proper location of the endoprosthesis, it was wrapped by the free end of polypropylene (PPP) mesh

increasing to a larger range of motion, were suggested and active movements, such as abduction, flexion, extension, were also encouraged according to the different clinical situations.

Results

Two patients (one patient lost to follow-up and one patient with chondrosarcoma who died of the disease six months after the reconstruction procedure) were excluded from this study. The other 16 cases (16/18) were observed for 30–96 months with an average follow-up of 56 months. Most patients (15/16) experienced some alleviation of pain in two weeks after the reconstruction surgery (VAS, pre VS post; 7.8±1.8 vs. 3.1 ±1.3). The patient with postoperative pain (1/18) was an 18-year-old woman with a diagnosis of osteosarcoma. The symptom of pain disappeared after three weeks of treatment of NSAIDs and physical therapy. Ten patients (10/18) returned to their occupations within five months.

Functional assessments were performed at the time of final follow-up. The mean MSTS upper extremity functional outcome score was 20 (66.7 %, range, 16–27). Mean shoulder abduction was 36° (range, 18–125°) and mean shoulder

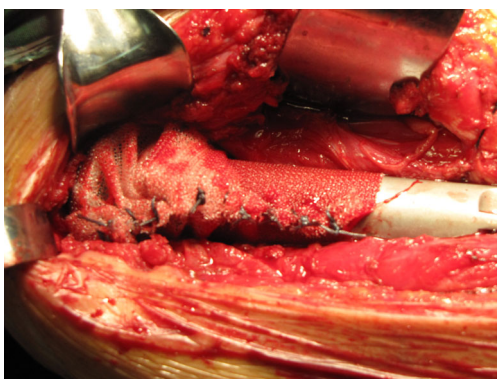

Fig. 4 The formation of "polypropylene (PPP) mesh sheath". The remaining rotator cuff tendons and surrounding soft tissues were sutured to the PPP sheath and covered the endoprosthesis

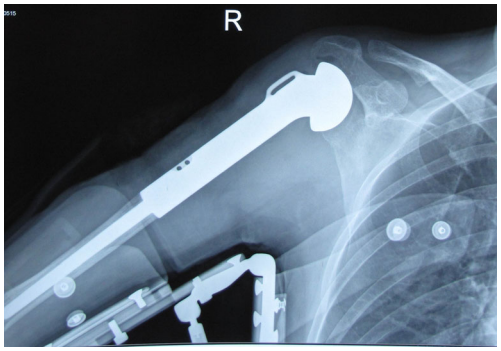

Fig. 5 A 38-year-old patient with the diagnosis of chondrosarcoma who underwent endoprosthesis-polypropylene (PPP) mesh composite reconstruction surgery. The reconstructive upper limb was maintained on an abduction splint

flexion was 39° (range, 21–120°). The deltoid muscle, a critical muscle affecting the function and stability of reconstructive shoulder [17, 25], is often involved in the resection. As shown in Table 2, the patients with deltoid muscle resection (13/16, 81 %) had a significantly reduced range of motion in both abduction and flexion as compared with those in whom the deltoid muscle was reserved.

Infection, periprosthetic fracture and shoulder dislocation were not observed in our study. Local recurrence occurred in one patient (1/16) with osteosarcoma, and the patient died of the disease one month after the last follow-up. Prosthesis loosening occurred in one patient (1/16) who often lifted heavy weights, and the patient had to undergo the revision surgery. In one patient (1/16) who underwent endoprosthesis-PPP mesh composite reconstruction as a revision surgery, the prosthetic humeral head moved upward a little three months after operation, and the "anterior subluxations" were not changed at the last follow-up (Table 3).

Discussion

The shoulder joint has the largest range of motion in the human skeleton, which is closely related with its complex anatomy (including rotator cuff and joint capsule). Previous studies have stated that rotator cuff tendons and capsule are critical for stabilizing the shoulder joint [16, 17, 24]. Once these complex structures are destroyed, it is difficult to repair especially in patients who underwent proximal humeral resection. Advances in surgical interventions and metallic endoprosthesis have permitted orthopaedic oncologists to reconstruct large segments of diseased bone [2, 3, 8, 9, 13, 14]. However, the reattachment of remaining soft tissues after endoprosthesis reconstruction is a challenge because of poor metal–soft tissue adhesion. In the past, many strategies including osteoconductive scaffolds [25], coating of prosthesis with novel materials [26,

Table 2 Effect of deltoid muscle resection (partial/total) on shoulder joint functional outcomes

Functional outcomes	Deltoid muscle resection	Deltoid muscle reservation
Total patients	13 (13/16)	3 (3/16)
Abduction (range)	22°±8° (18–66°)	77°±42° (50–125°)
Flexion (range)	30°±17° (21–70°)	79°±35° (58–120°)

The patients with deltoid muscle resection had a significantly reduced range of motion in both abduction and flexion, which suggests that the deltoid muscle may play an important role in postoperative shoulder joint function

27] and predetermined suture sites embedded in the metallic prosthesis [28], have been used to promote soft tissue adhesion and ingrowth. All of these procedures have been associated with joint instability, recurrent dislocation and poor limb function [25–28]. With the development of biomaterials, surgeons have been attempting to reconstruct the destroyed capsule and improve the remaining soft tissue reattachment by biomaterial–soft tissue incorporation [16, 17]. In this study, we introduced a common and cheap biomaterial, a PPP mesh, to reconstruct capsule to reduce/prevent shoulder joint dislocation and instability, and evaluated the postoperative function level and elaborated complications associated with the reconstruction procedure.

Previous studies showed that glenohumeral joint instability and dislocation have a high recurrence rate in patients who underwent EP reconstruction [15, 29–31]. Bos et al. reported five of 18 patients (5/18) suffered dislocations that required revision surgery [30]. Ross et al. reported that 19 of 25 patients (19/25), treated with several different implants, suffered subluxations (16 cases) and dislocations (three cases) [31]. Moreover, five patients received EP reconstruction in our institution before the beginning of this study, and one of them (1/5) suffered dislocation and one (1/5) suffered subluxations (Table 3). Therefore, we postulated that use of an endoprosthesis-PPP mesh composite would decrease shoulder joint dislocation and strengthen its stability after tumour resection of proximal humerus, and we continued using the PPP mesh reconstruction in all patients after the first procedure was performed in March 2005.

Table 3 Effect of EP and EP-PPP mesh composite reconstruction on shoulder stability

Shoulder stability	EP reconstruction	EP-PPP reconstruction
Total patients	5[a]	16
Dislocation	1 (20 %)	0 (0)
Subluxations	1 (20 %)	1 (6.25 %)

EP endoprosthesis, *PPP* polypropylene

[a] Five patients received the pure EP reconstruction after the tumour resection before this study

In the past, several biomaterials, the PTT tube [16] and ePTFE tube [17], have been used to reconstruct destroyed joint capsules, which significantly reduces the rate of joint instability. Marulanda et al. reported that, of 16 patients treated with endoprosthesis reconstruction supplemented with a synthetic ePTFE tube, only one (1/16) experienced anterior subluxation of the shoulder [17]. Gosheger et al. reported that no cases (0/16) of subluxation or dislocation were observed in 16 patients with endoprosthesis reconstruction supplemented with a synthetic PTT tube [16]. In this series, we used a common and cheap biomaterial, PPP mesh, to reconstruct destroyed shoulder capsule and obtained similar clinical results. As shown in Table 3, only one patient (1/16) suffered anterior subluxations and no cases sustained dislocation. Recently, Ioannou et al. also reported nine of 21 patients (9/21) received the capsule reconstruction using PPP mesh and achieved stable shoulders [32]. Therefore, the PPP mesh may be an alternative for capsule reconstruction. In comparison to PTT and ePTFE tube, the PPP mesh has many potential advantages, such as larger pore size facilitating the reattachment of surrounding soft tissues, excellent plasticity and reasonable price.

In the present study, the mean MSTS upper extremity functional outcome score was 67 %. Mean active shoulder abduction and flexion were 36° and 39°, respectively. These patients in our series showed loss of a range of active motion when compared with that of 16 patients treated with endoprosthesis–ePTFE tube reconstruction in the study by Gosheger et al. [17]. The possible explain is that our patients experienced four to five weeks of abduction fixation on an abduction splint, while the patients in the study of Gosheger et al. began their shoulder passive motion during the hospital stay. Although the functional results are comparable, we think that the functional outcomes depend on many factors, such as different orthopaedic oncologists, tumour type, soft tissue involvement, pre- and post-operative therapy and different function exercise program.

Although these results support our primary hypothesis, this study is limited by the fact that it is a retrospective analysis, small sample and without a control group. All of these defects are associated with relatively rare proximal humerus reconstruction for tumours [13, 16, 17, 33]. Although our experience is very limited, the procedure offers some interesting information. The endoprosthesis reconstruction on the basis of nonabsorbable PPP mesh can significantly reduce the rate of glenohumeral joint instability and dislocation and improve patient's quality of life.

References

1. Bell RS (2003) Treatment of axial skeleton bone metastases. Clin Orthop Relat Res 415:198–200
2. Sharma S, Turcotte RE, Isler MH, Wong C (2007) Experience with cemented large segment endoprostheses for tumors. Clin Orthop Relat Res 459:54–59
3. Dieckmann R, Liem D, Gosheger G, Henrichs MP, Höll S, Hardes J, Streitbürger A (2013) Evaluation of a reconstruction reverse shoulder for tumor surgery and tribological comparison with an anatomical shoulder arthroplasty. Int Orthop 37:451–456
4. DeGroot H, Donati D, Di Liddo M, Gozzi E, Mercuri M (2004) The use of cement in osteoarticular allografts for proximal humeral bone tumors. Clin Orthop Relat Res 427:190–197
5. Rodl RW, Gosheger G, Gebert C, Lindner N, Ozaki T, Winkelman W (2002) Reconstruction of the proximal humerus after wide resection of tumors. J Bone Joint Surg (Br) 84:1004–1008
6. Squire G, Grundy TJ, Ferran NA, Harper WM, Ashford RU (2013) Long-term survival of proximal humerus allografts for reconstruction following resection of malignant bone tumours. Acta Orthop Belg 79:260–265
7. Abdeen A, Hoang BH, Athanasian EA, Morris CD, Boland PJ, Healey JH (2009) Allograft-prosthesis composite reconstruction of the proximal part of the humerus: functional outcome and survivorship. J Bone Joint Surg Am 91:2406–2415
8. Streitbuerger A, Henrichs M, Gosheger G, Ahrens H, Nottrott M, Guder W, Dieckmann R, Hardes J (2014) Improvement of the shoulder function after large segment resection of the proximal humerus with the use of an inverse tumour prosthesis. Int Orthop [Epub ahead of print]
9. Kiss J, Sztrinkai G, Antal I, Kiss J, Szendroi M (2007) Functional result and quality of life after shoulder girdle resections in musculoskeletal tumors. J Shoulder Elbow Surg 16:273–279
10. Linberg BE (1999) Interscapulo-thoracic resection for malignant tumors of the shoulder joint region. Clin Orthop Relat Res 358:3–7
11. Onoda S, Sakuraba M, Asano T, Miyamoto S, Beppu Y, Chuman H, Kawai A, Nakatani F, Kimata Y (2011) Use of vascularized free fibular head grafts for upper limb oncologic reconstruction. Plast Reconstr Surg 127:1244–1253
12. Amin SN, Ebeid WA (2002) Shoulder reconstruction after tumor resection by pedicled scapular crest graft. Clin Orthop Relat Res 397:133–142
13. van de Sande MA, Dijkstra PD, Taminiau AH (2011) Proximal humerus reconstruction after tumour resection: biological versus endoprosthetic reconstruction. Int Orthop 35:1375–1380
14. Potter BK, Adams SC, Pitcher JD Jr, Malinin TI, Temple HT (2009) Proximal humerus reconstructions for tumors. Clin Orthop Relat Res 467:1035–1041
15. Kumar D, Grimer RJ, Abudu A, Carter SR, Tillman RM (2003) Endoprosthetic replacement of the proximal humerus: long-term results. J Bone Joint Surg (Br) 85:717–722
16. Gosheger G, Hillmann A, Lindner N, Rödl R, Hoffmann C, Bürger H, Winkelmann W (2001) Soft tissue reconstruction of megaprostheses using a trevira tube. Clin Orthop Relat Res 393: 264–271
17. Marulanda GA, Henderson E, Cheong D, Letson GD (2010) Proximal and total humerus reconstruction with the use of an aortograft mesh. Clin Orthop Relat Res 468:2896–2903
18. Roth CC, Holley TD, Winters JC (2006) Winters, synthetic slings: which material, which approach. Curr Opin Urol 16:234–239
19. Niknejad K, Plzak LS 3rd, Staskin DR, Loughlin KR (2002) Autologous and synthetic urethral slings for female incontinence. Urol Clin N Am 29:597–611
20. Bingener J, Kazantsev GB, Chopra S, Schwesinger WH (2004) Adhesion formation after laparoscopic ventral incisional hernia repair with polypropylene mesh: a study using abdominal ultrasound. JSLS 82:127–131
21. Enneking WF, Spanier SS, Goodman MA (1980) A system for the surgical staging of musculoskeletal sarcoma. Clin Orthop Relat Res 153:106–120
22. Aliabadi-Wahle S, Cnota MA, Choe EU, Jacob JT, Flint LM, Ferrara JJ (1998) Efficacy of a novel synthetic material to close exposed fascial defects. South Med J 91:733–738
23. Neer CS 2nd, McIlveen SJ (1988) Humeral head replacement with reconstruction of the tuberosities and the cuff in 4-fragment displaced fractures. Current results and technics. Rev Chir Orthop Reparatrice Appar Mot 74:31–40
24. Glanzmann MC, Goldhahn J, Flury M, Schwyzer HK, Simmen BR (2010) Deltoid flap reconstruction for massive rotator cuff tears: mid- and long-term functional and structural results. J Shoulder Elbow Surg 19:439–445
25. Yang X, Tare RS, Partridge KA, Roach HI, Clarke NM, Howdle SM, Shakesheff KM, Oreffo RO (2003) Induction of human osteoprogenitor chemotaxis, proliferation, differentiation, and bone formation by osteoblast stimulating factor-1/pleiotrophin: osteoconductive biomimetic scaffolds for tissue engineering. J Bone Miner Res 18:47–57
26. Freels DB, Kilpatrick S, Gordon ES, Ward WG (2002) Animal model for evaluation of soft tissue ingrowth into various types of porous coating. Clin Orthop Relat Res 397:315–322
27. Runne WC, van Sambeek KJ, Stierum JL, van Tongerloo RB (1989) Femoral endoprosthesis fixation with a soft, flexible low modulus stem coating. Four to six year clinical results. Orthopedics 12:529–535
28. Wittig JC, Bickels J, Kellar-Graney KL, Kim FH, Malawer MM (2002) Osteosarcoma of the proximal humerus: long-term results with limb-sparing surgery. Clin Orthop Relat Res 397:156–176
29. Kitagawa Y, Thai DM, Choong PF (2007) Reconstructions of the shoulder following tumour resection. J Orthop Surg (Hong Kong) 15: 201–206
30. Bos G, Sim F, Pritchard D, Shives T, Rock M, Askew L, Chao E (1987) Prosthetic replacement of the proximal humerus. Clin Orthop Relat Res 224:178–191
31. Ross AC, Wilson JN, Scales JT (1987) Endoprosthetic replacement of the proximal humerus. J Bone Joint Surg (Br) 69:656–661
32. Ioannou M, Papanastassiou J, Athanassiou AE, Ziras N, Kottakis S, Demertzis N (2009) Surgical options in cases of tumorous destruction of the proximal humerus: twenty-one patients followed from 4-9 years. J BUON 14:57–61
33. Scotti C, Camnasio F, Peretti GM, Fontana F, Fraschini G (2008) Modular prostheses in the treatment of proximal humerus metastases: review of 40 cases. J Orthop Traumatol 9:5–10