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Changes in Bone Density in Metal-Backed and All-Polyethylene Medial Unicompartmental Knee Arthroplasty

Chloe E.H. Scott, BSc, MSc, FRCS(Tr&Orth) ^{a,b}

Frazer A.Wade, FRCSEd (Orth) ^b

Rajarshi Bhattacharya, MSc, FRCS(Tr&Orth) ^b

Deborah MacDonald, BA(Hons) ^b

Pankaj Pankaj, PhD ^a

Richard W. Nutton, MD, FRCS(Orth) ^b

^a School of Engineering, University of Edinburgh, Edinburgh, UK

^b Department of Orthopaedics, Royal Infirmary of Edinburgh, Edinburgh, UK

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1 **Changes in bone density in metal backed and all-polyethylene medial**
2 **unicompartmental knee arthroplasty**

3

4 **Abstract (200 words)**

5 Background: Proximal tibial strain in medial unicompartmental knee replacement (UKR) may
6 alter bone mineral density (BMD) and cause pain. The aims of this retrospective cohort study
7 were to quantify and compare changes in proximal tibial BMD in metal-backed (MB) and all-
8 polyethylene (AP) medial UKRs, correlating these with outcome, particularly ongoing pain.

9 Methods: Radiographs of 173 MB and 82 AP UKRs were analysed using digital radiograph
10 densitometry at 0, 1, 2 and 5 years. The mean greyscale of 4 proximal tibial regions was
11 measured and converted to a ratio: the GSRb (greyscale ratio b) where $GSRb > 1$ represents
12 relative medial sclerosis.

13 Results: In both implants GSRb reduced significantly to 1 year and stabilised with no
14 differences between implants. Subgroup analysis showed less improvement in OKS in
15 patients whose GSRb increased by $>10\%$ at 1 year (40/255) compared to patients whose
16 GSRb reduced by $>10\%$ at both one (8.2 Vs 15.8, $p=0.002$) and five years (9.6 Vs 15.8,
17 $p=0.022$). Patients with persistently painful UKRs (17/255) showed no reduction in GSRb at
18 one year compared to a 20% reduction in those without pain ($p=0.05$).

19 Conclusions: BMD changes under medial UKAs are independent of metal backing. Medial
20 sclerosis appears to be associated with ongoing pain.

21

22

23 **Keywords:** Unicompartmental knee arthroplasty; bone mineral density; unexplained pain;
24 digital radiodensitometry.

25

26

Footnote 1 Abbreviations:

BMD Bone mineral density; GSRa Grey scale ratio a (digital radiodensitometry ratio of medial to lateral proximal tibial condyles); GSRb Grey scale ratio b (digital radiodensitometry ratio of medial fourth to lateral three fourths proximal tibial

27 **Introduction**

28 Joint registries show higher revision rates for unicompartmental knee arthroplasties (UKAs)
29 compared to total knee arthroplasties (TKAs) ^[1-3]. Unexplained pain is the second most
30 common reason for UKA revision after aseptic loosening ^[4, 5], and undoubtedly contributes to
31 the poorer survival of UKA compared to TKA. Elevated proximal tibial strain with repetitive
32 microfracture and remodelling may contribute to this pain ^[6]. Tibial bone models of UKAs
33 have shown greater microdamage under all-polyethylene tibial components compared to
34 metal-backed components ^[7]. In TKA, tibial component metal backing distributes stresses
35 more evenly than in all-polyethylene implants, but causes stress shielding along
36 undersurface projections ^[8]. The clinical significance of this is unclear with equivalent long
37 term outcomes in both types of TKAs ^[9]. Both overloading and shielding of bone can alter
38 bone mineral density (BMD).

39 Bone mineral density is routinely measured using dual x-ray absorptiometry (DEXA), but can
40 be measured using digital radiological densitometry. This technique derives changes in BMD
41 from calibrated anteroposterior (AP) radiographs of the knee and has been validated against
42 DEXA ^[10]. It has been used to assess changes in tibial BMD in TKA ^[11] and to investigate the
43 role of altered BMD in TKA failure ^[12]. Stress shielding and low BMD may cause reduced
44 cancellous support to implants resulting in subsidence. Alternatively, proximal tibial
45 microdamage and adaptive remodelling from overload may cause pain and a relative
46 increase in BMD under the implant.

47 The primary aim of this study was to examine changes in tibial BMD in medial UKAs of two
48 designs: a mobile bearing metal-backed implant (MB) and a fixed bearing all-polyethylene
49 implant (AP). We hypothesized that medial BMD would increase under the less stiff all-
50 polyethylene tibial components due to repetitive microfracture and remodelling. Secondary
51 aims included investigating the effect of patient demographics on BMD and the effect of
52 BMD changes on clinical outcome, with particular reference to unexplained pain.

53

54

55 **Materials and Methods**

56 Ethical approval was obtained for this study. Patients who had undergone UKA from 1999-
57 2007 at our institution were identified using our prospectively collected arthroplasty
58 database. All patients who had undergone a cemented Oxford mobile bearing metal-backed
59 UKA (MB) (Biomet, Swindon, United Kingdom) or a cemented Preservation fixed bearing all-

60 polyethylene tibia UKA (AP) (DePuy, Johnson & Johnson Professional Inc., Raynham,
61 Massachusetts, USA) were included in the study. The second of bilateral UKAs were
62 excluded as were patients who had died.

63 Medical and operation notes were reviewed for all patients. Data recorded included age,
64 sex, weight, and body mass index (BMI).

65 To assess BMD, anteroposterior weight-bearing knee radiographs were examined at 5 time-
66 points for each patient: pre-operative, immediate postoperative, and at 1, 2 and 5 years post-
67 operatively. All radiographs on radiographic film were digitised using a UMAX Power Look
68 2100XL flatbed scanner (RSA Biomedical, Naperville, Illinois, USA) at 256 (8-bit) greyscale
69 and 300dpi resolution and were saved as TIFF files for analysis. Digital radiographs from the
70 PACS system (Kodak Carestream, Rochester, NY, USA) were exported for analysis as TIFF
71 files. Image analysis was performed using ImageJ 1.45m, a public domain Java based
72 scientific image processing and analysis package ^[13]. Implant alignment ^[14] and pixel value
73 statistics were measured following calibration, producing a range of greyscale values from 0-
74 255 for each pixel. Each image was calibrated such that air (black pixels) had a value of 0
75 and the femoral component (white pixels) a value of 255 ^[11]. The mean greyscale value of
76 pixels within user defined regions of interest (ROIs) were calculated. Regions of interest
77 were defined using the tibial anatomical axis and standardised measurements (Table 1) to
78 create 4 ROIs: 2 medial (A1 and A2) and 2 lateral (A3 and A4) (Figure 1). Regional
79 boundaries were selected to maximise trabecular bone content and exclude artefact from
80 fibular head, cement and peripheral cortical bone ^[11] (Figure 1d).

81

82 Regions were transposed to all radiographs of a given patient to ensure the same areas
83 were measured. Mean density measurements were recorded for each ROIs in each patient
84 at each follow up. To facilitate quantitative comparison of radiographs taken at different
85 times, the mean grey scale was represented as a ratio, the greyscale ratio (GSR). This
86 compared the density of medial to lateral ROIs (GSRa, equation 1) and the most medial ROI
87 to the remainder of the proximal tibia (GSRb, equation 2) corrected for area. All
88 measurements were taken by a single observer (CEHS). A GSR>1 reflected a relative
89 medial sclerosis.

90 Equation1:

$$GSRa = \frac{(\overline{A1}(A1pix) + \overline{A2}(A2pix))}{(A1pix + A2pix)} / \frac{(\overline{A3}(A3pix) + \overline{A4}(A4pix))}{(A3pix + A4pix)}$$

91

92 Equation 2:

$$GSRb = \bar{A1} / \frac{\bar{A2}(A2pix) + (A3(A3pix) + \bar{A4}(A4pix))}{(A2pix + A3pix + A4pix)}$$

Where \bar{A} = mean greyscale of ROI pix = area in pixels of ROI

93

94 Prior to surgery, all patients completed a Short-form (SF-12) health questionnaire ^[15]
95 (physical and mental components) and Oxford Knee Score (OKS) ^[16]. Postoperative
96 questionnaires (SF-12 and OKS) were sent at 12 months. In April 2013 a similar
97 questionnaire was sent to patients with the addition of patient satisfaction measurements ^[17]
98 and knee specific pain questions. Patients were asked to indicate the pain level from their
99 knee with a visual analogue pain scale (VAS) from no pain (0) to the worst pain imaginable
100 (100). If pain was present, patients were asked to indicate its location by ticking as many
101 boxes as applied from “at the front of the knee”, “at the back of the knee”, “on the inside
102 edge of the knee”, “on the outside edge of the knee”, “at the top of the shinbone”, “all over
103 the knee” and “other”. Patients were asked if they had undergone revision or reoperation of
104 their UKA for any reason with tick-box options. This data was correlated with the notes.

105

106 *Statistical Analysis*

107 Analysis was performed using SPSS version 19.0 (SPSS Inc., Chicago, IL, USA).
108 Parametric (paired and unpaired T-tests) and non-parametric (Wilcoxon Rank and Mann-
109 Whitney U) tests were used to assess continuous variables for differences between UKA
110 cohorts. Nominal categorical variables were assessed using a Chi square or Fisher’s exact
111 test. Repeated measures ANOVA was used to examine changes in parametric variables
112 over the 5 year study period. Correlation of continuous variables was assessed using
113 Pearson correlation. A p value of <0.05 was considered to be statistically significant. For
114 changes in GSR and PROMs over time, significance was set at p<0.0125 incorporating a
115 Bonferroni correction for the 4 timepoints tested. Post-hoc power analyses were performed
116 using the method of Lehr ^[18]. Subgroup analysis was performed on those with GSRb which
117 increased or decreased by >10% and on those with and without painful UKRs.

118

119

120 **Results**

121 The study group consisted of 173 MB and 82 AP UKRs in 255 patients. Table 2 details
122 preoperative patient characteristics. Table 3 details postoperative alignment. Significantly
123 more proximal tibia, as approximated by D4 (as a percentage of the tibial width) was
124 resected to implant the MB implant (mean 21.8%, SD 3.6) compared to the AP (17.9%, SD
125 2.6, $p<0.001$ unpaired T-test). Greater overhang was present in the MB group (mean 0.3,
126 SD 1.7) with underhang in the AP group (mean -0.9, SD 1.4, $p<0.001$ unpaired T-test).
127 There was no difference in resultant femorotibial angle between implants.

128

129 *Grey Scale Ratios*

130 A total of 945 radiographs were analysed. The greyscale within each ROI was normally
131 distributed, therefore mean greyscale was considered an appropriate measure. Across all
132 UKAs, GSRa did not change significantly with time. However, GSRb decreased significantly
133 in the first postoperative year, remaining stable thereafter ($p<0.001$, repeated measures
134 ANOVA) (Figure 2).

135 Prior to surgery, the AP group displayed significantly higher GSRb than the MB. GSRb
136 reduced significantly over the 5 year period in both AP ($p<0.001$, repeated measures
137 ANOVA) and MB UKAs ($p=0.014$, repeated measures ANOVA) (Figure 3). In both implants,
138 there was a significant negative correlation between preoperative GSRb and 1 year change
139 in GSRb (Pearson's correlation AP-0.292, $p<0.05$; MB -0.607, $p<0.01$). There was no
140 correlation between tibial resection depth and GSRb change in either implant.

141 Using the method of Lehr, our minimal sample size of 82 would enable detection of a 13%
142 difference in GSRb at 1 year (SD 0.298) as significant at 80% power and a significance level
143 of 0.05.

144

145 *PROMs*

146 The mean follow-up for the >5year questionnaire was 100 months for all UKAs (62-158).
147 There were significant postoperative improvements in the physical component score (PCS)
148 of the SF-12 for both implants ($p<0.001$, repeated measures ANOVA) with no change from 1
149 to 5 years (MB $p=0.203$, AP $p=0.793$, paired T-tests). OKS improved significantly in both
150 implants ($p<0.001$, repeated measures ANOVA). Again this improvement occurred in the

151 first year with no significant changes thereafter and no differences between implants (Table
152 4).

153

154 There was no significant correlation between preoperative GSRb and preoperative OKS
155 (Pearson's correlation 0.105). Nor was there correlation between absolute OKS and
156 absolute GSRb at 1 or 5 years in either implant (1yr: AP 0.09, MB 0.251; 5yrs: AP -0.004,
157 MB 0.11, Pearson's correlation). However, negative linear correlations were found for
158 change in GSRb and improvement in OKS at 1 year (AP -0.312 $p=0.044$, MB -0.287
159 $p=0.065$) (Figure 4).

160

161 Overall 81% of MB patients and 78% of AP patients were satisfied with their knee at >5
162 years. Satisfaction with pain relief was high in both groups: MB 89% and AP 88%. Pain at >5
163 years (VAS 0-100) did not differ between implants, but did differ significantly between those
164 satisfied (MB 14.6 and AP 14.9) and those dissatisfied (MB 48.0 and AP 47.7, $p<0001$,
165 unpaired T test). The location of pain reported by patients is shown in Figure 5. The trend
166 towards more medial pain in the AP group was not significant ($p=0.127$, Chi squared).

167

168 *Subgroup Analysis*

169 Forty patients (12 AP and 28 MB) displayed a >10% increase in GSRb over 1 year with a
170 mean increase of 0.21 (SD 0.17). A >10% reduction in GSRb occurred in 113 patients with a
171 mean decrease of 0.34 in the first year (SD 0.20). In 103 patients GSRb changed by <10%.
172 Improvement in OKS at 1 and 5 years differed significantly between those with increased
173 and decreased GSRb at 1 year (Table 5).

174 During the study period, 16/173 MB and 7/82 AP UKAs were revised. Figure 6 details modes
175 of failure. Revisions for pain (2MB and 5AP) were performed at mean 34 months (range 18-
176 45). Despite no preoperative differences in GSRb, patients revised for pain had a mean
177 increase in GSRb of 10% in year 1 compared to a mean decrease of 20% in those not
178 revised for pain ($p=0.017$, unpaired T-test, 95%CI 0.06 to 0.6) (Figure 7).

179 Combining revisions for pain (2MB and 5AP) with patients "poorly" satisfied with pain relief
180 but not offered revision (6MB and 4AP), absolute GSRb at 1 year was higher compared to
181 non-painful UKAs, and this approached significance ($p=0.051$, Table 6). Mean GSRb
182 reduced over 1 year in patients without painful UKAs, but remained unchanged in painful

183 UKAs. Again, this approached significant ($p=0.052$, Table 6). Significantly less improvement
184 in the 1 year OKS (4.25, SD 11.1) was found following revision for pain compared to
185 revisions for all other modes of failure (19.4, SD 10.6, $p=0.026$ unpaired T-test).

186

187 *Alignment*

188 Though there was no difference in resultant femorotibial angle (FTA), the AP tibia was
189 implanted significantly more varised and with greater PTS than the MB (Table 3). The mean
190 tibial component coronal alignment for all UKAs was 86.7° (range 78-93). There was no
191 correlation between GSRb and tibial component coronal alignment (-0.073) or FTA (0.106,
192 Pearson's correlation). There was no significant difference in GSRb between patients with
193 varus tibial components and those without using both 87° (1.0 Vs 0.96, $p=0.263$ student T-
194 tests) and 85° (0.98 Vs. 0.99, $p=0.865$, student T-tests) definitions. There was no difference
195 in the tibial coronal alignment in those with painful UKAs (+/- revision) (mean 86.6°) and
196 those without (86.2° , $p=0.684$ student T-tests). Similarly there was no difference in sagittal
197 alignment between those dissatisfied with painful UKAs (+/- revision) (mean 87.6°) and those
198 without (86.7° , $p=0.237$ Mann Whitney U test). Femorotibial angle did not differ significantly
199 in those with painful UKAs and those without (177.4 Vs 177.5, $p=0.882$, student T-test).

200

201 *Sex, Age and BMI*

202 Females displayed a higher GSRb (higher relative medial BMD) in both groups at every time
203 point. In the MB group, the mean preoperative GSRb in women was 0.99 compared to 0.85
204 in men ($p=0.005$, 95%CI -0.25 to -0.05). These differences remained significant at 1 year.
205 There was no significant difference in the *change* in GSRb over the first year between men
206 and women in the MB group ($p=0.602$, unpaired T-test). In the AP group, again women had
207 a higher mean preoperative GSRb of 1.13 compared to men, 0.93 ($p=0.001$, 95% CI -0.33 to
208 -0.08, unpaired T-test). Once again these differences remained at 1 year, with no significant
209 differences in the *change* in GSRb over the years between the sexes.

210 Preoperative GSRb negatively correlated with age (Pearson's correlation -0.440, $p<0.01$).
211 Younger patients displayed greater relative medial sclerosis preoperatively. No significant
212 correlation was apparent between change in GSRb at 1 year and age, absolute BMI, weight
213 or tibial resection depth in either implant.

214 Patients with a BMI >30 had significantly higher preoperative GSRb (1.03, SD 0.28) than
215 those with BMI <30 (0.93, SD0.27, p=0.025, 95%CI -0.2 to -0.01 unpaired T-test). BMI
216 above or below 30 had no effect on *changes* in GSRb in the MB group. In the AP group, the
217 differences in preoperative GSRb for patients with BMIs above or below 30 (BMI >30 GSRb
218 1.13 compared to BMI<30 GSRb 0.96, p=0.012, unpaired T-test) resolved by 1 year
219 postoperatively.

220

221 **Discussion**

222 The greatest changes in BMD were found immediately below the UKA tibial components at
223 the most medial quadrant measured, reflected by GSRb being the most reactive measure.
224 This is consistent with the findings of previous medial UKA DEXA studies ^[19]. The most
225 significant finding of this study was an overall decrease in medial sclerosis (GSRb) after
226 medial UKA with no differences apparent between all-polyethylene and metal-backed
227 implants. This finding contradicts our original hypothesis that greater medial sclerosis would
228 occur under the all-polyethylene components. This hypothesis was based upon
229 biomechanical data showing greater proximal tibial microdamage under all-polyethylene
230 compared to metal-backed UKA implants ^[7]. The relationship between implant and bone
231 turnover appears more complex *in vivo* than simply less stiff implants creating greater
232 cancellous bone overload, and thus sclerosis, via microfracture and adaptive remodelling or
233 avascularity. A number of confounding variables (age, weight, BMI, bone size, resection
234 depth, activity level, preoperative BMD and bone quality) affect loading and the response of
235 bone to this. We have attempted to investigate some of these variables here, but small
236 subgroups increase the possibility of type 2 errors and significant relationships may have
237 been missed.

238

239 Using the same digital radiological densitometry method, a similar reduction in medial BMD
240 has been found following TKA ^[11]. In isolated medial compartment osteoarthritis, progressive
241 medial tibial condyle overload elevates medial BMD compared to lateral ^[20]. Restoring
242 medial compartment height and femorotibial angle with a UKA offloads the medial condyle.
243 This would be expected to reduce medial BMD, and thus GSRb as occurred here during the
244 first postoperative year. This concurs with the hypothesis of Simpson et al ^[6] and with the
245 DEXA findings of others ^[19, 21]. To our knowledge is the first study to correlate such changes
246 with outcome in UKA.

247

248 The modes of failure differed between implants. The commonest mode of failure for the AP
249 implant was pain, whereas development of lateral OA predominated in the MB implant.
250 There were no cases of tibial collapse, but tibial loosening was more common in the MB
251 implant. These revisions were performed before tibial radiolucencies in the Phase III Oxford
252 UKA implant were recognised as non-pathological lesions. Though revisions for pain were
253 greater in the AP group, the proportion of painful UKAs was the same for both implants. The
254 difference in revision rate may represent different approaches to painful AP and MB UKAs
255 due to concerns for implant stiffness in AP tibias and for bone loss management in MB
256 revisions ^[7]. Proximal tibial adaptive remodelling following TKA continues up to 2 years
257 postoperatively, evident on bone scans. It has been suggested that if adaptive remodelling
258 stabilises at 2 years, painful UKAs should settle then too ^[6]. This is not supported by our
259 results where 18-26% of patients reported ongoing medial pain at >5 years, with most
260 revisions for pain (6/7) were performed after 24 months. National Joint Registry data shows
261 revisions for unexplained pain to occur consistently up to 7 years ^[5]. Revisions for pain had
262 poorer postoperative outcomes than revisions for other reasons and this supports the
263 findings of others ^[22].

264

265 A study of BMD changes in matched failing and non-failing TKAs (measured using digital
266 radiological densitometry) has shown a mean reduction in medial BMD in non-failing knees,
267 but a significant increase in medial BMD in those going on to fail by medial collapse ^[12]. In
268 medial UKAs, we found postoperative elevation of (or maintenance of high) medial BMD to
269 be associated with pain, but not collapse. If painful UKAs had been left without revision,
270 more may have failed by tibial collapse. Pain was associated with younger age and elevated
271 BMI, an association reported before ^[22] with no differences between fixed and mobile
272 bearing UKAs ^[5]. The association between medial sclerosis and pain has not been reported
273 previously. It suggests that younger, heavier patients may experience persistent overload
274 even in MB implants. Interestingly, preoperative GSRa (reflecting medial to lateral proximal
275 tibial BMD) was less in those patients who went on to increase their BMD and develop pain.
276 This lends support to the concept of avoiding UKA in those with osteopenic bone.

277

278 GSRb was greatest preoperatively in women. Previous TKA studies show men to have
279 higher lateral condyle BMD than women ^[11]. This falsely reduces the GSRb in men. Patient
280 selection may have biased this further by excluding women with osteoporosis/radiographic

281 osteopenia from undergoing UKA. The greater proportion of women in the AP group
282 undoubtedly contributed to the higher starting GSRb in this group. The lesser tibial resection
283 used in the AP implant may also have led to measurement of a more sclerotic region.
284 Younger patients, and those with BMI>30, displayed greater preoperative medial sclerosis,
285 suggesting that GSRb may reflect medial load.

286

287 Three previous studies have examined BMD in UKAs. Hooper et al ^[23] used DEXA in 79
288 uncemented Oxford UKAs comparing operated and non-operated knees at 2 years. They
289 found a mean decrease in BMD in all regions of the operated tibia, greatest medially
290 (corresponding to ROI A1). Changes over time were not examined and comparisons were
291 not with the preoperative knee. Soininvaara et al ^[19] performed DEXA scanning on 21 metal-
292 backed fixed bearing UKAs up to 7 years reporting a mean increase in medial tibial condyle
293 BMD of 9% at 1 year. The ROIs used did not exclude cement, cortical condensations or
294 fibular head composite shadowing. Richmond et al ^[21] used quantitative CT to assess tibial
295 BMD in 26 MB and 24 AP UKAs reporting a mean reduction in BMD medially under the tibial
296 component of <5% in both UKAs, but significantly greater in the AP implant. Though studies
297 are few, there is little consistency in findings regarding BMD in UKA. It appears that BMD
298 increases in some patients and decreases in others. The bigger sample size in our study has
299 facilitated a more detailed examination of this than has been possible previously.

300

301 The digital radiodensitometry method used in this study can be used on any digital
302 radiograph using the public access software Image J, making it more accessible and
303 cheaper than DEXA scanning ^[13]. However, whilst this technique can be used to compare
304 relative BMDs, it is unsuitable for absolute values and requires validation before use as a
305 clinical decision making tool could be recommended. There is often reluctance to offer UKA
306 to patients with poor BMD due to concerns regarding tibial subsidence. Our results suggest
307 that caution may also be required in young, heavy patients who are at risk of continued
308 sclerosis and ongoing pain following UKA.

309

310 This study has a number of limitations, including its retrospective design. The tibial
311 component material is not the only design difference between these UKA implants as one is
312 fixed and the other mobile bearing. Digital radiological densitometry is an inferred rather than
313 a true measure of BMD, though it has been validated against DEXA scanning ^[10]. We have

314 tried to strengthen this methodology by representing our findings as a ratio of medial to
315 lateral ROIs rather than as absolute values. This methodology can be used retrospectively
316 facilitating examination of a greater sample size. It also avoids additional radiation required
317 by quantitative CT. Implant alignment was measured on short leg radiographs, not hip-knee-
318 ankle radiographs, and as such may be less accurate. Subgroup analysis may be
319 underpowered raising the possibility of type 2 errors, but was performed to try to better
320 understand the clinical consequences of altered BMD. The 10% level used in subgroup
321 analysis to define patients with increased or decreased BMD is arbitrary, but lies within the
322 7.3 to 17.4% range that BMD is thought to decrease by in TKA ^[12], and is above the mean
323 9% increase reported in UKA previously ^[19]. However, until further studies have been
324 performed to determine what constitutes a clinically significant change in BMD, this remains
325 an arbitrary, though informed, limit.

326

327 **Conclusions**

328 This retrospective cohort study has shown no difference in proximal tibial BMD between
329 medial UKAs with and without tibial component metal backing. Despite a mean reduction in
330 medial tibial BMD following medial UKAs, some patients display a localised increase in
331 medial tibial density with sclerosis. This may reflect ongoing microdamage and adaptive
332 remodelling in overloaded and overstrained bone and here was associated with younger
333 age, elevated BMI and persistent pain with worse Oxford Knee Scores.

334

335

336

337 Table 1. Standardisation of the ROIs

Step	Figure	Description
1	1a	Tibial diaphysis measured at 2 points (green lines)
2	1a	Tibial anatomical axis (AA, red line) drawn by bisecting green lines
3	1a	Line D1 drawn through lateral corner of implant perpendicular to AA
4	1a	Vertical distance from lateral tibial spine to D1 measured as D4. This is a proxy measure of tibial resection depth and is represented as a % of D1
5	1b	D4 used to transpose D1 on to a preoperative radiograph
6	1b	Line D2 drawn parallel to D1 at a distance 0.5 D1 to mark distal boundary
7	1b	2 vertical lines (D3s) drawn where D2 intersects the cortices
8	1c	4 ROIs thus created: A1, A2, A3, A4.
9	1d	ImageJ polygon tool used to select each region for analysis, excluding the fibular head, cortical condensations and cement.

338

339 Table 2. Preoperative patient characteristics.

	Variable	MB (n=173)	AP (n=82)	P value	95% CI
Demographics	Female Sex	79 [45.6]	49 [59.8]	0.044 [†]	
	Age	66.4 (7.8)	68.3 (9.1)	0.127*	-4.2 to 0.53
	BMI	28.8 (4.3)	28.7 (4.8)	0.886*	-1.24 to 1.4
	Weight	81.4 (14.5)	78.7 (15.1)	0.218*	-1.6 to 7.2
PROMs	OKS	20.8 (7.8)	20.1 (6.0)	0.614*	-3.2 to 1.9
	PCS	30.3 (6.39)	31.23 (7.11)	0.400*	-3.12 to 1.25
	MCS	50.5 (11.78)	50.8 (11.51)	0.957 [∞]	-4.07 to 3.65
Alignment	FTA (lateral angle)	181.7 (2.9)	181.6 (2.6)	0.952*	-0.83 to 0.88
	TPA	85.0 (3.6)	85.6 (2.5)	0.023 [§]	
	PTS	3.5 (11)	3.5 (4)	0.458 [§]	
BMD	Time of XR (months preop)	1.18 (6)	0.79 (6)	0.938 [§]	
	GSRa	0.98 (0.19)	1.10 (0.18)	<0.001*	-0.18 to -0.07
	GSRb	0.91 (0.28)	1.05 (0.26)	0.002*	-0.22 to -0.05

340 OKS=Oxford Knee Score, PCS = physical component score of SF-12, MCS = mental component score of SF-12,
 341 FTA = femorotibial angle, TPA = native tibial plateau angle, PTS = native posterior tibial slope, XR = radiograph,
 342 GSR = greyscale ratio

343 Mean (SD), number [%], median (IQR) for TPA, PTS, comorbidities, time of XR

344 [†] Chi squared test, *Two-tailed student T-test, [§] Kruskal Wallis test, [∞] Mann-Whitney U-test

345

346

347 Table 3. Postoperative alignment recorded according to Sarmah et al ^[14]

	MB (n=173)	AP (n=82)	P value	95% CI
Overhang (mm)	0.3 (1.7)	-0.9 (1.4)	<0.001*	0.75 to 1.6
Resection depth D4 (% of tibial width)	21.8 (3.6)	17.9 (2.6)	<0.001*	3.15 to 4.74
FTA (lateral angle)	177.3 (2.6)	178.2 (3.1)	0.06*	-1.59 to 0.04
Change in FTA	4.5 (4.1)	3.75 (3.2)	0.111 [§]	
Tibia				
Coronal (Valgus +ve)	-2.9 (4.0)	-3.6 (3.7)	0.186 [§]	
Sagittal (Additional slope +ve)	0.5 (5.5)	-1.5 (3)	<0.001 [§]	
Femur				
Coronal (Valgus +ve)	2.9 (5.2)	-0.5 (5.1)	<0.001*	-4.7 to -2.0
Sagittal (Flexion +ve)	2.65 (6.5)	-1.5 (7.1)	<0.001*	2.2 to 6.2

348 FTA = femorotibial angle, MPTA = medial proximal tibial angle, PTS = posterior tibial slope

349 Mean (SD), number [%], median (IQR) change in FTA, tibial angles

350 *Two-tailed student T-test, [§] Kruskal Wallis test

351

352 Table 4. Postoperative PROMs by UKR implant.

		MB (n=158)	AP (n=75)	P value	95% CI
OKS	Improvement to 1 yr	15.6 (9.90)	13.4 (8.17)	0.208*	-1.22 to 5.56
	Improvement to 5 yrs	14.1 (10.29)	14.73 (8.82)	0.727*	-4.27 to 2.99
PCS	Improvement to 1 yr	11.0 (10.66)	9.6 (10.89)	0.486*	-2.65 to 5.54
	Improvement to 5 yrs	8.6 (11.61)	9.6 (11.01)	0.652*	-5.08 to 3.20
MCS	Improvement to 1 yr	1.1 (11.41)	0.13 (9.06)	0.644*	-3.16 to 5.08
	Improvement to 5 yrs	-2.08 (12.27)	-1.45 (12.04)	0.777*	-5.07 to 3.79
Pain VAS	5 yr	20.2 (25.69)	22.2 (26.99)	0.525 [°]	-10.41 to 6.47

353 Mean (SD), number [%]

354 * Two sample T-test, [°] Mann-Whitney U-test

355

356 Table 5. Relationship between change in GSRb at 1 year and PROMs at 1 and 5 years.

		↑GSRb at 1 year	↓GSRb at 1 year	P value	95% CI
Both UKRs		(n=40)	(n=113)		
	OKS Imp at 1yr	8.2 (9.99)	15.8 (8.3)	0.002*	-12.4 to -2.8
	OKS Imp at 5 yrs VAS Pain at 5 yrs	9.6 (11.4) 20.1 (24.5)	15.8 (9.1) 23.0(27.1)	0.022* 0.712*	-11.4 to -0.9 -18.8 to 12.9
MB		(n=28)	(n=64)		
	OKS Imp at 1yr	9.0 (11.6)	16.6 (6.5)	0.023*	-14.2 to -1.1
	OKS Imp at 5 yrs VAS Pain at 5 yrs	10.2 (11.3) 16.2 (21.9)	15.6 (9.9) 19.7 (25.3)	0.129* 0.647*	-12.5 to 1.7 -18.7 to 11.7
AP		(n=12)	(n=49)		
	OKS Imp at 1yr	6.4 (4.6)	14.9 (8.2)	0.033*	-16.2 to -0.7
	OKS Imp at 5 yrs VAS Pain at 5 yrs	8.2 (11.8) 19.6 (33.8)	8.4 (16.0) 23.7 (24.7)	0.086* 0.698*	-16.7 to 1.2 -25.4 to 17.2

357 Imp = improvement in, Mean (SD), *=unpaired T-tests

358

359 Table 6. Characteristics of painful (+/- revision) and not painful UKR (MB and AP included)
360 patients.

Variable	Painful UKR (n=17)	Not painful (n=237)	P value	95% CI
Female Sex	8 [47]	120 [51]	0.961 [†]	
Age	60.4 (7.6)	67.4 (8.2)	0.001*	-11.2 to -2.8
BMI	32.7 (5.1)	28.5 (4.2)	<0.001*	1.9 to 6.5
Wt	88.1 (17.6)	79.8 (14.4)	0.034*	0.6 to 16.1
Pre-op OKS	15.9 (7.5)	20.8 (7.1)	0.061*	-0.2 to 10.0
Pre-op GSRb	1.04 (0.30)	0.96 (0.28)	0.334*	-0.09 to 0.26
1 yr GSRb	1.09 (0.17)	0.98 (0.21)	0.051*	0.01 to 0.24
1 yr Change in GSRb	0.02 (0.2)	-0.21 (0.3)	0.052*	0.005 to 0.363

361 Mean (SD), number [%]

362 [†] Chi squared test, * two sample T-test

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366 References

- 367 1. NJR. NJR of England and Wales: 9th Annual Report. In: Wales NEa, ed. 2012
368 2. Australian. Australian Orthopaedic Association: National Joint Replacement Registry Hip and Knee
369 Arthroplasty Annual Report 2012. In. 2012
370 3. Swedish. The Swedish Knee Arthroplasty Register Annual Report 2011. In. 2011

- 371 4. Baker PN, Petheram T, Avery PJ, Gregg PJ, Deehan DJ. Revision for unexplained pain following
372 unicompartamental and total knee replacement. The Journal of bone and joint surgery American
373 volume 94(17): e126, 2012
- 374 5. Baker PN, Jameson SS, Deehan DJ, Gregg PJ, Porter M, Tucker K. Mid-term equivalent survival of
375 medial and lateral unicondylar knee replacement: an analysis of data from a National Joint Registry.
376 The Journal of bone and joint surgery British volume 94(12): 1641, 2012
- 377 6. Simpson DJ, Price AJ, Gulati A, Murray DW, Gill HS. Elevated proximal tibial strains following
378 unicompartamental knee replacement--a possible cause of pain. Medical engineering & physics 31(7):
379 752, 2009
- 380 7. Scott CE, Eaton MJ, Nutton RW, Wade FA, Pankaj P, Evans SL. Proximal tibial strain in medial
381 unicompartamental knee replacements: A biomechanical study of implant design. The bone & joint
382 journal 95-B(10): 1339, 2013
- 383 8. Bartel DL, Burstein AH, Santavicca EA, Insall JN. Performance of the tibial component in total knee
384 replacement. The Journal of bone and joint surgery American volume 64(7): 1026, 1982
- 385 9. Bettinson KA, Pinder IM, Moran CG, Weir DJ, Lingard EA. All-polyethylene compared with metal-
386 backed tibial components in total knee arthroplasty at ten years. A prospective, randomized
387 controlled trial. The Journal of bone and joint surgery American volume 91(7): 1587, 2009
- 388 10. Hernandez-Vaquero D, Garcia-Sandoval MA, Fernandez-Carreira JM, Suarez-Vazquez A, Perez-
389 Hernandez D. Measurement of bone mineral density is possible with standard radiographs: a study
390 involving total knee replacement. Acta orthopaedica 76(6): 791, 2005
- 391 11. Small SR, Ritter MA, Merchun JG, Davis KE, Rogge RD. Changes in tibial bone density measured
392 from standard radiographs in cemented and uncemented total knee replacements after ten years'
393 follow-up. Bone & Joint Journal 95-B(7): 911, 2013
- 394 12. Ritter MA, Davis KE, Small SR, Merchun JG, Farris A. Trabecular bone density of the proximal tibia
395 as it relates to failure of a total knee replacement. Bone & Joint Journal 96-B(11): 1503, 2014
- 396 13. ImageJ. In. <http://imagej.nih.gov/ij/download.html>;
- 397 14. Sarmah SS, Patel S, Hossain FS, Haddad FS. The radiological assessment of total and
398 unicompartamental knee replacements. The Journal of bone and joint surgery British volume 94-
399 B(10): 1321, 2012
- 400 15. Dunbar MJ, Robertsson O, Ryd L, Lidgren L. Appropriate questionnaires for knee arthroplasty.
401 Results of a survey of 3600 patients from the Swedish Knee Arthroplasty Register. JBJS Br 83(3): 339,
402 2001
- 403 16. Dawson J, Fitzpatrick R, Murray D, Carr A. Questionnaire on the perceptions of patients about
404 total knee replacement. Journal of Bone & Joint Surgery, British Volume 80-B(1): 63, 1998
- 405 17. Scott CEH, Howie CR, MacDonald D, Biant LC. Predicting dissatisfaction following total knee
406 replacement: a prospective study of 1217 patients. The Journal of bone and joint surgery British
407 volume 92-B(9): 1253, 2010
- 408 18. Petrie A. Statistics in orthopaedic papers. The Journal of bone and joint surgery British volume
409 88-B(9): 1121, 2006
- 410 19. Soininvaara TA, Harju KA, Miettinen HJ, Kroger HP. Periprosthetic bone mineral density changes
411 after unicondylar knee arthroplasty. The Knee 20(2): 120, 2013
- 412 20. Li MG, Nilsson KG. The effect of the preoperative bone quality on the fixation of the tibial
413 component in total knee arthroplasty. The Journal of arthroplasty 15(6): 744, 2000
- 414 21. Richmond BI, Hadlow SV, Lynskey TG, Walker CG, Munro JT. Proximal Tibial Bone Density Is
415 Preserved After Unicompartamental Knee Arthroplasty. Clinical orthopaedics and related research,
416 2013
- 417 22. Kerens B, Boonen B, Schotanus MG, Lacroix H, Emans PJ, Kort NP. Revision from
418 unicompartamental to total knee replacement: the clinical outcome depends on reason for revision.
419 The bone & joint journal 95-B(9): 1204, 2013

420 23. Hooper GJ, Gilchrist N, Maxwell R, March R, Heard A, Frampton C. The effect of the Oxford
421 uncemented medial compartment arthroplasty on the bone mineral density and content of the
422 proximal tibia. *The bone & joint journal* 95-B(11): 1480, 2013

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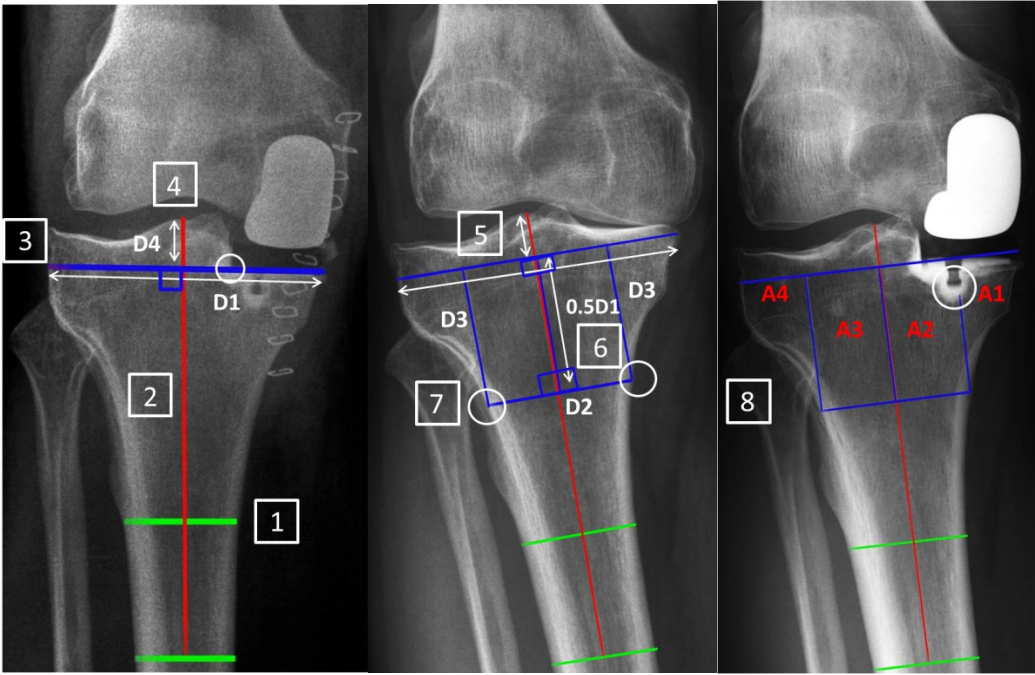


Figure 1a-c. Delineating the regions of interest (ROIs).

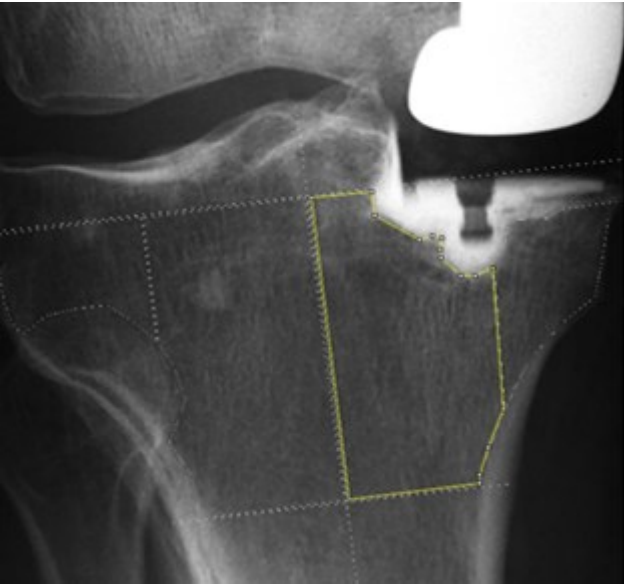


Figure 1d. ROIs for analysis with exclusion of fibular head, cortical condensation and cement (magnified).

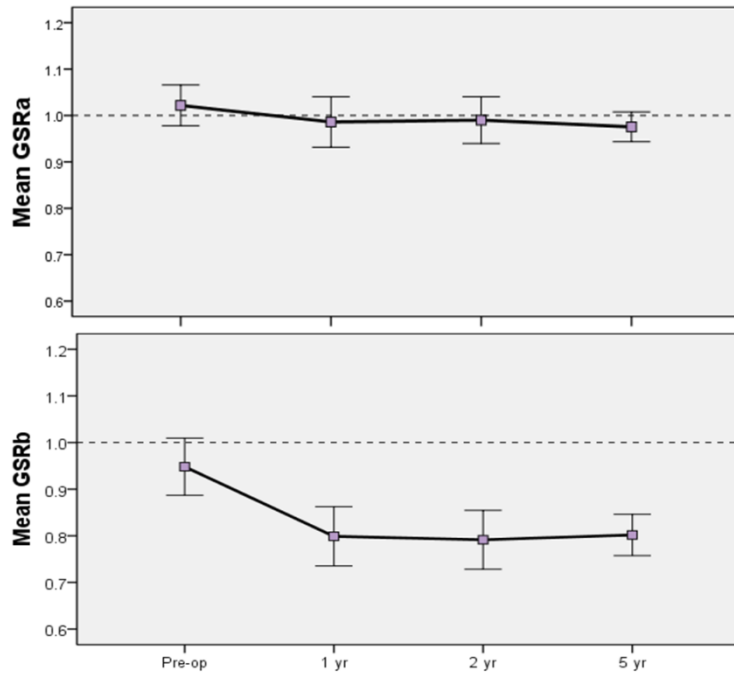


Figure 2. Changes in GSRa and GSRb over 5 years of follow up across the entire UKA population showing significant reductions in the mean GSRb in the first postoperative year ($p < 0.001$, ANOVA)

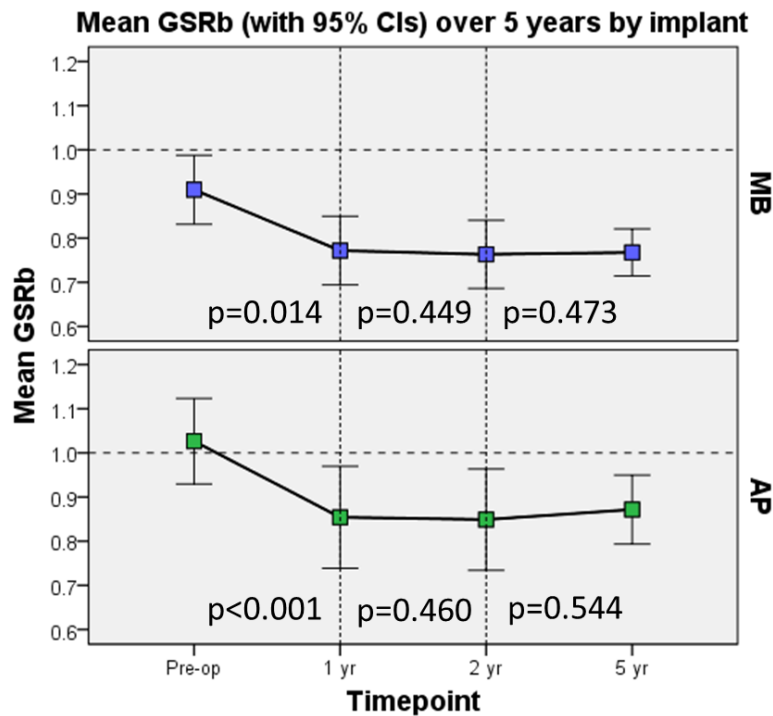


Figure 3. GSRb over time by implant showing reduced GSRb in both implants, ie a GSR < 1 . This change is significant in the first postoperative year in both the MB ($p = 0.014$, ANOVA) and AP ($p < 0.001$) implants, with no significant changes beyond this (Paired T-tests).

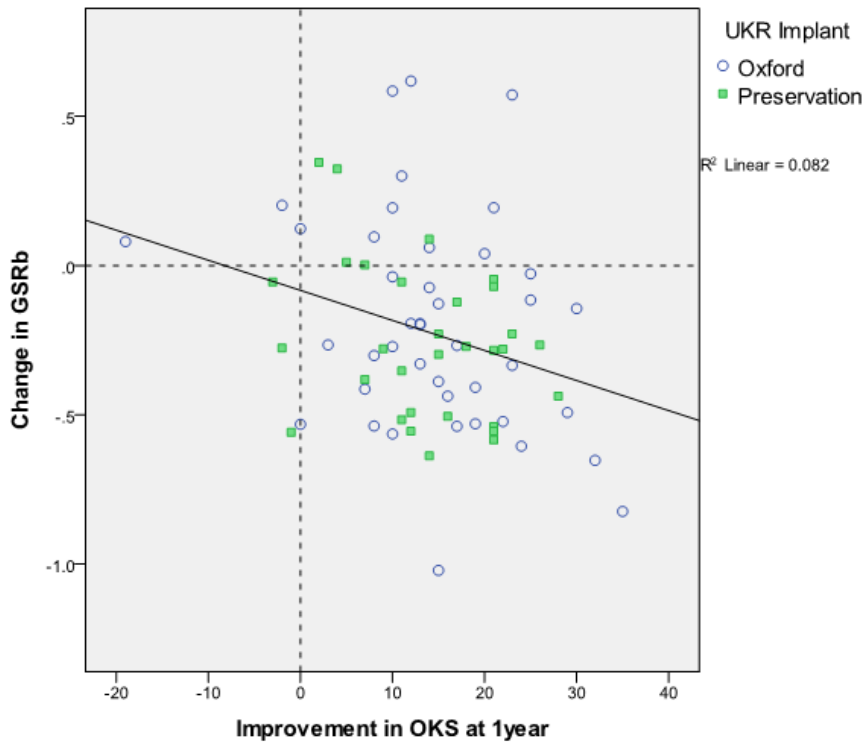


Figure 4. Scatter graph of improvement in OKS at 1 year and change in GSRb at 1 year.

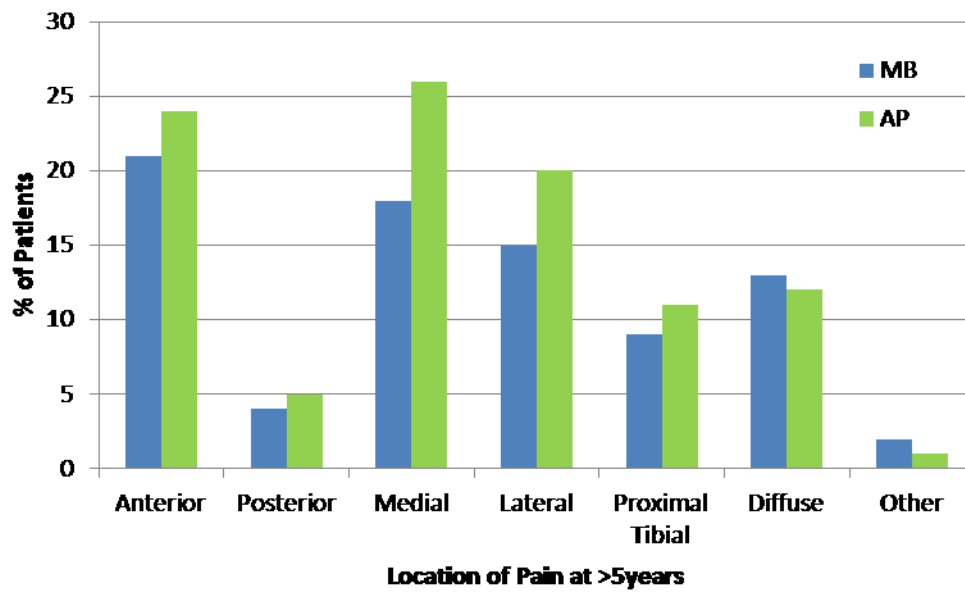


Figure 5. The location of pain by implant at >5years in patients with unrevised UKRs.

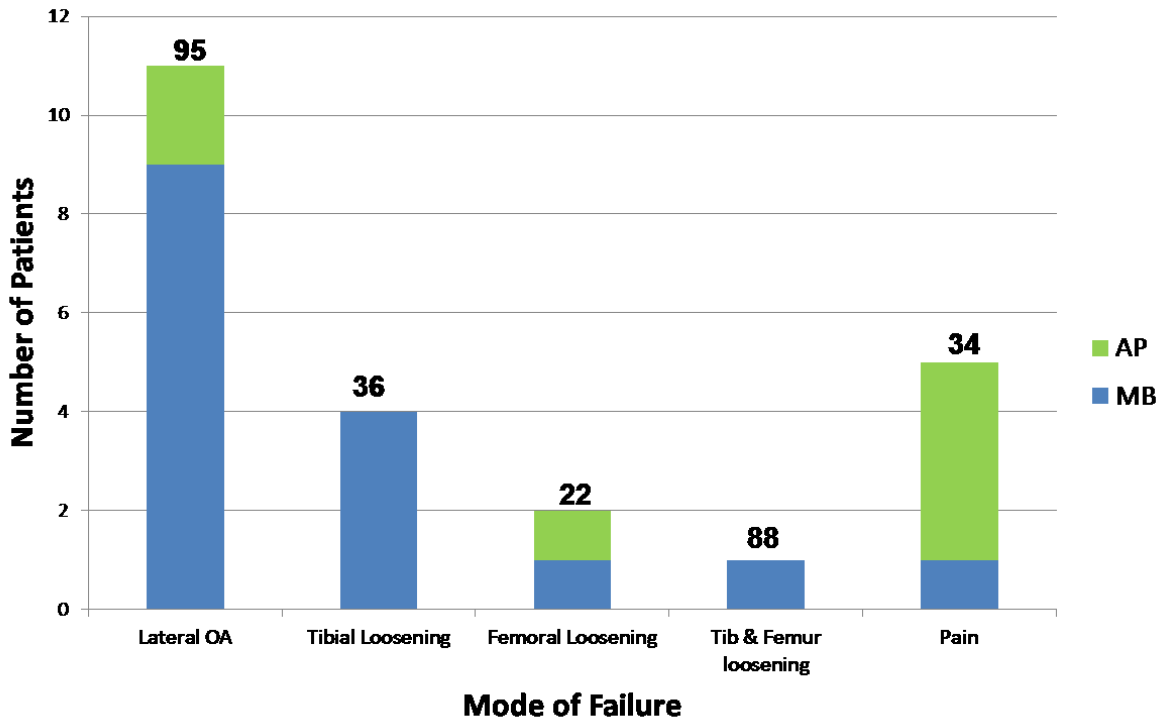


Figure 6. Modes of UKA failure by implant with mean survival times for each mode in months.

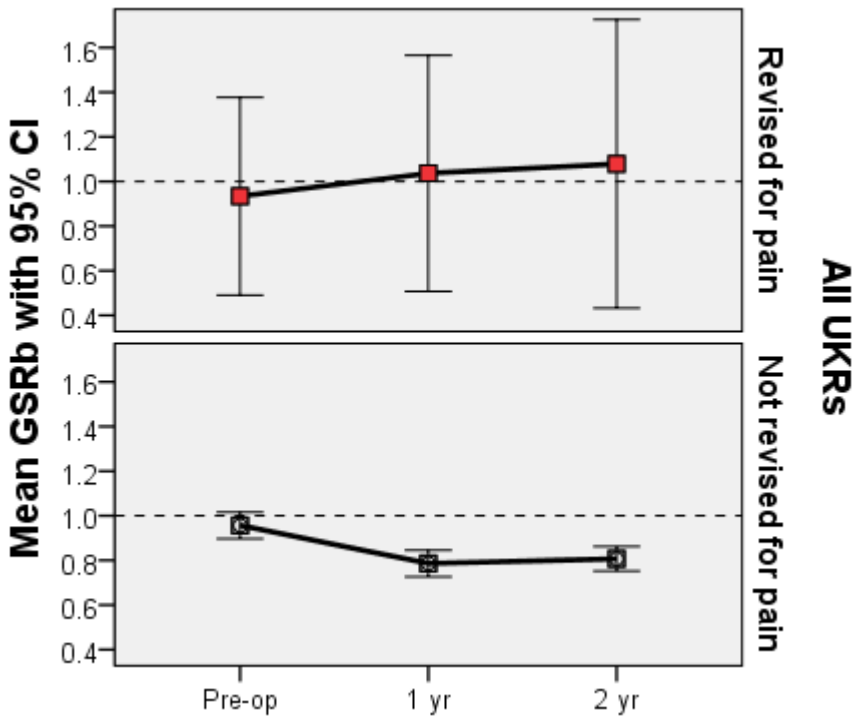


Figure 7. GSRb in patients with and without painful UKAs (both AP and MB implants).