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Change In Bone Mineral Density After Total Ankle Replacement: A Two Year Follow Up

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Abstract

Background: Bone strength around the components is critical for arthroplasty survival. Literature is scarce on changes in bone mineral density (BMD) around total ankle arthroplasty (TAA) designs. This study quantified BMD changes around the components of the uncemented Mobility™ prosthesis preoperatively and postoperatively, while evaluating clinical outcomes.

Methods: This prospective study included patients undergoing TAA between March 2008 and April 2009. BMD was measured using the DEXA Hologic® scanner at seven regions of interest (ROIs) around the prosthesis preoperatively and at 1- and 2-year follow-ups. AOFAS scores were also recorded.

Results: Twenty-three patients were included. A significant mean BMD decrease (17%, $p<0.01$) was observed in the lateral malleolus, while the medial tibial metaphysis showed a 7% increase, though not statistically significant. BMD changes at other ROIs were minimal. AOFAS scores improved significantly over the 2 years ($p<0.05$).

Conclusion: Significant BMD loss occurred in the lateral malleolus, likely due to stress shielding. Minimal changes in other regions suggest a stable mechanical environment. Long-term follow-up is necessary to determine the clinical impact of these changes.

Keywords: Total Ankle Arthroplasty, Bone Mineral Density, Stress Shielding, Ankle Replacement

INTRODUCTION

Strong trabecular bone surrounding the prosthesis is essential for the survival of joint replacement. This issue has been proven in studies of total hip and knee replacement [7,11,13]. This issue should be similarly important in total ankle arthroplasty. There is paucity of literature on changes of bone mineral density (BMD) around the ankle following total ankle arthroplasty [6]. Despite evident preservation of bone on radiographs, little has been published regarding bone mineral content postoperatively and the strong trabecular bone surrounding the prosthesis.

Periprosthetic fractures are a notable complication associated with TAR, often attributed to surgical technique or osteolysis affecting peri-implant bone density [15]. This underscores the need for a better understanding of BMD dynamics around ankle arthroplasty components.

This prospective study used a method to quantify BMD in different regions of the surrounding bones adjacent to tibial and talar components of uncemented Mobility ™ ankle prosthesis, by analysing BMD in different regions around ankle before and after ankle arthroplasty.

MATERIALS AND METHODS:

This was a prospective study with patients from a single centre. Patients who underwent a total ankle replacement (TAR) between March 2008 and April 2009 were included in this study. The data collected was part of routine clinical audit for ankle replacement patients at the hospital and was registered with Clinical Governance department within the institution; therefore ethical approval was not needed. A sub-group of patients included were part of a randomized controlled trial of total ankle replacement (TAR) carried out in the same institution; local ethical committee approval was obtained for this study.

Operative procedure and Prosthesis

All operative procedures were performed by the senior author, using a consistent operative technique. The implant used was Mobility™ [DePuy International, Leeds, UK]. It consisted of two metal parts, cast from cobalt chrome and was porous coated. Fixation on both tibial and talus aspects was cementless. A gliding polyethylene meniscus separated the two metal components. This arrangement allowed mainly compressive forces to act on the bone-prosthesis interface, as shear forces are attenuated by the rotation and gliding of the polyethylene meniscus.

Post op management

A standard postoperative regime was used. Following five days of negative pressure wound therapy (which we found very effective in aid wound healing)[9], all patients were mobilized in CAM, with protected full weight bearing on crutches for four to six weeks [1].

Assessments

1.BMD using DEXA scan:

For measuring BMD, Dual Energy X-ray Absorptiometry (DEXA) scans were utilized

To determine the statistical significance of changes in bone mineral density (BMD) compared to baseline measurements, the Least Significant Change (LSC) was calculated using the formula:

$$LSC=1.96\times 2\times \text{Precision Error}$$

where the Precision Error is derived from repeated measurements under consistent conditions. The LSC provides a threshold above which observed changes in BMD can be considered statistically significant, accounting for measurement variability. All DEXA scans were performed and analyzed by trained technicians following standardized protocols, and quality control measures ensured precision reliability as per the local Freeman Hospital Protocol. Patients underwent these scans pre-operatively and at one and two years post-operatively. The scans were performed using Hologic® DXA scanners (Hologic Delphi-W® and Hologic Discovery-A®), which were subject to recommended calibration and quality control. Patients were scanned seated with the index leg fully extended, parallel to the couch side and internally rotated by 15 degrees, as per the Mortise radiographic view (Figure 2). The scan extended from the proximal half of the metatarsals to the distal third of the tibia and fibula. HOLOGIC software automatically excluded metallic elements from further analysis but some manual adjustment of the bone map was required, as in denser areas such as the talus.

Figure 2: Position of the Ankle During Scan.

Rectangular regions of interest (ROI) [17x17 pixels] were positioned on Antero-posterior view of the first post-operative image coinciding with the central portion of the each malleolus. Further regions of equal size, each 17x17 pixels, were then placed proximally to follow the medial edge of tibia and lateral edge of fibula. Two further regions [52x8 pixels] were then placed over the talus and tibial shaft at either end of the ankle prosthesis. (Figure 3).

The template for the first post-operative scan was then transferred (using the software) to the preoperative and post-operative scans. This technique produces identical areas of interest for each scan to allow comparison of results. BMD was expressed as a percentage of each patient's original preoperative BMD to show relative changes with the passage of time for each patient.

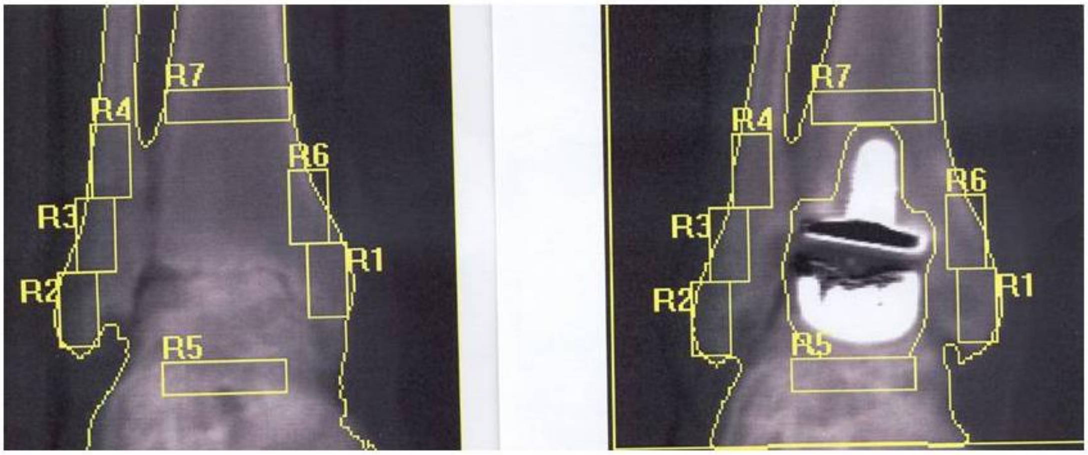

Figure 3: Ankle were divided into 7 regions to quantify the results.

2.PROMs:

The clinical outcomes of the patients were evaluated using the American Orthopaedic Foot and Ankle Society (AOFAS) scores, preoperatively and at one and two years postoperatively

3. Statistical Analysis:

Statistical analysis of the collected data was performed using SPSS software (version 17). For descriptive statistics Median and range were used for continuous variables and frequencies and percentages were used for categorical variables. To compare preoperative to postoperative BMD Wisconsin rank test was used to assess significant changes in BMD for different regions between assessment times. To study the differences in AOFAS scores from preoperative to two years and Student's T-test to assess significant changes in BMD for different regions between assessment times.

This detailed and comprehensive methodology ensured a robust and reliable evaluation of the changes in BMD following TAR with the Mobility™ prosthesis, providing critical insights into the adaptation of bone post-arthroplasty.

RESULTS

Twenty three patients underwent Mobility™ Ankle arthroplasty for a diagnosis of osteoarthritis between March 2008 and April 2009. All had pre-operative bone densitometry scans of the ankle, repeated at one and two years after surgery. Mean age at baseline was 63.3 years (SD 9, range 43 to 80). There were seven female and 15 male patients (one patient had a bilateral TAA).

The AOFAS scores showed significant improvement post-surgery. The preoperative average score of 28.8 increased to 78.7 at 12 months and 76.9 at 24 months postoperatively ($p < 0.05$), (Figure 1).

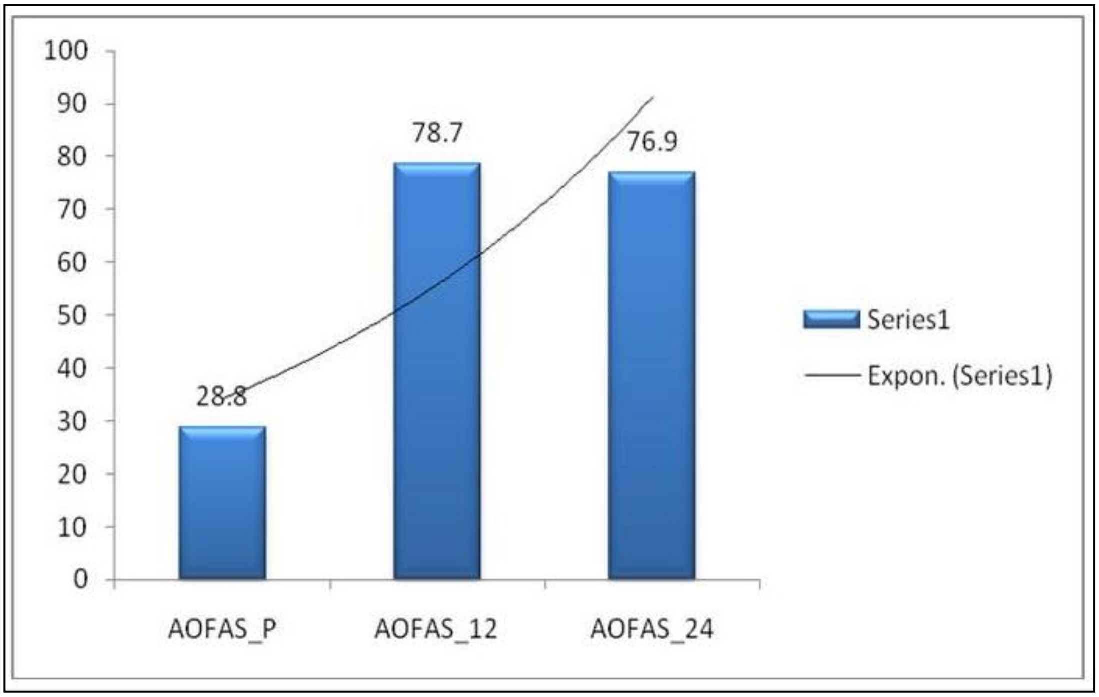

Figure 1: AOFAS score improvement from preoperative to preoperative year 1 and 2.

Mean BMD within the lateral malleolus decreased significantly from 0.5g/cm^2 to 0.42g/cm^2 (17% reduction, P > 0.01), at one and two years postoperatively - R2 (Figure 4).

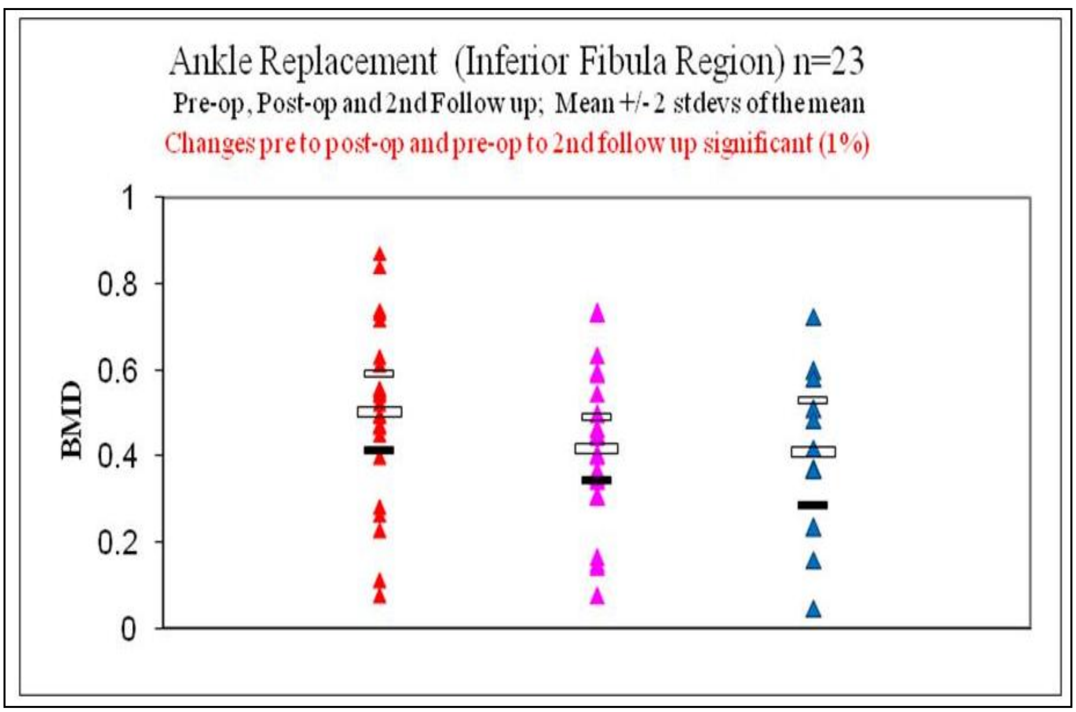

Figure 4: BMD changes over the lateral Malleolus R2.

There was an insignificant increase in BMD at medial side metaphysis ,7% (+0.07 g cm $^{-2}$, R6) (Figure 5), but this just failed to reach significance at the 1% level, mean BMD within medial malleolus decreased slightly from 0.67g/cm^2 to 0.64 g/cm^2 at the same period. There was insignificant increase in BMD in tibia just proximal to implant (R7) and at talus (R5).

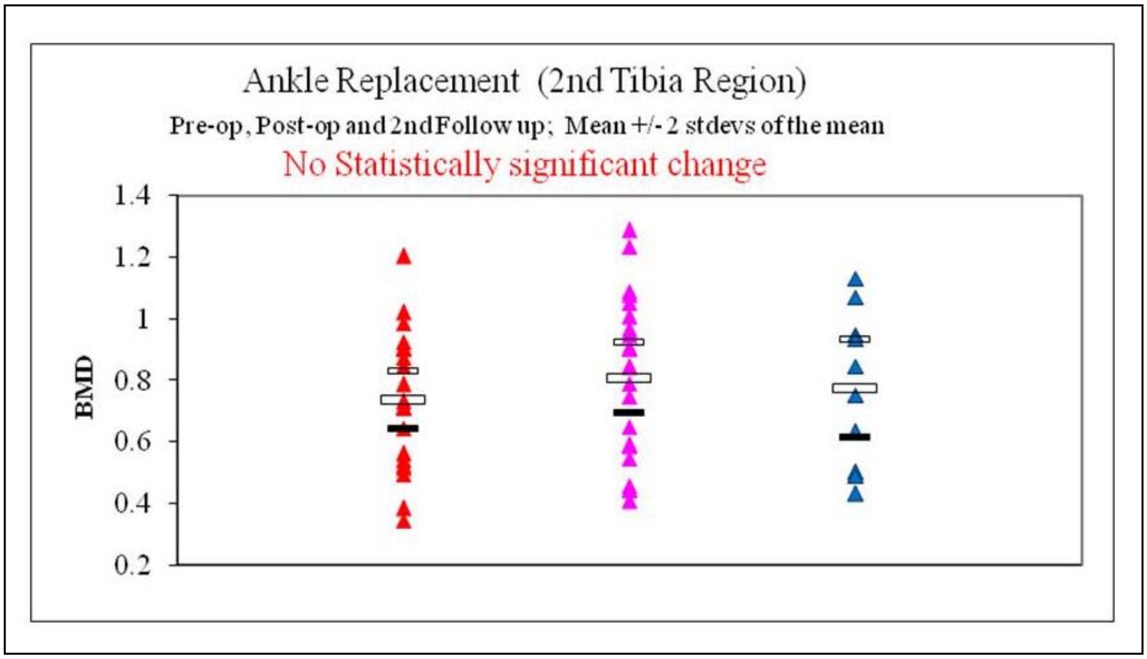

Figure 5: Changes in BMD over tibia region.

DISCUSSION

In this study, a method was developed and utilized to measure bone mineral density around the ankle, taking into consideration the design of the prosthesis being used. There is paucity of literature on a well recognised method for reliable measurement of bone mineral density of the ankle in the presence of ankle prosthesis. Zerahn & Kofoed [14, used similar methods in their study, but BMD over the malleolar area was not investigated.

This is a prospective study of BMD of three component Total Ankle Replacement. BMD was measured in multiple zones of the ankle, including the malleoli, in patients who underwent a porous coated uncemented TAR; both preoperatively and postoperatively using dual-energy X-ray absorption (DEXA).

The main finding of this study was a significant decrease in BMD at the lateral malleolus and negligible decrease in medial malleolus, with no significant increase at the medial tibial metaphysic, 7% (+0.07 g cm $^{-2}$, R6) (Figure 4). We could not find any previous study reporting change in BMD over the malleoli in association with TAR to compare our findings with.

McGarvey et al, studied malleolar fracture after Agility and STAR Total Ankle Arthroplasty [8]. The authors had suggested unloading of the malleoli as a potential cause leading to disuse osteoporosis, this is a logical explanation of the delayed presentation of some fractures that occurring after five or seven years. This could be due to osteolysis from debris or/and stress shielding. Agility and STAR implant design features may have some of their own effect on the surrounding bone.

The current study proved McGarvey et al's theory about disuse osteoporosis and stress shielding in malleoli following ankle replacement. However they reported that fracture occurred at the junction between medial malleolus and medial side metaphysis of tibia, which is the area of no significant increase BMD in our study (ROI R6). This zone might be subjected to increased mechanical stresses, hence some increase in BMD (7%) or occasional postoperative malleolar / metaphyseal fractures noticed in our patients within the first year post implantation. The results of our experience with peri-prosthetic fractures associated with the use of Mobility^{TM} (DePuy, Johnson & Johnson) prosthesis were evaluated [2]. In this study there was 6.4% incidence of medial sided postoperative fractures, within the first three months postoperatively. All postoperative fractures were in the same area, medial malleolar/ metaphyseal zone. Similar results had been reported by Myerson et al [10] and Buechel et al [4].

The current study results also showed no significant increase in BMD in tibia just proximal to implant (R7) and at talus (R5), which could be explained by the increased weight bearing and loading following ankle arthroplasty. There has been no previous study describing the change of BMD in talus following total ankle arthroplasty. Osteolysis has been reported in this talar area with other implants including Buechel and Buechel [4] , STAR [11] and SALTO [3]. However, these implants have longer follow-up than mobility ankle arthroplasty.

Zerahn & Kofoed [6,7] reported significant increase in BMD adjacent to hydroxyapapitate coated tibial component of STAR prosthesis, which was not a finding in our study. This maybe because of the use of a different implant with hydroxyapatite coating, the author's zone of interest was next to the flat part of tibial component. In porous coated Mobility stem tibial component BMD increased all around the metal. It is worth mentioning that the literature expressed concerns regarding the small dimension of the tibial component of STAR prosthesis and the lack of circumferential bone support which makes the tibial component prone to subsidence in the distal tibia cancellous bone.

Valderabano et al [12] reported tilting of the tibial component in 9 of 68 ankles (13%) within the first three months, without progression thereafter. This could explain the potential cause of significant increase in BMD adjacent to Tibial component of STAR prosthesis. Our study patients did not use a plaster cast post operatively and were allowed full weight bearing mobilization. This treatment protocol did not show any subsidence, tilting or change in tibial component position post implantation. This could be due to addition of a stem to the Mobility tibial component considering that Mobility tibial flat part is circumferentially even smaller that STAR. BMD is increased equally around the stem making the flat part stable. No stress shielding was noticed above the flat part of tibial component.

Zerahn & Kofoed et al, [6,7] studies reported similar results to this series, where there was more evident increase in BMD on the medial metaphyseal side of tibia than lateral. Hintermann [5], suggested that due to the non-anatomic cylindrical shape of the talus, there may be load transfer to the medial side and overstress to the medial ligaments and capsule.

This could be a reasonable explanation of consistence increase in BMD on medial side of distal tibia and possibly explain the medial sided pain in the first preoperative year in some patients following TAR. Continuing pain after one year could not be due to medial increased stresses as no BMD increase is recorded in our study in this area.

It would be of interest to follow up this case series in the long term, to establish any further change in BMD and later incidence of deterioration in quality of bone and possible association with failure of TAR.

Limitations

Despite these promising results, the study has limitations. The small number of patients and the relatively short follow-up period limit the ability to generalize the findings and fully understand the long-term effects of TAR on BMD and functional outcomes. Additionally, the study's reliance on a single implant design means there is no comparative data from other manufacturers, which could provide a broader perspective on the performance of different TAR systems. Furthermore, we were unable to correlate BMD changes with Patient-Reported Outcome Measures (PROMs) due to the limited follow-up duration. In addition, the lack of a gold standard for BMD measurement in the ankle, as at present, there are no established gold standard techniques for measuring BMD in the ankle, which limits the comparability of this study's findings with other studies. Variations in methodology across studies can contribute to discrepancies in results.

Furthermore, a full-body DXA scan was not included in this study, which may have provided a more comprehensive assessment of systemic bone health. Prolonged immobility, commonly associated with conditions like fractures or decreased activity, is a known risk factor for osteoporosis and could contribute to broader changes in bone mineral density [16,17].

CONCLUSION

This study underscores the influence of stress distribution on peri-prosthetic bone health after uncemented TAR, revealing decreased BMD in the lateral malleolus and, to a lesser extent, the medial malleolus, alongside increased mechanical stress at the tibial metaphysis. These results highlight the importance of optimizing prosthetic designs to reduce bone loss and the need for long-term studies to track bone quality and TAR outcomes.

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التغير في كثافة العظام المعدنية بعد استبدال الكاحل الكلي – متابعة لمدة عامين

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الملخص

خلفية الدراسة والأهداف : تعد قوة العظام المحيطة بمكونات المفاصل الاصطناعية أمرًا حاسمًا لبقاء واستقرار هذه المكونات. ومع ذلك، تندر الأبحاث حول التغيرات في كثافة العظام المعدنية بعد عمليات استبدال الكاحل الكلي و هدفت هذه الدراسة إلى قياس التغيرات في كثافة العظام المعدنية حول مكونات المفاصل الاصطناعي قبل وبعد العملية ، وتقييم النتائج السريرية المصاحبة.

المنهجية: أجريت دراسة مستقبلية على 23 مريضًا خضعوا لاستبدال الكاحل الكلي بين مارس 2008 وأبريل 2009. تم استخدام جهاز DEXA من نوع Hologic® لقياس كثافة العظام المعدنية في سبع مناطق محددة حول المفصل الاصطناعي قبل العملية وفي الفترات التالية لها (سنة وسنتين). كما تم قياس درجات AOFAS

النتائج: أظهرت النتائج انخفاضًا كبيرًا في كثافة العظام المعدنية (17%) في المنطقة الجانبية للكاحل، مع زيادة غير كبيرة (7%) في كثافة المنطقة الداخلية لعظم الظنبوب. ($p<0.05$) كما تحسنت درجات AOFAS بشكل ملحوظ خلال فترة المتابعة

الاستنتاجات: تشير الدراسة إلى أن فقدان كثافة العظام المعدنية في المنطقة الجانبية للكاحل قد يكون ناتجًا عن الحماية من الإجهاد. ويوصي الباحثون بدراسات طويلة المدى لتقييم التأثير السريري لهذه التغيرات.

الكلمات الدالة: استبدال الكاحل الكلي، كثافة العظام المعدنية، الحماية من الإجهاد، جراحة الكاحل.