Transfemoral Bone-Anchored Limb Use Improves Osteoarthritic Musculoskeletal Biomarkers after 12-Months: A Quantitative Magnetic Resonance Imaging Study

Brecca M. M. Gaffney[1-2], Mitchell A. Ekdahl[1-2], Julio Carballido-Gamio[2], Cory L. Christiansen[2], Jason W. Stoneback[2]
[1]University of Colorado Denver, Denver, CO, [2]University of Colorado Denver Anschutz Medical Campus, Aurora, CO
brecca.gaffney@ucdenver.edu

Disclosures: Brecca M. M. Gaffney (N), Mitchell A. Ekdahl (N), Julio Carballido-Gamio (N), Cory L Christiansen (N), Jason W. Stoneback (Revivo International, ReSenso, AQ Solutions, Validus Cellular, Smith & Nephew, NuVasive Specialized Orthopedics)

INTRODUCTION: Transfemoral socket prosthesis users are up to 14 times more likely of developing bilateral hip osteoarthritis (OA) as compared to their healthy counterparts.[1-2] This increased risk is commonly attributed to movement compensations required for the loss of joints and altered force transmission within the socket prosthesis that cause habitually altered joint loading, with altered muscle forces being the primary contributor to altered joint loading.[3-4] Bone-anchored limbs (BALs) are a promising alternative for individuals suffering from failed socket use that directly attach the prosthesis to the distal end of the residual limb through a bone-anchored implant. Previous biomechanical evidence has demonstrated that transfemoral BAL use changes hip joint loading during walking,[5-6] which is likely driven by increased amputated limb gluteus medius muscle force.[7-8] As hip abductor muscle weakness is a primary etiological factor in hip OA because it influences the muscle's ability to stabilize and load the joint,[9] these previous results may indicate that BAL use has a positive influence on OA pathomechanics. However, it remains unknown if this change in force transmission and joint loading have a positive influence on the etiology of hip OA as evidenced by changes in musculoskeletal tissue composition. Therefore, our objective was to use quantitative magnetic resonance imaging (qMRI) to determine the influence after one year of transfemoral BAL use on gluteus medius muscle volume/fatty infiltration and cartilage health, common musculoskeletal biomarkers of OA. We hypothesized that BAL use would increase bilateral hip muscle volume and improve composition (reduced fatty infiltration), resulting in improved bilateral cartilage health (lower T_2 relaxation times).

METHODS: With IRB approval, qMRI was collected from 9 individuals with unilateral transfemoral amputation at two timepoints (4 who underwent BAL implantation (2F/2M, Age: 63.0±4.7 y/o, BMI: 28.5±3.8 kg/m^2, Time since amputation: 23.6±22.9 years) and 5 socket-use participants (1F/4M, Age: 56.4±11.1 y/o; BMI: 28.5±4.7 kg/m^2, Time since amputation: 19.4±20.2 years)). Images were collected 2 days prior to BAL implantation surgery and 12-months following surgery for the BAL group and at two timepoints separated by 12 months for the socket control group using a 3T GE Signa PET/MR Scanner (GE Healthcare) with three pulse sequences: 1) axial T1-weighted LAVA for muscle volume, 2) axial 3D 6-point IDEAL IQ for muscle fat infiltration, and 3) sagittal 2D MESE T_2 for cartilage assessments. Bilateral gluteus medius was segmented to create 3D surface reconstructions to calculate volumes (normalized by body mass (kg) and height (mm)).[10] Muscle composition within each individual muscle was quantified as the proton density fat fraction (PDFF) based on the IDEAL algorithm [16]. Cartilage segmentation was done using semi-automatic edge detection and Bezier splines with special contrast and edge enhancements, and T_2 relaxation time maps were generated by fitting a mono-exponential decay within each voxel using the Levenberg-Marquardt algorithm.[11] The average T_2 relaxation times of the combined femoral and acetabular cartilages was determined. The longitudinal change (Δ) in bilateral gluteus medius volume, muscle fatty infiltration, and cartilage T_2 relaxation times were compared between groups using Cohen's *d* effect size.

RESULTS: Gluteus medius volume was increased or unchanged in BAL users and decreased in socket users over 12-months (amputated limb Δ: 0.07±0.24 mm^2/kg (BAL) vs. -0.23±0.15 mm^2/kg (socket), d=1.59; intact limb Δ: 0.01±0.22 mm^2/kg (BAL) vs. -0.15±0.22 mm^2/kg, d=0.71) (Fig. 1a). Gluteus medius fatty infiltration was decreased in BAL users and increased in socket users over 12-months (amputated limb Δ: -5.06±4.75% (BAL) vs. 0.21±3.14% (socket), d=-1.35; intact limb Δ: -0.91±1.82% (BAL) vs. 1.30±1.66% (socket), d=-1.3) (Fig. 1b). Cartilage T_2 relaxation times were reduced in BAL users and increased in socket users over 12-months (amputated limb Δ: -1.20±2.64 ms (BAL) vs. 5.87± 5.80 ms (socket), d=-1.50; intact limb Δ: --3.25±3.32 (BAL) vs. 4.76±4.19 ms (socket), d=-2.08) (Fig. 1c).

DISCUSSION: Our results demonstrate that 12-months of transfemoral BAL use improves gluteus medius volume and composition in a manner different than that of a socket prosthesis, which collectively led to improved measures of hip articular cartilage health (decreased T_2 values). The decreased gluteus medius muscle volume and increased fatty infiltration in socket prosthesis users over the course of 12-months is indicative of continued gluteus medius atrophy, which is well documented in transfemoral socket prosthesis users.[12] Unfortunately, gluteus medius atrophy has been linked as a contributing factor to hip OA progression,[13] which is evident in the increased T_2 relaxation times that is a biomarker of worsened cartilage health. However, BAL use resulted in the opposite effect on the gluteus medius muscle, with these early results demonstrated increased bilateral muscle volume and decreased fatty infiltration. This is likely an underlying mechanistic factor to our prior work demonstrating increased muscle forces which lead to normalized joint loading when using a BAL.[5] The current results demonstrated improved bilateral cartilage health as marked by decreased T_2 relaxation times over the course of 12-months. To our knowledge, these results are the first to demonstrate that BAL use has a positive influence on hip musculoskeletal composition in a manner that likely indicates a positive etiological influence on OA in this high-risk population.

SIGNIFICANCE/CLINICAL RELEVANCE: Transfemoral BAL use increased bilateral gluteus medius muscle volume, reduced fatty infiltration, and improved hip cartilage composition after 12-months, which were the opposite changes observed in socket prosthesis users. As it is known that BAL use improves joint mechanics, these results are the first to demonstrate that this will also improve the progression of osteoarthritic changes over time.

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IMAGES AND TABLES:

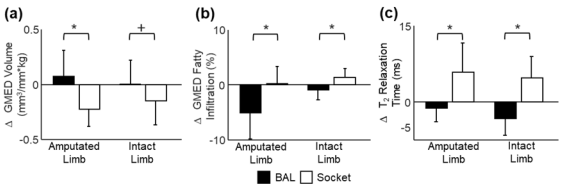

Figure 1. Mean±1 SD bilateral change in (a) gluteus medius volume and (b) fatty infiltration, and (c) hip cartilage T_2 relaxation times in BAL users (black) and socket controls (white) over 12-months. * indicates large effect and + indicates medium effect.