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CLINICAL RESEARCH

Use of Compressive Osseointegration Endoprostheses for Massive Bone Loss From Tumor and Failed Arthroplasty: A Viable Option in the Upper Extremity

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Abstract

Background Endoprostheses using principles of compressive osseointegration have shown good survivorship in several studies involving the lower extremity; however, no series to our knowledge have documented the use of this technology in the management of massive bone loss in the upper limb.

Questions/purposes (1) What proportion of upper extremity implants using compressive osseointegration fixation principles achieved durable short-term fixation, and what were the modes of failure? (2) What surgical complications resulted from reconstruction using this technique?

Methods A multiinstitutional retrospective review identified nine patients (five women; four men) who underwent 13 endoprosthetic replacements between 2003 and 2014 using compressive osseointegration (Compliant® Prestress Device [CPS]; Biomet Inc, Warsaw, IN, USA) in the upper extremity, including two proximal humeri, two humeral diaphyses, seven distal humeri, and two proximal ulna. During the early part of that period, the indication for use of a compressive prosthesis in our centers was revision of a previous tumor reconstruction (allograft-prosthetic composite or stemmed endoprosthetic reconstruction) (three patients; five implants), or revision arthroplasty with massive bone loss (three patients, four implants); more recently, indications became somewhat more permissive and included posttraumatic bone loss (one patient, one implant), primary bone sarcoma, and resections with very short remaining end segments after diaphyseal resections (two patients, three implants). Minimum followup was 24 months; one patient (one implant) was lost to followup before that time with the implant intact at 14 months and no patients have died. The mean age of the patients was 45

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Each author certifies that his or her institution approved the human protocol for this investigation, that all investigations were conducted in conformity with ethical principles of research, and that informed consent for participation in the study was obtained.
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years (range, 21–62 years). Mean followup was 68 months (range, 24–141 months). Implant revision for any cause and for failure of the CPS mechanism was recorded. Modes of failure were categorized as soft tissue, aseptic loosening, structural, infection, and tumor progression; CPS modes of failure were defined as lack of fixation, with or without bone or implant fracture.

Results Of the 12 implants accounted for beyond 2 years, six had undergone revision of any kind. Only two revisions in two patients were attributable to lack of CPS fixation at the bone-implant interface; one of the patients also had periprosthetic and implant fracture develop through the traction bar. Other modes of failure were aseptic loosening of the standard ulnar component (two patients, two implants), bushing wear (one patient; one implant) and infection resulting in two-stage exchange and free soft tissue transfer with retention of the CPS spindle (one patient, one implant). Complications for all nine patients included one transient radial nerve palsy, one ulnar nerve sensory neurapraxia, one superficial infection, and two glenohumeral subluxations, one underwent revision surgery with implantation of a constrained liner.

Conclusions A compressive osseointegration endoprosthesis is an option for very difficult revisions or sarcoma resection in the upper extremity in which the remaining segment of host bone is too short for a conventional prosthesis. However, surgeons must inform patients that these are salvage operations, and revision surgery is common. Long-term followup of more patients is necessary to further document the survivorship of these implants in the upper extremity.

Level of Evidence Level IV, therapeutic study.

Introduction

Massive bone loss in the upper extremity is a challenging problem, in terms of the technical demands of reconstructing these defects and in improving patient function. In the upper extremity, endoprosthetic replacement represents one of a host of treatment modalities, including osteoarticular allografts, irradiation with reimplantation, claviculo pro humeri [7], and allograft-prosthesis composite reconstruction (Table 1). Endoprosthetic replacement is most commonly used for reconstruction after bone sarcoma resection; however, failed shoulder and elbow arthroplasty and massive posttraumatic bone loss are also potential indications for this procedure [10, 31].

The proximal humerus is a common location for primary and secondary malignancies involving bone [8, 9]. Tumors involving the elbow are less common [18, 27] and make up less than 1% of all bone sarcomas [18]. Aseptic loosening along with infection and instability are the most commonly reported complications in these patient populations [2, 8, 9, 11, 14, 18, 20, 22, 24–28, 30, 32].

Endoprostheses using principles of compressive osseointegration have been used with success in the lower extremity with similar rates of survivorship as more-traditional stemmed implants [6, 16, 21, 23]. The technology involves compression of a porous-coated spindle at the bone-implant interface by applying a preselected amount of force through spring-loaded Belleville washers and a traction bar, which is secured in adjacent bone with pin fixation. Its design is intended to enhance osseointegration through stable compression, preventing stress shielding and thus reducing the prevalence of aseptic loosening [21]. The implant is particularly useful in large bony defects with a small remaining end segment, where replacement of the entire length of the bone might otherwise be required [6]. We are aware of only two other published case reports, both from our institutions, discussing the use of the Compress® Compliant Pre-stress Device (CPS) (Biomet Inc, Warsaw, IN, USA) [10, 15] in the upper extremity. The current study extends the followup for these four patients and includes additional patients and surgical locations in a multicentered approach from institutions with expertise in this unique form of reconstruction.

We therefore asked (1) What proportion of upper extremity implants using compressive osseointegration fixation principles achieved durable short-term fixation, and what were the modes of failure? (2) What surgical complications resulted from reconstruction using this technique?

Table 1. Options for reconstruction of massive bone loss in the upper extremity

Compressive osseointegration endoprosthesis
Cemented or uncemented stemmed endoprosthesis
Allograft prosthetic composite
Allograft +/− vascularized fibula
Osteoarticular allograft
Claviculo pro humeri
Irradiation with reimplantation

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Patients and Methods

A multiinstitutional retrospective study involving four institutions from 2003 to 2014 identified nine patients (five women; four men) who were treated with 13 upper extremity endoprosthetic replacements using the CPS. Inclusion criteria for the study were skeletally mature adults older than 18 years treated with a CPS implant for reasons of malignancy, arthroplasty, or trauma involving the upper extremity.

Patient demographics, details of prior surgery, and indication for the CPS were recorded (Table 2). CPS implant variables such as the anchor plug size, number of fixation pins, amount of force applied, implant revision for any cause, revision for failure of the CPS mechanism, and the timing of implant revision were tabulated for all patients with a minimum 24-month followup (Table 3). Modes of failure were categorized as soft tissue, aseptic loosening, structural, infection, and tumor progression, per Henderson et al. [17]; CPS modes of failure were defined as lack of fixation, with or without bone or implant fracture [16]. All surgical complications were recorded for the entire cohort of nine patients (Table 4). Four patients were previously reported on in case reports from our institutions [10, 15], but are included to extend the followup for these implants and to add additional patients from other centers known to be performing this type of reconstruction.

Mean followup was 68 months (range, 24–141 months) for the eight patients with a minimum followup of 24 months; one patient (one implant) was lost to followup before that time with the implant intact at 14 months. For all nine study patients, the mean age was 45 years (range, 21–62 years). Five of nine patients had an initial diagnosis of a primary malignant bone tumor (two osteosarcoma, one Ewing's sarcoma, one spindle cell sarcoma, one malignant bone tumor not otherwise specified). These patients were treated with chemotherapy and surgery; none received radiation. Three patients had loose, infected total elbow arthroplasties, and one patient had massive bone loss in the setting of an open fracture. The distal humerus was involved in six patients, the proximal humerus in two, and the humeral diaphysis in one. All infections were managed with two-stage revision with removal of all previous implants, insertion of an antibiotic-impregnated spacer, and intravenous antibiotics before insertion of the CPS implant.

Surgical Indications and Technique

During the early part of the study period, the indications for use of a compressive prosthesis in our centers was revision of a previous tumor reconstruction (allograft-prosthetic composite or stemmed endoprosthetic reconstruction) (three patients; five implants), or revision arthroplasty with massive bone loss (three patients, four implants); more recently, indications became somewhat more permissive and included posttraumatic bone loss (one patient, one implant), primary bone sarcoma (one patient; one implant), and resections with very short remaining end segments after diaphyseal resection (one patient; two implants). Seven patients overall had the CPS implanted in the setting of very difficult revision surgery; two patients with sarcoma had multiple revisions of allograft prosthetic composites, one patient with trauma with an open fracture and 12 cm of bone loss had previous cement spacers and external fixation, and four patients had bone deficiency and loss of fixation in the setting of total elbow arthroplasty or endoprosthetic replacement (three infections; one aseptic loosening). The CPS was implanted primarily in one patient with a diaphyseal tumor and one with a proximal humeral primary bone sarcoma.

The Mini Compress® Compliant Pre-stress Device (Biomet Inc) was used in all patients at the bone-implant interface [8]. This was coupled with various modular endoprostheses to replace the segmental humeral bone loss. In distal humeral replacements, this was coupled with a fully constrained, hinged, cemented standard ulnar component. A custom Compress® implant was designed for use in the proximal ulna in one patient.

Preoperatively, the cortical thickness was measured, ensuring there was a minimum 2.5 mm. Requirements for remaining juxtaarticular bone was 4.6 cm to insert the short anchor plug and traction bar. After marking orientation, the bone was osteotomized perpendicular to its long axis. The bone then either was removed en bloc with the tumor or the previous arthroplasty bony cuts were refreshed to the appropriate level. A standard or short anchor plug then was selected, and the triple reamer was used to prepare the intramedullary canal [5]. The final triple reamer determined the anchor plug and centering sleeve sizes. An extramedullary drill guide was attached to the final anchor plug, which was inserted in the bone. This device was used to guide the transverse fixation pins, which are tapped into place after drilling of the bone. The number of transverse fixation pins depended on the cortical thickness and on the anchor plug size (Table 3). A face reamer then was used to prepare the osteotomized bone for the spindle. A centering sleeve helped to align the spindle with the traction bar and anchor. The amount of compressive force then was selected; 400 pounds was used for the majority of patients. No defined method of force selection currently exists, however, the maximum force tolerable to the remaining bone stock is the goal, and tends to be 800 N in the lower extremity and 400 N in the upper extremity. The nut driver was tightened, thereby compressing the Belleville washers,

Table 2. Patient demographics, previous surgery, and indications for a compressive osseointegration endoprosthesis

Patient	Age (years)	Gender	Diagnosis	Site	Previous surgery	Indication for CPS
1	45	Female	Fibroblastic osteosarcoma	DH	Inadvertent curettage + ORIF; wide resection + APC	Nonunion and aseptic loosening
2	62	Male	Osteosarcoma	DH	Extraarticular resection + multiple revisions APC (3); fascia lata and Achilles allograft for triceps insufficiency	Aseptic loosening
3	21	Female	Open fracture	DH	Irrigation, débridement, and external fixation	Open fracture with massive bone loss
4	62	Male	Infection	DH	TEA	Septic loosening
5	52	Female	Infection	DH	TEA	Septic loosening
6	30	Female	Sarcoma, NOS	PH	Proximal humeral EPR	Aseptic loosening
7	49	Male	Malignant bone tumor, NOS	PH	None	Tumor
8	65	Female	Infection	DH	ORIF; TEA	Septic loosening
9	23	Male	Ewing's sarcoma	Humeral diaphysis	None	Tumor

CPS = Compress® Compliant Pre-stress Device; NOS = not otherwise specified; DH = distal humerus; PH = proximal humerus; ORIF = open reduction and internal fixation; APC = allograft-prosthetic composite; TEA = total elbow arthroplasty; EPR = endoprosthetic reconstruction.

Table 3. Revision of compressive osseointegration endoprostheses in the upper extremity

Patient	CPS implant	Anchor plug size/ number fixation pins	Amount of force (pounds)	Revision for CPS failure	CPS implant survival (months)	Any-cause revision	Followup (months)
1	DH	12 mm/5 pins	400	No	72	None	68
2	DH	11 mm/5 pins	400	No	64	Revision standard ulnar component for aseptic loosening; revision for lack of fixation CPS ulnar component	66
	PU	2.9 mm/5 pins	400	Yes	6		
	PU	3.9 mm/5 pins	400	No	48		
3	DH	8 mm/6 pins	200	No	24	None	24
4	DH	Custom/5 pins	400	No	83	Revision for bushing exchange	83
5	DH	Unknown/5 pins	400	No	14	None	14
6	PH	14 mm/5 pins	400	No	54	Débridement + implant retention for superficial infection	54
7	PH	10 mm/5 pins	600	No	101	Joint capsule reconstruction for glenohumeral instability; two-stage revision + soft tissue flap for deep infection and skin erosion (CPS retained)	141
8	DH	11 mm /5 pins	400	Yes	6	Revision for lack of CPS fixation, interface collapse; revision standard ulnar component for aseptic loosening	72
	DH	11 mm /5 pins	400	No	66		
9	Humeral diaphysis (2)	Unknown/5 pins	400	No	39	None	36
		Unknown/5 pins	400	No	39	None	36

CPS = Compress® Compliant Pre-stress Device; DH = distal humerus; PU = proximal ulna; PH = proximal humerus.

and the additional intercalary segments were assembled to give the appropriate limb length.

Postoperatively, patients were treated with prophylactic antibiotics for 24 hours. Protocols for postoperative ROM and progression to activity slightly varied based on institution. Patients with proximal humeral implants generally wore a shoulder immobilizer, were limited to 5 pounds of lifting, and allowed pendulum exercises for 6 weeks. Progressive active ROM as tolerated was allowed from 6 to 12 weeks and weightlifting beyond 10 pounds was restricted indefinitely. For reconstructions involving the humeral diaphysis and elbow, progressive active ROM of the

Table 4. Modes of failure and complications after upper extremity compressive endoprosthetic reconstruction

Patient number	CPS bone	Mode of CPS failure	Timing of CPS failure (months)	Other mechanical failures	Other complications
1	DH	None	N/A	None	Transient radial nerve palsy
2	DH	None	N/A	Type 2 (aseptic loosening) standard ulnar component–revised to CPS	None
	PU	Type 3 (structural) fracture of ulnar traction bar, periprosthetic fracture	6	None	None
	PU	None	N/A	None	None
3	DH	None	N/A	None	None
4	DH	None	N/A	Type 3 (structural) bushing exchange	Ulnar nerve distribution numbness
5	DH	None	N/A	None	None
6	PH	None	N/A	None	Superficial infection, inferior glenohumeral subluxation
7	PH	None	N/A	Type 4 (deep infection)	None
				Type 1 (glenohumeral instability)	
8	DH	Type 3 (structural) deficient bone, failure of fixation	5	None	None
	DH	None	N/A	None	None
9	HD	None	N/A	None	None
	HD	None	N/A	None	None

CPS = Compress® Compliant Pre-stress Device; DH = distal humerus; PH = proximal humerus; PU = proximal ulna; HD = humeral diaphysis, N/A = not applicable.

shoulder and elbow was allowed once the wounds were healed. Lifting was restricted similar to the proximal humerus indefinitely.

Outcomes Assessment

Patients were seen in the clinic at 2, 6, and 12 weeks postoperatively and then every 3 months for the first year. Patients who had an arthroplasty then were followed on a yearly basis, and patients with tumors continued to be followed up every 3 months for Year 2, every 6 months from Years 3 to 5, and then yearly. Radiographs were performed at each visit.

Statistical Analysis

Given the small sample size, we report descriptive statistics alone. Proportions are presented to quantify revisions and surgical complications.

Results

Overall, the proportion of patients requiring any-cause revision was four of eight. Of the 12 implants accounted for beyond 2 years, six had undergone revision of any kind (Table 3). Only two implant revisions in two patients were attributable to lack of CPS fixation at the bone-implant interface; one of these patients had periprosthetic and implant fracture develop through the traction bar. These modes of failure can be defined as Type 3 structural failures (as per the classification system of Henderson et al. [17]). One patient (Patient 8) with a distal humeral CPS (Fig. 1) had lack of spindle fixation and ingrowth owing to deficient osseous support at 5 months postoperatively (Fig. 2). The second patient (Patient 2) with a distal humeral CPS underwent implantation of a custom proximal ulnar CPS owing to aseptic loosening of the standard, cemented ulnar component. This ulnar CPS component subsequently underwent revision for lack of incorporation and subsequent fracture through the traction bar at 6 months (Fig. 3). Both of these patients had initial conversion surgery with implantation of a CPS in the setting of a multiply operated extremity with allograft-prosthetic composite reconstruction, and both underwent revision surgery with implantation of another CPS. Four hundred pounds of force were selected for all but two patients; five transfixation pins were used in all but one patient who received six pins.

Other modes of failure were aseptic loosening, polyethylene wear, and infection [17]. Aseptic loosening of the standard ulnar component occurred in two patients (two implants): Patient 2 (previously described) and

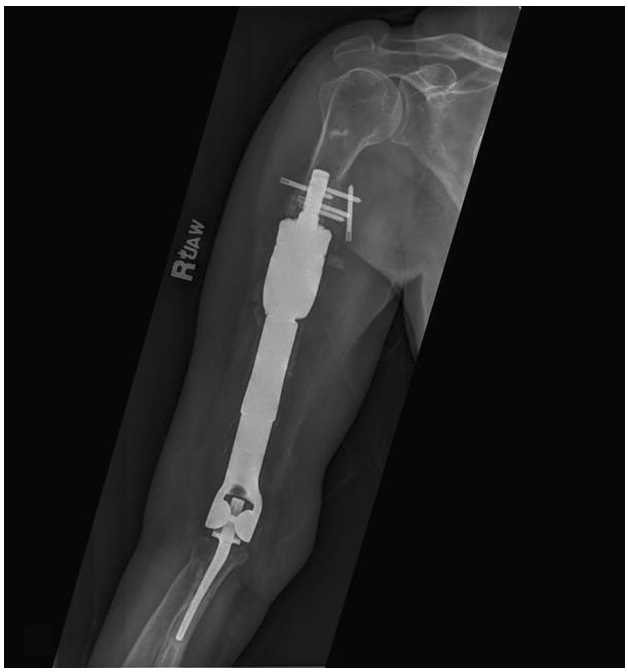

Fig. 1 The plain radiograph shows early structural failure with lack of ingrowth and bone-prosthesis interface collapse at 5 months postoperatively in Patient 8 who had a distal humeral CPS implanted for a failed total elbow arthroplasty. This implant was successfully revised to another CPS device.

Patient 8, who underwent eventual revision surgery with implantation of a stemmed, cemented radial component after aseptic loosening of two standard ulnar components. One patient (one implant) underwent exchange of polyethylene bushings at 83 months. One patient (Patient 7) had recurrent instability, skin erosion, and infection resulting in a two-stage exchange with the addition of a glenoid component and constrained liner. A free soft tissue transfer was performed for implant coverage and wound closure. The CPS spindle was well fixed and was retained during the two-stage exchange where all other metal components were exchanged. No recurrence of infection has occurred at 8 years followup.

Surgical complications included recurrent instability (2), skin breakdown (1), infections (2), and nerve palsy (2) (Table 4). Overall, four of nine patients had a complication develop postoperatively. One patient had a transient radial nerve palsy develop that resolved spontaneously at 9 months, and one patient had an ulnar nerve sensory neurapraxia. One patient with inferior subluxation of the glenohumeral joint had a superficial infection develop that successfully resolved with irrigation, débridement, and implant retention at 3 years postoperatively. There were no local recurrences in patients with bone tumors and no secondary amputations. All patients remain alive without evidence of disease.

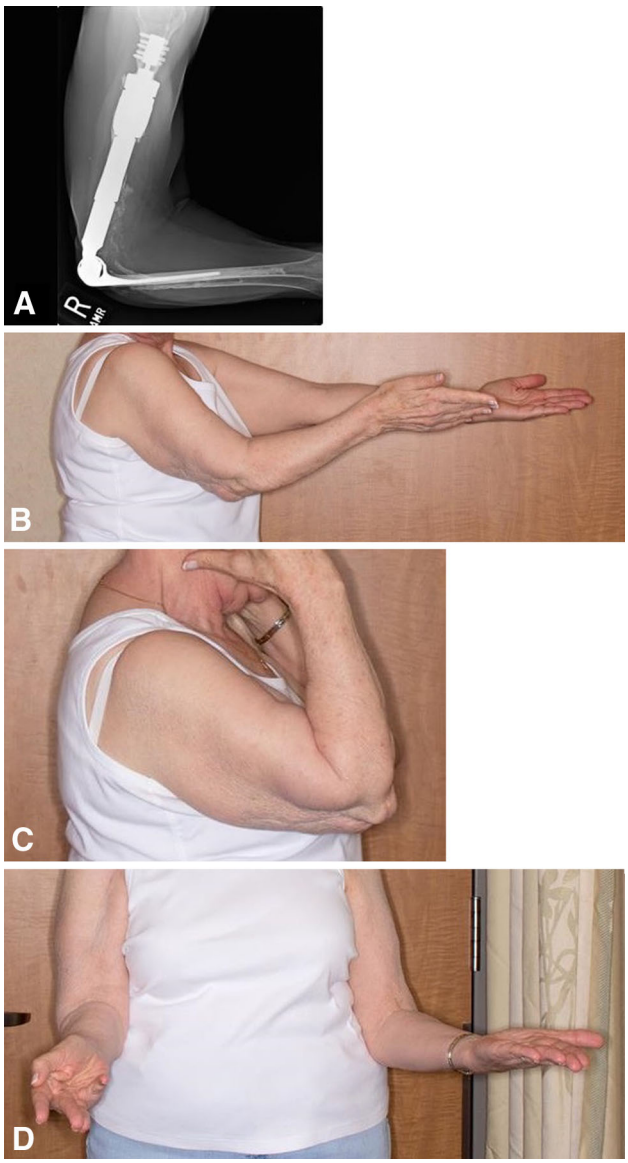

Fig. 2A–D (**A**) A plain radiograph shows a well-fixed, revised distal humeral CPS and cemented radial component 1.5 years after two subsequent revisions for aseptic loosening of the ulnar component in Patient 8. The patient is showing (**B**) elbow extension, (**C**) flexion, and (**D**) supination.

Discussion

Despite advances in modern endoprosthetic designs, reconstruction of massive bone loss in the upper extremity remains a challenge. An alternative to stemmed endoprostheses is self-adjusting, compliant, compressive osseointegration. The goal of this approach is to stimulate osseointegration and permanent biologic fixation by creating compression at the bone-implant interface. The implant design aims to avoid stem stress shielding and prevent osteolytic wear debris from accessing the intramedullary canal, thus decreasing the prevalence of aseptic loosening. The use of this implant in

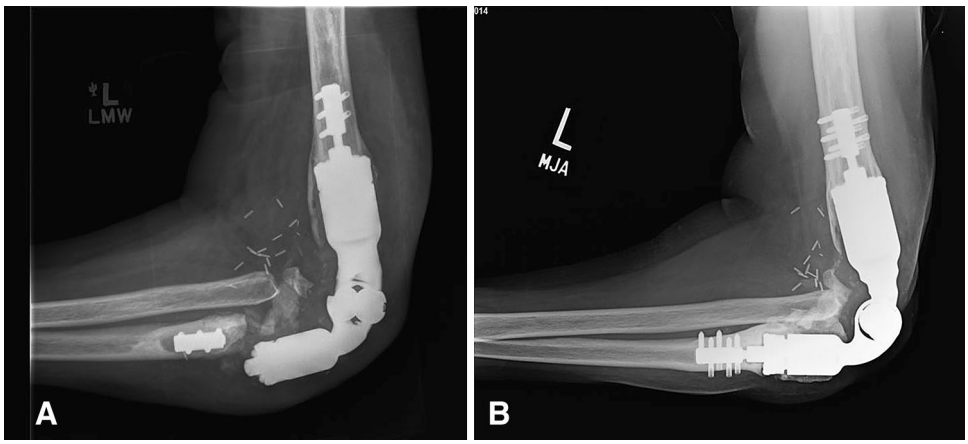

Fig 3A–B (**A**) A plain radiograph shows a well-fixed distal humeral compression implant adjacent to a failed ulnar compression component in Patient 2. The mode of failure was lack of ingrowth, periprosthetic fracture at the bone-prosthesis interface, and prosthetic fracture through the titanium traction bar. (**B**) The patient underwent revision surgery with implantation of another compression endoprosthesis.

Table 5. Summary of outcomes in upper extremity endoprosthetic reconstruction

Study	Endoprosthesis type	Sample size total (upper extremity)	Location	Aseptic loosening	Infection	Any-cause revision	Periprosthetic fracture	Secondary amputation	Mean followup (months)
Current study	CPS	8	2 PH, 6 DH, 1 diaphysis	2 ulna	2	4	0	0	68
Tyler et al. [29]	CPS	221 (6)	2 PH, 4 DH	NR	NR	0	0 (all 6 lower extremity)	0	50
Kulkarni et al. [18]	Stemmed EPR	10	DH	3	0	4	0	0	96
Abudu et al. [1]	Stemmed EPR	18 (2)	2 diaphysis	2	0	2	0	0	65 (median)
Ahlmann & Menendez [2]	Stemmed EPR	6 (1)	1 diaphysis	1	0	1	0	0	21.6
Raiss et al. [24]	Stemmed EPR	39	PH	1	2	5	0	1	38
Cannon et al. 8]	Stemmed EPR	83	PH	0	2	2	0	0	30
Kumar et al. [19]	Stemmed EPR	100	PH	6	1	7	0	8	108
Asavamongkolkul et al. [3]	Custom Stemmed EPR	59	30 PH, 4DH, 9 diaphysis	2	2	2	0	3	90

CPS = Compress® Compliant Pre-stress Device; EPR = endoprosthetic replacement; PH = proximal humerus; DH = distal humerus; NR = not reported.

patients with multiply operated extremities with severe bone deficiency is relatively novel in the upper limb. To our knowledge, only two case reports have been published addressing outcomes of four distal humeral compression implants [10, 15]. The patients in those studies are included in the current study with extended followup, additional surgical indications and implant locations across different institutions to provide a viable, alternative method of reconstruction for difficult salvage reconstructions in the upper limb.

There are several study limitations worth mentioning. The first is selection bias; the majority of our patients underwent very complex reconstructions, and often there were previous cement mantles and very thin remaining cortices. In these scenarios, the CPS implant was selected as an option to obtain a biologic solution where cemented options otherwise had failed, to gain fixation without removing the whole cement mantle (in those without infection) and to preserve more bone. We included all cases of patients from each respective institution, contacted other institutions known to be using the CPS implant, and the biomedical device company to identify other patients in whom this implant had been used as a result of its rarity. However, we have not captured data for every patient who was offered a different type of reconstruction or an amputation during the same time. Second, the small size and heterogeneity of the patient population make it difficult to compare results by diagnosis or anatomic site in the

upper extremity. Since the study is not powered nor designed to detect differences among these groups, we avoided comparisons and simply report the results of each reconstruction. In addition, our followup was short, and we expect that failures of some of these reconstructions may yet occur. Moreover, one patient was lost to followup before 2 years, and one patient who had 2 years followup (Patient 3) has not been evaluated during the last 6 years, thus we cannot be certain of the status of these reconstructions. Third, the multiinstitutional nature of the patient population may contribute to differences in surgical techniques and postoperative management, which might influence outcomes. However, surgical technique followed the implant manufacturer's recommended technique in all instances, and slight but minor variations in postoperative protocols were observed among centers.

Little is known about the behavior of the CPS in the upper extremity, but some reports have found the CPS to be generally reliable in the lower extremity [4, 12, 23], with 5- and 10-year implant survivorship ranging from 80% to 89% [16, 21]. Our series of complex upper limb reconstructions had a large proportion of patients who underwent revision surgery, however, revision of the CPS component was less common (two patients; two of 12 implants). These structural prosthetic failures were characterized by failure of spindle ingrowth, bone-implant interface collapse, and fracture of the traction bar in the second patient, similar to other studies of this implant [16, 21, 29]. Both of our failures occurred within the first 6 months of the index surgery, corroborating the findings of Healey et al. [16] that nearly all CPS mechanical failures occur early during the course of treatment. Modes of failure in the upper extremity tend to be site-specific, with aseptic loosening being common (Table 5). Numerous studies have reported the outcomes after implantation of stemmed endoprostheses in the proximal humerus [3, 8, 11, 14, 20, 22, 24–26, 28, 30, 32], with long-term implant survivorship ranging from 87% to 97% [8, 19]. Surgical outcomes have improved with modern endoprosthetics [3, 8, 11], and rates of aseptic loosening are less common than in the lower extremity, ranging from 0% to

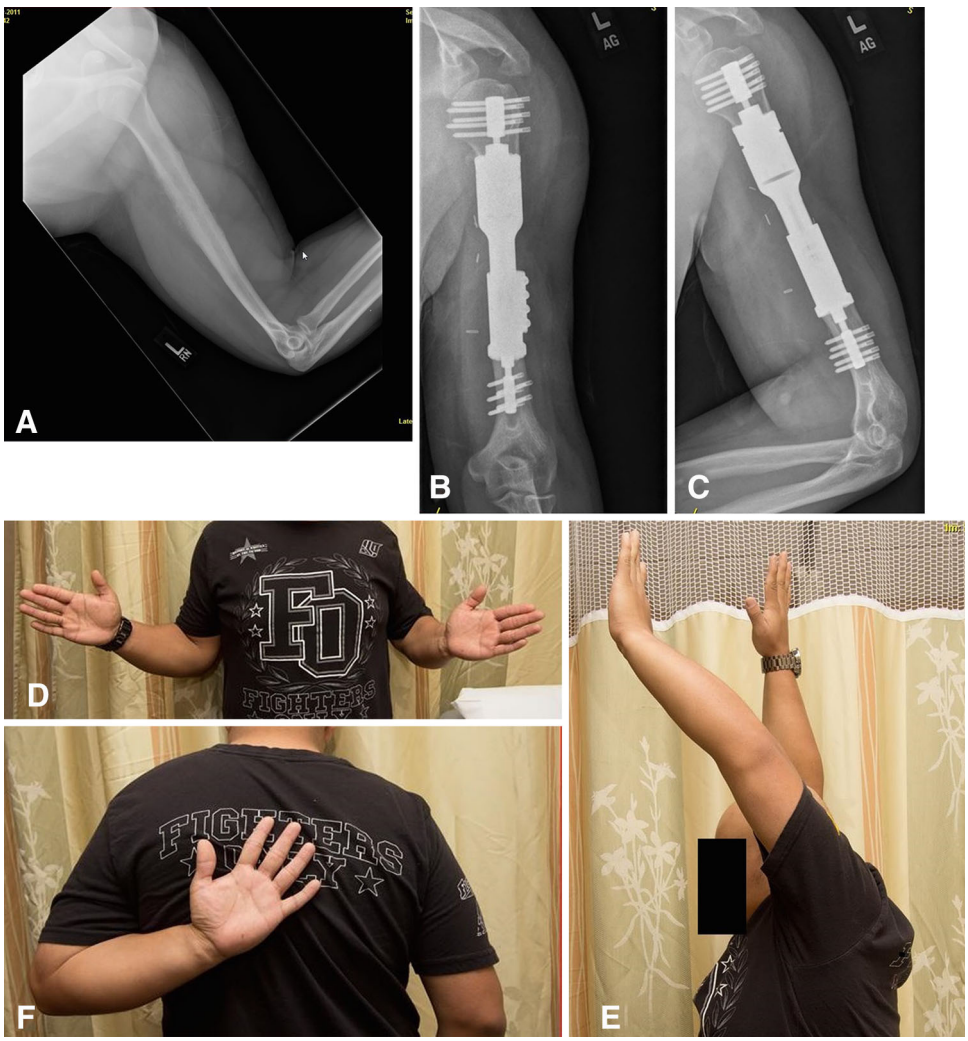

Fig. 4A–F (**A**) A preoperative radiograph for Patient 9, a 22-year-old man with Ewing's sarcoma of the proximal humerus, shows a poorly delineated lesion involving the humeral diaphysis with features of a primary, malignant bone sarcoma with soft tissue extension. Reconstruction using an intercalary compression implant was performed, and the patient's postoperative (**B**) AP and (**C**) lateral radiographs are shown. The patient is shown demonstrating ROM of his shoulder (**D**) in external rotation, (**E**) forward flexion, and (**F**) internal rotation.

7% in series mostly consisting of primary resection and reconstruction [3, 8, 9, 13, 19, 24]. Aseptic loosening did not occur in either of our patients with proximal humeral endoprostheses, but did prompt revision of the standard, cemented ulnar component in two of our patients with the distal humeral CPS. Similarly, Kulkarni et al. [18] reported on three of 10 patients with distal humeral stemmed endoprostheses who underwent revision for aseptic loosening of the humeral component, and an additional three had an exchange of polyethylene bushings at a later stage. Diaphyseal resections are rare, but aseptic loosening is exceedingly common and approaches 100% in small, heterogeneous retrospective series [1, 2]. This is in contrast to our patient (Fig. 4A), who despite a short followup of 36 months, has retained both CPS implants (Fig. 4B-C) and has good function (Fig. 4D-F).

The patients in this series underwent large, difficult reconstructions, and so it is not surprising that surgical complications were relatively common (Table 4). Many of these complications were site-specific, in particular those involving nerve injuries. We observed radial nerve palsy and an ulnar sensory neurapraxia, which both resolved spontaneously in one patient each and were associated with distal humeral resections. Kulkarni et al. [18] reported that no patient had nerve palsy, deep infection, or local recurrence, or needed a secondary amputation with distal humeral replacement in their series. Glenohumeral instability is commonplace after proximal humerus reconstruction, although many patients can be managed nonoperatively [3, 8, 19]. Raiss et al. [24] reported four humeral head dislocations in 39 stemmed MUTARS® implants (implantcast, Buxtehude, Germany); two underwent revision surgery to correct the version. Proximal humeral migration occurred in 29% of patients along with five anterior dislocations in the series reported by Cannon et al. [8]; however, only one needed revision. In our series, both patients with proximal humerus reconstructions had subluxation develop; one underwent two-stage revision with implantation of a constrained liner and free flap coverage for skin erosion and infection; the other patient was managed nonoperatively.

Conclusion

The use of endoprostheses using principles of compressive osseointegration is not widespread in the upper extremity. We observed timing and modes of CPS failure that are in keeping with those reported for the lower extremity. Our study showed that this technology adds to the armamentarium of surgical options for the experienced upper limb surgeon when dealing with massive bone loss, extremely poor bone quality, and difficult revision surgery. Of particular benefit is the ability to preserve juxtaarticular bone in long resections with short remaining end segments and in young patients who may need future revision surgery during their lifetime. Surgeons must inform patients, however, that these are salvage operations, and revision surgery is common. Long-term followup of more patients is necessary to further document the survivorship of these implants in the upper extremity.

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