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Original Article

Comparison of gait parameters in distal femoral replacement using a metallic endoprosthesis versus allograft reconstruction

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ABSTRACT

Background/aim: Restoration of gait mechanics after reconstruction have been associated with improved functional outcomes and increased longevity of the reconstruction. The goal of this study is to compare the gait mechanics of an allograft reconstruction of the distal femur to both metallic endoprosthetic reconstruction relative to normal control subjects.

Methods: Gait parameters were captured using motion capture system, and then analyzed and compared for patients with metallic endoprosthetic reconstructions, and patients with allograft reconstructions of the distal femur following resection of malignant bone tumor, with subjects having no history of musculoskeletal disorders serving as a control group.

Results: All reconstructed distal femurs following tumor resection resulted in decreased range of motion reflected in observed flexion/extension angles compared to the normal limbs. The allograft reconstructed knees demonstrated normal patterns of rotation whereas the metal subjects had abnormal patterns of rotation and statistically significant differences in rotational moments.

Conclusion: Allograft distal femoral reconstruction after malignant excision remains a viable option for surgeons faced with problems associated with iatrogenic muscle, bone and soft tissue defects.

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1. Introduction

Malignant bone tumors of the distal femur are often managed with wide excision of the primary lesion without amputation. The goals of limb salvage surgery are to retain as much uninvolved tissue as possible to maximize the functional outcome for the patient. The reconstruction options for limb preserving segmental distal femoral resection include metallic endoprosthesis, osteoarticular allograft, intercalary allograft arthrodesis, and tumor sterilization (radiation, cryotherapy or microwave treatment) of the distal femur.^{1–5}

Acceptable medium to long-term outcomes have been reported for both endoprosthetic and osteoarticular allograft reconstruction types.^{3,4,6} The advantages and disadvantages of each reconstruction type have been described elsewhere,^{3,7} but of particular interest to this study are the benefits derived from having soft tissue attachments on the allograft for the purposes of reconstruction and thus reproducing normal kinematics of the knee. Endoprosthetic reconstructions of the distal femur rely on fully constrained mechanical articulations to provide mediolateral and anteroposterior stability. The allograft reconstruction provides attachment points for collateral and cruciate ligaments as well as retained muscles from the thigh and pelvis. Loss of the cruciate ligaments in the native knee has shown to result in diminished proprioception in the knee.^{8,9} The complex relationship of lower extremity proprioception and muscle response is thought to play an important role in the standing balance of subject.¹⁰ Standing balance, more than muscle strength, has been found to correlate with measureable gait parameters in patients undergoing lower extremity physical therapy following knee injury.¹¹

Restoration of gait mechanics after reconstruction have been associated with improved functional outcomes and increased longevity of the reconstruction.^{12,13} Prior studies have thoroughly evaluated the mechanics of the distal femoral metallic endoprosthesis both in clinical follow up and in implanted telemetric studies.^{12–14} The goal of this study is to compare the gait mechanics of an allograft reconstruction of the distal femur to both metallic endoprosthetic reconstruction relative to normal control subjects. We hypothesized that proprioception would be improved in the allograft reconstruction group and this would be evidenced as well in more normal gait parameters.

2. Methods

Patients with malignant and benign aggressive tumors of the distal femur who underwent wide resection and reconstruction of the distal femur were identified from our institutional database. We selected a group of patients that lived in close proximity of the testing area, were independent ambulators and were followed for at least two years from the date of surgery.

Ten patients who underwent resection of a malignant bone tumor participated in a post-operative evaluation of gait parameters. Five of the patients had resection of malignancy followed by metallic endoprosthetic reconstruction. Five

patients had allograft reconstructions of the distal femur. Ten volunteer subjects served as a control for the same gait parameters. The demographics of the two study groups are shown in Table 1. Notable is the significant difference in the age of the patients with the allograft group and the time from surgery.

Data was collected using eight Vicon[®] motion capture cameras (Vicon Motion Systems, Inc, Oxford, England) with standard reflective markers and four Kistler[®] force plates (Kistler Instrumente AG, Winterthur, Switzerland). All measurements completed during the testing session using participants who provided informed consent prior to enrolling in this study. Procedures were approved by the University of Miami's institutional review board for human subjects. Trials consisted of patients walking naturally over force plates more than ten times.

The six best trials were selected whereby the subject's foot contacted one force plate at any one moment during the gait cycle. The three groups analyzed were patients with metal replacements (Stryker[®] cemented modular rotating knee system without patellar resurfacing), fresh frozen osteoarticular allografts (all from a single tissue bank procured aseptically and cryopreserved with glycerol followed by controlled rate freezing), and normal control subjects. Joint position during gait cycle was recorded to allow for classification of the gait pattern by descriptive statistics.

To assess proprioception, the center of pressure or the point location of the vertical ground reaction force vector, was measured. Sway or the displacement of the body from the center of gravity was determined. To conduct this experiment, subjects stood with one foot on separate force plates simultaneously for 45 s. The variations in the center of pressure in the anteroposterior and mediolateral directions were recorded in millimeters. The subjects were tested with their eyes closed to maximize the reliance on proprioceptive input from the extremities to maintain standing balance. Means and standard deviations were collected for the parametric data and groups were compared using Student's t-test with alpha set to 0.05 to assess for statistical significance.

Table 1 – Patients demographics.

	Metallic	Allograft	p
Sex (% male)	80.00	80.00	
No of subjects	5	5	
Height (cm)	175.75 (±8.49)	163.00 (±8.01)	
Weight (kg)	89.63 (±15.46)	66.04 (±8.27)	
Age in years	42.25 (±5.9)	28.60 (± 5.6)	0.006
Post operative limb length discrepancy	1 cm	3 cm	0.095
Side	2R, 3L	2R, 3L	
Years post operative	3.6 (±0.8)	7.4 (±5.4)	<0.0001
Control group			
No of subjects			10
Height (cm)			175.75 (±1.90)
Weight (kg)			71.81 (±3.86)
Age in years			26.58 (±0.97)

Table 2 – Gait parameters of the two reconstruction groups compared to normal reference ranges (“Gait analysis: an introduction”, by Michael W. Whittle, Oxford: Butterworth-Heinemann, 2001).

	Metal	Allograft	p	Normal
Cadence (steps/min)	103 (± 10)	107.75 (± 8.30)	0.293	86–126
Stride Length (m)	1.31 (± 0.13)	1.34 (± 0.11)	0.657	1.22 to 1.82
Speed (m/s)	1.12 (± 0.16)	1.20 (± 0.11)	0.289	0.96 to 1.68
Step length ratio	49.83 (± 1.17)	50.25 (± 0.96)	0.420	50.00
Stance duration (operative %)	70.5 (± 7.42)	62.75 (± 4.11)	0.050	62.00
Stance duration (non-operative %)	73.17 (± 8.775)	64.25 (± 4.11)	0.050	62.00
Difference in stance phases	2.67 (± 2.66)	1.5 (± 3.11)	0.331	

3. Results

The allograft patients were assessed at 7.4 ± 5.4 years after the reconstruction and the metallic reconstruction patients were assessed at an average 3.6 ± 0.8 years post operatively ($p < 0.0001$). The volunteer controls were tested during the same testing session as the reconstruction patients.

The group of patients with allograft reconstructions showed similar cadence, speed, stride length, and step ratios compared to metallic implants which were in the range of normal healthy controls. The differences in the groups were that the metallic endoprosthetic reconstructions all showed increase in stance phase for both limbs (71% operative and 73% nonoperative) compared to the allograft reconstruction group (63% and 64%, $p = 0.05$ for both) who retained a normal stance phase duration for both operative and nonoperative limbs ($p = 0.74, 0.35$). The stance phase duration for the operative limb was universally decreased throughout both groups but the difference in duration between the limbs was not significant. These results are summarized in Table 2.

Center of pressure technique on pressure plates yielded sway measurements in the anteroposterior and mediolateral directions for reconstructed leg. The M/L sway in millimeters for the control, allograft and metallic reconstruction groups were 20.79 ± 1.60 , 5.80 ± 1.33 and 25.37 ± 8.62 respectively. The A/P sway in millimeters for the groups in the same order were 19.76 ± 2.23 , 26.03 ± 9.36 and 41.00 ± 12.53 respectively as shown in Table 3. The differences reached significance ($p < 0.05$) for the allograft group compared to control and metal groups in the M/L direction, and for the metal group compared to controls in the A/P direction. There was no significant difference in the A/P sway between the allograft and control groups (see Fig. 1).

Knee flexion and extension differences between limbs were increased in both metal and allograft groups compared to control subjects. Knee rotation had a near-normal pattern throughout the gait cycle for allograft subjects but was unpredictable in the group of metal subjects. The quantitative differences in rotation are summarized in Table 4. Hip

Table 3 – Center of pressure sway of reconstructed limb during quiet stance.

	Mediolateral		Anteroposterior	
Control	20.79 mm	(± 1.6)	19.76 mm	(± 2.2)
Metal	5.80 mm	(± 1.3)	26.03 mm	(± 9.4)
Allograft	25.37 mm	(± 8.6)	41.00 mm	(± 12.5)

Amplitude Ranges in Eyes Open Condition **Figure 1 – Center of pressure sway in millimeters for injured and uninjured limbs for the 3 groups.**

abduction and adduction ranges approached normal for the allograft group in pattern and magnitude but were increased in magnitude for the metal group of subjects. The values of hip and knee angles are summarized in Table 4 as well. These average ranges of values for hip abduction and adduction as well as knee flexion/extension and rotation are summarized as follows. The differences in knee motion comparing the normal and affected sides were significantly different for both allograft and metal reconstructed subjects. Differences in knee rotation and hip abduction were markedly increased in metal reconstructed limbs compared to control and to allograft reconstructed limbs and this difference was statistically significant.

Table 4 – Joint motion ranges in degrees and vector moments in Newton-meters/kg.

	Allograft	Metallic	Control
Hip Ab/Adduction angle range	3.09	14.07	5.63
Knee rotation angle range	5.86	6.28	6.80
Knee flexion/Extension angle differences (Compared to contralateral side)	12.49	14.07	5.64
Moment – Knee flexion/extension	0.28	0.15	0.14
Moment – Knee varus/valgus	0.22	0.28	0.13
Moment – Knee rotation	0.03	0.10	0.02

Stiff knee gait on the left (L) compared to unaffected side on the right (R)

Hyperextension gait on the L compared to unaffected side on the R

Rigid knee gait associated with flexion contracture on L compared to unaffected side on the

R

Figure 2 – Flexion/Extension at the knee during the gait cycle for the following gaits: Stiff knee gait on the left (L) compared to unaffected side on the right (R), Hyperextension gait on the L compared to unaffected side on the R, Rigid knee gait associated with flexion contracture on L compared to unaffected side on the R.

The gait patterns of most patients with either reconstruction were stiff knee gaits with a loss of early stance phase flexion. There was one patient in the allograft group with a very stiff knee with less than 10 degrees of flexion/extension motion during stance phase. There was one patient in the metallic reconstruction group who had a hyperextension knee gait with excessive hyperextension during the shock absorbing phase of early stance. Representative gait patterns are shown in Fig. 2.

4. Discussion

All reconstructed distal femurs following tumor resection resulted in decreased range of motion reflected in observed flexion/extension angles compared to the normal limbs. The allograft reconstructed knees demonstrated normal patterns of rotation whereas the metal subjects had abnormal patterns of rotation and statistically significant differences in rotational moments. This implies that higher forces are needed for rotation during the gait cycle. This is due to prosthetic design and may have long-term consequences with regard to prosthetic wear and loosening.

Both reconstructive options used in this study have well described early and late complications. The infection rate in the early postoperative phase has been reported near 5% for metallic prosthesis^{1,6,15} and about 10% for allografts.^{2,3} Intermediate complications are often related to mechanical failures of the prosthesis or fracture of the allograft.^{1–4,6,7,15} There are reports of good survivorship for both allograft^{2–4} and metallic endoprosthetic reconstructions^{1,6,7,15} but these reconstructive options still have high rates of revision at 5, 10 and 20 years.

Energy consumption is less in patients with limb salvage compared to amputees. It has been demonstrated that patients with resection and prosthetic knee replacement had a lower energy cost during gait when compared to above knee amputees for treatment of osteosarcoma about the knee.¹⁶ Although lower, energy consumption is still 35% greater than normal controls and energy cost negatively correlates with the percentage of the distal femur that is resected.¹⁷ Following tumor resection, the adductor magnus muscle is detached from the distal femur and is not re-attached to the metal prosthesis. With a more proximal resection, more adductor muscle is lost with diminished strength and mechanical advantage. This may lead to an abduction lurch during gait and may be one factor for increased energy cost. The differences in abduction/adduction angles between the reconstructed limb and normal limb were significantly increased in the metal reconstructed group. These differences were not observed in allograft subjects.

Aseptic loosening for metallic prostheses and progressive arthrosis of allograft joints are the primary modes of failure in the long-term evaluation of distal femoral reconstructions. The observation of arthritic changes at 10 years was 35% whoever many were not painful. In this group of 48 patients, only four (8%) required metallic resurfacing arthroplasty.³ Aseptic loosening rates have been reported at 24% at ten years.⁶ Need to add the Henderson data here. The gait patterns for patients undergoing this type of reconstruction can be

significantly affected. There is some discussion that abnormal gaits and muscle moments about a knee reconstruction could lead to motion contributing to late failure of the reconstructions.

This study demonstrates that there is retained proprioceptive input which appears to allow a gait pattern with single leg support time to be closer to normal. There was a marked decrease in the operative leg mediolateral sway compared to controls and this was likely due to the larger residual leg length discrepancy of the allograft group, causing some shielding of the leg from coronal plane forces. Other confounding aspects of this sample studied were the age difference with allograft reconstruction group being younger and also the time from surgery being significantly longer for the allograft group. The potential for self selection of surviving reconstructions performing better due to full rehabilitation or survival of the reconstruction due to good mechanics. A matched group of metallic reconstruction patients with respect to age of reconstruction would be a better match.

Allograft distal femoral reconstruction after malignant neoplasm excision remains a viable option for surgeons faced with the difficult problems associated with the iatrogenic muscle, bone and soft tissue defects. The residual collateral and cruciate ligaments, when repaired to the allograft segment, seem to provide improved proprioception in quiet stance, which translates to more normal single versus double limb support time in comfortable gait.

Conflicts of interest

All authors have none to declare.

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