Original Article

Computer navigation and distal femoral reconstruction in the oncologic patient[☆] Brian T. Palumbo^{a,*}, Eric Henderson^b, Justin Rizer^c, Douglas G. Letson^c, David Cheong^c^a Florida Orthopaedic Institute, 13020 Telecom Parkway N, Tampa, FL, United States^b Orthopaedic Oncology, Dartmouth-Hitchcock Medical Center, The Geisel School of Medicine at Dartmouth, Lebanon, NH, United States^c Moffitt Cancer Center, Tampa, FL, United States

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ABSTRACT

Objectives: As adjuvant treatments for musculoskeletal malignancies improve expectations of preserved function increase. We questioned whether computer navigation for distal femoral reconstruction would improve outcomes.

Methods: Twenty oncology patients were reviewed after distal femoral reconstruction using navigation. Outcomes included local recurrence, implant revision, patient function, patellofemoral complications and leg-length inequality.

Results: Implant survivorship was 85% at 26 months. There were no local recurrences and 3 failures for aseptic loosening. Good functional outcomes were observed in remaining cases.

Conclusion: Computer navigation for distal femoral reconstruction resulted in acceptable functional outcomes and implant survivorship. Reduced local recurrence were observed at intermediate follow-up.

Level of Evidence: Level IV

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1. Introduction

Limb-sparing surgery for primary and metastatic tumors of the distal femur has gained acceptance as a reliable surgical option for tumor resection and restoration of function.^{1–4} Distal femoral tumor resection requires surgical expertise and precision to achieve negative tumor margins while preserving important muscular and neurovascular structures. Further, final reconstruction necessitates experience with complicated megaprosthetic systems in order to restore limb-length and lower extremity alignment in the absence of native anatomic landmarks.

Inadequate tumor resection, limb-length discrepancy and component malrotation after distal femoral reconstruction are known challenges with conventional techniques and

instrumentation.^{5,6} In the setting of primary malignant bone tumors, insufficient tumor resection may result in positive surgical margins and is associated with increased local recurrence rates and an accompanying rise in secondary procedures.^{7–9} Inadequate restoration of femoral length can lead to joint line elevation, patella baja, and impingement.⁶ This may result in actual and perceived limb-length discrepancies, gait abnormalities, diminished functional scores and overall patient dissatisfaction.¹⁰ The absence of femoral landmarks risks femoral and tibial component malrotation resulting in patellofemoral instability, maltracking, anterior knee pain and diminished outcomes.^{1,5,6,11–14} These issues are not isolated to the field of musculoskeletal oncology but impact megaprosthetic reconstructions of failed total knee arthroplasties (TKAs) in the field of adult reconstruction.

Computer-assisted navigation (CAN) has been utilized in subspecialties such as adult reconstruction, spine, and trauma. Comparative studies of conventional jigs with CAN in TKA have been reported extensively in the literature but is without a clear consensus.^{15–19} While many studies demonstrate improved accuracy in conventional component alignment, long-term clinical benefit and survivorship remain unproven. We have used

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computerized tomography (CT) based CAN at our institution to aid in resection of musculoskeletal tumors and limb reconstruction since 2008. The clinical application of this technology allows the surgical team to create a three-dimensional platform for surgical planning and designation of reconstructive parameters with pre-operative and intraoperative CT and/or MR imaging. In theory, this allows for improved accuracy and precision in tumor resection, restoration of native femoral length and rotational alignment.

The purpose of this study is to report the clinical and radiographic results of distal femoral replacement using CAN for oncologic purposes. Further, we hypothesized that CAN would result in comparable clinical outcomes to recent historical controls while minimizing leg-length inequality and patellofemoral complications. Additionally, we hypothesized that CAN would improve tumor resection and lower the incidence of positive surgical margins without a significant increase in operative time, blood loss, or complications.

2. Methods

Our institutional database was reviewed for all distal femoral replacements employing CAN. From April 2008 to September 2012, twenty consecutive distal femoral tumor resections and endoprosthesis reconstructions were performed using CAN. All surgeries were performed by two surgeons (DC and DGL) at one, National Cancer Institute (NCI) designated institution. Appropriate institutional investigational approval was obtained prior to initiation of the study.

An independent, retrospective review of patient's medical records were completed by two observers (X.H. and J.R.). There were seven females and 13 males with a mean age of 40 years (range, 15–73 years). The median body mass index (BMI) was 29 (range, 16–44). Thirteen cases were performed on the right lower extremity and seven on the left. Surgeries were performed for primary sarcomas of bone in 16 cases and metastatic disease in four. Perioperative data collected included estimated blood loss, pre- and post-operative hemoglobin levels, blood transfusion rates, and length of hospital stay. Clinical data included functional assessment by post-operative Musculoskeletal Tumor Society scores (MSTS), range of motion, pain, complications, and revision surgery (Table 1).

2.1. MSTS scoring system

Described by Enneking,²⁰ the MSTS is based on patient function (pain, functional activities, and emotional acceptance) and factors specific to either the upper limb (hand positioning, manual dexterity, and lifting ability) or the lower limb (use of external supports, walking ability, and gait).²⁰ There are a total of 6 categories that the evaluator scores from 0 to 5 based on established criteria for a total score of 30 points. In each category specific values (0, 1, 3, or 5) equate to specific levels of performance. Intermediate values of 2 or 4 are assigned when, based on the examiners determination, the performance is between the specified values. Descriptive terms such as excellent, good, fair, or poor are not assigned to specific numeric ranges: rather the result is expressed as the proportion of expected normal function for the patient.

2.2. Surgical technique

All patients received pre-operative prophylactic antibiotics and all surgeries were performed through a lateral sub-vastus approach to the distal femur. Extremity tourniquets were not used and hemostasis was maintained with the use of electrocautery and suture ligatures. The femoral component was cemented in 16 (76%) cases and press-fit in four (20%) cases while all tibial components were cemented. The Global Modular Restoration System (GMRS) (Stryker Orthopaedics, Mahwah, New Jersey) was used for endoprosthesis reconstruction in all cases. All patients received postoperative prophylactic antibiotics intravenously for the first 24 to 48 h and then orally for six weeks as part of the standard practices of the attending surgeons. Patients with cemented femoral components were allowed full-weight-bearing privileges on the first post-operative day whereas patients with press-fit femoral components were restricted to partial-weight-bearing for six weeks in the post-operative period.

2.3. Computer navigation technique

A CT and/or MRI of the affected extremity were obtained within two weeks of the planned surgery and imaging data were loaded into the Stryker Navigation System II software suite (Stryker

Table 1
Demographics, MSTS Score and Complications in all patients.

Patient	Age (years)	Gender	Diagnosis	MSTS Score	Complications
1	70	M	Metastatic Renal Cell Carcinoma	27	none
2	43	M	Chondrosarcoma	17	none
3	20	M	Chondroblastic Osteosarcoma	30	none
4	56	F	Endometrial Sarcoma - Metastatic	30	none
5	26	M	Osteosarcoma	25	none
6	46	F	Metastatic adenocarcinoma	14	Died from metastatic disease
7	23	M	Osteosarcoma	27	Died from metastatic disease
8	67	F	Chondrosarcoma	28	Surgical I&D and polyethylene exchange for infection
9	15	M	Osteosarcoma	17	None
10	73	F	Metastatic Renal Cell Carcinoma	*	Died from metastatic disease
11	26	M	Parosteal Osteosarcoma	22	Revision for femoral loosening
12	71	F	Chondrosarcoma	20	Surgical I&D and polyethylene exchange for infection
13	18	M	Osteoblastic Osteosarcoma	17	None
14	57	M	Chondrosarcoma	*	Lost to Followup
15	37	F	Dedifferentiated Parosteal Sarcoma	28	None
16	33	M	Osteosarcoma	14	None
17	19	M	Osteosarcoma	23	Patellar tendon avulsion after fall
18	47	F	Chondrosarcoma	24	Arthroscopic lysis of adhesions for arthrofibrosis
19	21	M	Periosteal sarcoma	10	Revision for femoral loosening
20	26	M	Osteosarcoma	25	Revision for femoral loosening

*Insufficient clinical data.

Orthopaedics, Kalamazoo, MI). Immediately pre-operatively, resection length, rotation, and anatomic landmarks were identified and digitally annotated. Intraoperatively, one tracker is fixed to a stable portion of the patient's bony anatomy via percutaneous Steinmann pins. This was a site that would not be resected or

manipulated, preferably on the bone affected by the tumor. One of two techniques was utilized to validate the patient's anatomy intraoperatively with pre-operative imaging. One method involved use of intraoperative fluoroscopy to obtain a 360° view of the operative site and was merged with pre-op CT or MRI. The second

Fig. 1. A. AP and lateral radiograph of a high-grade osteosarcoma of the distal femur in a 15 year-old male. B. A coronal T1- and STIR sequence magnetic resonance image of the same femur. C. Intraoperative photograph of the patient's extremity with the distal femur exposed and a navigation sensor implanted percutaneously in the proximal femur. D. Image of the surgeon using a navigated pointer to verify distal femoral rotation.

method utilized a manual-tracking instrument to register specific, intraoperative landmarks to their corresponding points on pre-operative imaging. Once validation was complete, registered navigated tools, such as pointers and osteotomes were used to execute the pre-operatively templated resection levels and planes. Navigated pointers were also used to measure implant rotation and compare limb-lengths intraoperatively (Fig. 1).

2.4. Pathological analysis

Margin analysis of all specimens were performed both intra-operatively and after decalcification by a board certified pathologist specializing in musculoskeletal oncology for the presence of malignant cells within a 1 cm marrow margin of the specimen. If malignant cells were observed in this zone additional resection of bone was performed until a negative marrow margin was obtained. Margin status of the remainder of the specimen was also assessed postoperatively and included evaluation of the soft-tissue envelope surrounding the specimen.

2.5. Radiographic analysis

Serial radiographs were obtained immediately post-operatively in the recovery room, at 6 weeks, 3 months, 6 months and then yearly. Post-operative computed tomography (CT) scanograms of complete bilateral lower extremities were performed to define leg-length discrepancies. Standard radiographs and scanograms were reviewed by a single independent observer (H.X) for the presence of limb-length discrepancies and evidence of mechanical failure and/or loosening. Limb-length discrepancy was assessed with digital imaging software (MedView, Ann Arbor, Mi) by measuring the distance from the acetabular roof to the tip of the medial malleolus (total lower extremity length) and the distance from the

acetabular roof to the proximal extent tibial baseplate or the tibial plateau (femoral length) (Fig. 2). Discrepancies were calculated as absolute values. Loosening of non-cemented femoral stems were diagnosed according to the criteria established by Engh and loosening of cemented stems according to criteria established by O'Neill and Harris, respectively.^{21,22}

2.6. Implant survival

Failure was defined as those cases requiring revision of the femoral and/or tibial components for any reason; routine bushing exchange was not considered a failure. The mode of failure was classified according to the system established by Henderson et al.^{3,23} This system delineates between mechanical and non-mechanical causes. Mechanical modes were defined as Type I, soft-tissue failures; Type II, aseptic loosening; and Type III, structural failure. Non-mechanical causes are categorized as Type IV, periprosthetic infection not amenable to component retention; and Type V; tumor progression.

3. Results

The mean time to latest follow-up was 26 months (range, 3 to 51 months). Of the 20 patients who underwent distal femur reconstruction with computer navigation, 3 died and 1 patient was lost to follow-up. All three deaths were due to progression of metastatic disease that was diagnosed prior to surgery, leaving 17 patients (85%) alive at final analysis. One 23 year-old male died four months postoperatively due to widespread pulmonary metastasis from high-grade osteosarcoma. One 46 year-old female with metastatic adenocarcinoma died 2 years post-operatively due to complications from metastatic disease. A 73 year-old woman with metastatic renal cell carcinoma died 3 months postoperatively.

Fig. 2. CT scanograms of the lower extremities demonstrating the digital measuring technique for (2A) femoral length discrepancy and (2B) leg-length discrepancy.

Insufficient data was available for this patient for calculation of MSTs score or radiographic evaluation. None of the patients who died required additional surgeries related to their reconstructions. One patient with a low-grade chondrosarcoma was lost to follow-up 5 months after surgery. This patient lacked sufficient clinical and radiographic data to be included in the analysis.

The mean operative time was four hours (range, 2.5–7 h) and the average surgical blood loss was 286cc (range, 150–1000cc). The mean pre- and post-operative hemoglobin levels were 12.2 g/dl (range, 9.3–15 g/dl) and 9.1 (range, 6.3–12.4 g/dl). Two patients (10%) received allogeneic blood transfusions post-operatively. The average hospital stay was 5.2 days (range, 3–10) and all patients were discharged home. Acute post-operative complications included 3 deep venous thromboses that were successfully treated with oral anticoagulation. There were two periprosthetic infections diagnosed at 3 weeks and 2 months postoperatively. Both were successfully managed with irrigation and debridement of the knee joint and exchange of all polyethylene components. In both cases their prosthesis was retained.

The mean pre- and postoperative arc of motion was 106° (range, 43°–128°) and 114° (range, 80°–130°), respectively. The mean post-operative MSTs score was 22 (range, 10–30). Only two patients required walking assistance devices postoperatively; one occasionally using a cane and one frequently using a walker. One patient fell three months post-operatively and avulsed her patella tendon. She refused revision knee surgery but required a hinged knee brace for ambulation. There were no other documented cases of extensor mechanism or patellofemoral complications including anterior knee pain, evidence of impingement, patella maltracking or dislocation.

Implant survival at latest follow-up was 85% with femoral and/or tibial revision as the endpoint. There were three Type II failures (aseptic loosening) and all were loosening of press-fit distal femoral components. These were revised at five months, six months, and 14 months postoperatively. Failures included one 26-year-old male with a final MSTs score of 26 and 123° arc of motion

after revision surgery. The second patient was a 21-year-old male with persistent knee pain after revision, a final MSTs score of 10 and range of motion of 105°. The third failure was a 26-year-old male with a final MSTs score of 25, a range of motion of 118° and persistent ipsilateral hip pain that necessitated narcotic medication. None of these cases required additional surgery related to their reconstruction. There were no cases of clinical or radiographic loosening of cemented components. One patient required arthroscopic lysis of adhesions and manipulation under anesthesia five months postoperatively for stiffness. His final MSTs score was 24 and he had a 40° flexion contracture.

All surgical margins were negative on final pathological analysis and there were no Type V (tumor progression) failures in our series to date. As previously mentioned, one patient with high-grade osteosarcoma of the left distal femur died four months postoperatively due to extensive pulmonary metastases. However he demonstrated no any evidence of local recurrence post-operatively and required no additional surgeries related to his reconstruction. The other two deaths in the series were due to progression of metastasis that was diagnosed prior to reconstructive surgery; there was no evidence of local recurrence in these cases.

The mean absolute femoral length discrepancy measured 0.67 cm (range, –0.75 cm–1.3 cm) and the mean overall absolute leg-length discrepancy was 0.69 cm (range, –1 cm–1.8 cm). There were no cases of symptomatic leg-length discrepancies and no patients required shoe lifts post-operatively.

4. Discussion

In this study of 20 distal femoral tumor resections and endoprosthetic reconstructions using CAN we observed excellent improvements in pain and function postoperatively in the short- and intermediate-term. This compares favorably to previous reports in the literature (Table 2). Negative surgical margins were achieved in 100% of cases and there were no local recurrences. Other than one tibial tubercle avulsion after a fall, there were no

Table 2
Historical review of distal femoral reconstruction for oncologic patients.

Lead Author	Case Number	Prosthesis Type	Followup (months)	Local Recurrence	Implant Survival Rate	Functional Outcome
Palumbo (current study)	20	Stryker Global Modular Replacement System	26	0%	85% at 4 years	mean MSTs score 21 (range, 43 to 128) not included
Henderson (literature review) (JBJS Am. 2011)	951	Stryker Global Modular Replacement System, Howmedica Modular Resection System, Kotz Modular Replacement System, Modular Replacement System and custom implants	NR	4.70%	73%	
Kinkel (J of Surg Onc. 2010)	77	MUTARS prosthesis	46	5%	57% at 5 years	mean Enneking score 73% (20% to 100%)
Jeys (JBJS Am. 2008)	228	Custom prostheses	NR	5%	68% at 10 years; 46% at 20 years	NR
Myers (JBJS Br. 2007)	335	Custom prostheses	144	6%	83% at 5 years; 67% at 10 years; 51% at 15 years	NR
Biau (JBJS Am. 2006)	91	GUEPAR-I and GUEPAR-II	62	7%	80% at 5 yrs; 52% at 10 yrs	40% -low activity; 56% moderate activity; 4% high activity
Ahlmann (JBJS Br 2006)	78	Howmedica MSRS	NR	3%	75% at 5 years, 58% at 10 years	mean MSTs score 22.9 (no range)
Wong (CORR 2006)	77	MRS Kinematic rotating hinge, Global Modular Replacement System, Duration rotating hinge	52	6.50%	84% at 5 years, 79% at 10 years	mean MSTs score 30 (no range)
Bickels (CORR 2002)	108	Custom prostheses	93.6	0%	93% at 5 years; 88% at 10 years	MSTs: 85% good to excellent; 8% fair; 6% poor
Kawai (JBJS Am. 1998)	40	Lane-Burstein knee	96	0%	85% at 3 years, 67% at 5 years, 48% at 10 years	mean MSTs 24 (range, 14–29)

NR = not recorded.

extensor mechanism or patellofemoral complications including anterior knee pain, patella maltracking or dislocation. Additionally, we report excellent restoration of leg-lengths, both radiographically and clinically with no cases of symptomatic leg-length discrepancies in our series.

Revision surgery was required in three cases; all of who had press-fit femoral stems that demonstrated loosening clinically and radiographically. At the time of revision surgery gross stem instability was apparent and cemented revision stems were utilized. A literature review performed by Henderson et al. reported that of 2861 distal femoral replacements for oncologic patients, 11.5% failed for aseptic loosening.³ While our 15% failure rate is higher, all of these failures were of non-cemented components. It is unclear if these failures were due to technical error, patient non-compliance with weight bearing or the potential negative biological effects of multimodal cancer treatment on stem ingrowth. The press-fit technique continues to be used by the attending surgeons, specifically in young adults with good ingrowth potential. Although evidence supporting this technique is limited, most series demonstrate promising results in regards to aseptic loosening. Griffen et al. reported a 2% aseptic loosening rate in 74 fixed-hinge distal femoral reconstructions.²⁴ Bruns et al. reported no cases of aseptic loosening in nine cementless distal femoral megaprotheses.²⁵

The challenge of restoring the native joint line and femoral rotation in the failed TKA with severe distal femoral bone loss mimics the oncologic scenario. Loss of anatomic landmarks such as the posterior femoral condyles, epicondyles and the trochlear groove may challenge even the most seasoned reconstructive surgeon. If femoral rotation is inappropriately restored, patella maltracking, patellofemoral pain and dislocation may result.⁵ Restoring the native joint line and leg-length is important as well. If not appropriately restored it is known to impact function, cause gait abnormalities, and increase joint reactive force. Moreover, inadequate length restoration may lead to patella baja, impingement and contribute to an unacceptably high rate of patellar complications.⁶ Schwab et al. reported a 63% patellar complication rate in 43 patients after distal femoral reconstruction. In this series there were two patellar fractures, two cases of patellar osteonecrosis and patella baja and impingement were common.⁶ Iverson et al. evaluated 638 Medicare patients age 65 years and older after primary total hip arthroplasty. They observed that a perceived leg-length discrepancy was associated with a 2-fold likelihood of poor functional outcomes.¹⁰

Megaprosthesis reconstruction for failed TKA is a salvage operation when no alternatives exist and is accompanied by inferior outcomes in most reported series.^{5,26,27} Holl et al. reported a mean improvement in Knee Society Scores (KSS) of 43–68 in 15 distal femoral reconstructions for failed TKAs with severe bone loss. They noted that, while function improved in most cases, patients continued to require walking assistance devices and had inferior functional outcomes relative to primary and revision TKA patients.²⁶ Additionally, Springer et al. reported a 13% patellar complication rate in 69 kinematic rotating hinge implants for failed TKA with a mean follow-up of 75 months.⁵ Interestingly, the issue of patellofemoral complications and pain is rarely cited in most relevant studies. This is likely due to infrequent megaprotheses use, relatively few reported series and generally lower expectations in this population subset. As the use of these devices expand in the subspecialties of orthopaedic trauma and adult reconstruction, the incidence of patellofemoral issues may become more apparent and better reported.

In the current study, CAN permitted us to reference the patient's native anatomy to re-approximate femoral rotation and length. In doing so we accurately restored leg lengths to a mean of 0.69 cm and there were no clinically significant leg-length discrepancies

noted. Additionally, other than one traumatic tibial tendon avulsion, we reproducibly restored patellar tracking and obviated extensor mechanism and patellofemoral complications in the remaining cases. While important differences exist among arthritic and oncologic cases, we believe that CAN is a novel, safe and effective method to restore rotation and length in the absence of normal anatomical landmarks in both of these scenarios.

Type V failure or local tumor recurrence is a devastating complication after primary tumor resection and is associated with an increased risk of morbidity as well as a need for additional surgery.^{7–9} Completely resecting the tumor during the primary surgery is crucial in minimizing the risk of local recurrence. However, in the case of distal femoral tumors, often only marginal resection is possible due to the close proximity of important neurovascular structures. CT-based computer navigation is useful in these circumstances and allows for improved accuracy in planning tumor resection. Mergers of MRI short tau inversion recovery-weighted (STIR) sequences and CT imaging allows for visualization of the reactive zone intraoperatively and whether the tumor's margins involve neurovascular structures during dissection. Local recurrence rates up to 7% of have been reported after limb sparing surgery for tumors involving the distal femur with conventional techniques and instrumentation.^{28,29} (Table 2) Henderson et al. reported a 3.9% incidence of local recurrence of in 2861 distal femoral replacements.³ Given that no local recurrences occurred in this series we submit that CAN may provide an advantage in tumor resection and warrants further investigation.

There are several limitations of this study. Its retrospective design and lack of a comparative cohort make defining a significant clinical and radiographic benefits of CAN difficult. While this study does not attempt to infer an absolute benefit of CAN relative to conventional methods, we do find that our results compare well to recent historical controls (Table 2). Additionally, good clinical outcomes and survivorship were achieved without negatively impacting perioperative metrics such as operative time and blood loss. Although we specifically reviewed patient data for patellofemoral complications, lack of prospective clinical analysis may have lead to unreported patellar symptoms and complications. Moreover, while scanograms were employed for femur-length and leg-length measurement, post-operative CT to assess component rotation was not performed because we felt additional radiation exposure was unwarranted in the absence of patellofemoral symptoms. While the cohort size was small and follow-up short, this reflects upon the relative infrequency of distal femoral reconstructions and the complex nature of following and managing oncologic patients.

5. Conclusion

In this study of 20 distal femoral reconstructions with CAN we observed good clinical and radiographic outcomes relative to recent historical controls. Other than one tibial tubercle avulsion after a fall, there were no patellofemoral complications or clinically significant leg length discrepancies in this series. Additionally, there were no cases of positive tumor margins noted on final pathologic analysis and no local recurrences have occurred to date. This study represents a novel use of computer navigation and our findings signify an encouraging benefit of restoring normal anatomic parameters in the absence of native landmarks in oncology patients. Further, similar utility may be found in revision knee arthroplasty with severe femoral bone loss.

Conflict of interest

The authors have none to declare.

Authors contribution

Dr. Palumbo contributed to study development, data analysis and writing of the manuscript.

Dr. Henderson contributed to study development, data collection, data analysis and editing of the manuscript.

Dr. Rizer collected clinical data, performed data analysis and assisted in manuscript editing.

Dr. Letson contributed to study development, data analysis and edited the manuscript.

Dr. Cheong is the senior author, contributed to study development, data analysis and edited the manuscript.

Institutional approval was obtained prior to initiation of this study.

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