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1 **High rate of radiolucent lines following the cemented original design of the ATTUNE®**
2 **total knee arthroplasty. A systematic review and meta-analysis**

3
4 **Aims:** Component loosening can be associated with the development of radiolucent lines
5 (RLLs). Our study aimed to assess the RLL rate of the cemented original version of the
6 ATTUNE® TKA.

7 **Materials and Methods:** A systematic search was undertaken using the Cochrane
8 methodology in four online databases. Studies were screened against predetermined criteria,
9 and data were extracted. Available National Joint Registries in the Network of Orthopaedic
10 Registries of Europe were screened for loosening and revision rates. Random effects model
11 meta-analysis was conducted.

12 **Results:** Eleven of 263 studies (n=3,119) were included. Meta-analysis of 10 studies showed
13 high rates of overall tibial or femoral RLLs for the cemented original version of the ATTUNE®
14 TKA. The rate of any RLL was estimated at 21.4% (95%CI: 12.7-33.7%) for all implant types
15 but was higher for certain subgroups: 27.4% (95%CI: 13.4-47.9%) for the CR type, and 29.9%
16 (95%CI: 15.6-49.6%) for the fixed-bearing type. Meta-analysis of 5 studies comparing the
17 ATTUNE with various other implants showed a higher risk of overall tibial or femoral RLLs
18 (OR: 2.841; 95%CI: 1.219-6.623, P=0.016) in the ATTUNE. Component loosening or revision
19 for loosening as reported by research studies were lower, estimated at 1.2% and 0.9%
20 respectively, but reported rates varied from 0 to 16.3%. There was no registry data reporting
21 specifically on revision due to loosening, but revision rates for all causes varied from 2.6 to
22 5.9% at 5 years between registries.

23 **Conclusion:** The original cemented ATTUNE® TKA system is associated with high rates of
24 RLLs, but their clinical significance is uncertain given the overall low reported rates of
25 component loosening and revision. However, in view of the observed high RLL rates and the
26 observed variation in the rates of component loosening and revision between studies and
27 registries, close surveillance of the original ATTUNE system is recommended.

28
29 **TAKE HOME MESSAGE**

- 30 • The original ATTUNE® TKA system is associated with a high rate of radiolucencies.
31 • The mechanism accounting for these radiolucencies is uncertain, hence it cannot be
32 concluded if modifications of the tibial tray under surface will address these issues.

- Close surveillance of the original design of the ATTUNE TKAs is recommended.

34

35 INTRODUCTION

36

37 The ATTUNE® (DePuy Synthes, Warsaw, IN, USA) was the successor to the PFC Sigma,
38 (DePuy Orthopaedics Inc., Warsaw, IN, USA) in part due to reported anterior knee problems
39 and dissatisfaction rates up to 21%^{43,50}. The ATTUNE® knee prosthesis was introduced in a
40 limited launch in 2011 and in general sale in 2013²¹. In 2014 a rotating platform type implant
41 was added⁵². The ATTUNE® was marketed as having a novel patella tracking system designed
42 to optimize patella tracking while maintaining bone coverage. This new design had a gradually
43 reduced femoral radius, enhancing the conformity between the femoral component and the
44 polyethylene (PE) insert to allow gradual femoral rollback and greater mid-flexion stability^{20,}
45³³. There was also a change from a tibial base peripheral locking design to a patented central
46 locking system aiming to provide a more constraint fixation and reduce backside micromotion
47¹⁶. The original ATTUNE tibial tray had less extensive grooves (cement pockets) in its under
48 surface³⁸.

49

50 Since its release, there have been reports of higher-than-expected rates of tibial loosening with
51 the ATTUNE system. The first of these reporting early tibial loosening at the implant-cement
52 interface for the ATTUNE TKA was in 2017 with 15 cases requiring revision within 2 years
53 from surgery¹². As this study did not define the population from which those revisions arose,
54 the revision rate for loosening could not be determined.

55

56 Progressive radiolucency at the implant-cement interface may be an early indicator for
57 loosening⁶³. The primary aim of this study was to assess the reported rates of radiolucent lines
58 (RLLs) following the cemented original version of the ATTUNE TKA and compare these to
59 those of other established systems. Secondary aims were to determine if these RLLs are
60 progressive and examine the relationship between RLL rates and loosening as reported by
61 research studies and national joint registries.

62

63 MATERIALS AND METHODS

64

65 The Cochrane methodology for systematic reviews was followed³¹. The predefined protocol
66 was published in PROSPERO (CRD42021277816). The systematic literature search strategy

67 included searching of electronic databases and scrutinizing the references of included studies.
68 The following databases were searched in November 2022 for any studies published since
69 2012: MEDLINE (Interface: EBSCOhost); Embase (Interface: OvidSP); and CINAHL
70 (Interface: EBSCOhost). Only studies available in English were included. The search algorithm
71 comprised of 2 searches: (i) "(ATTUNE OR total knee OR TKA OR TKR") AND
72 ("radiolucen* OR loosen*") (ii) ATTUNE AND knee. Results from both searches were
73 combined and screened for studies eligible for inclusion. All available national and regional
74 joint registries in and outside Europe were identified through the Network of Orthopaedic
75 Registries of Europe ⁴, and were screened for reported loosening and revision rates for the
76 cemented ATTUNE® TKA.

77

78 Inclusion/Exclusion criteria

79 *Population/Intervention/comparators:* The intervention was primary cemented ATTUNE
80 TKA.

81 *Outcomes:* Primary outcomes were the reported presence of RLLs at the implant-cement
82 interface on AP and/or lateral follow-up postoperative radiographs. Radiolucency was defined
83 as any RLL at the implant-cement interface on AP and/or lateral standing radiographs ²³.
84 Secondary outcomes were: (i) whether RLLs were progressive and (ii) loosening rates and
85 revision rates due to loosening assessed from research clinical studies and national joint
86 registries.

87 *Study designs:* Randomized controlled studies, prospective and retrospective cohort studies,
88 case-control studies, and case series with at least 20 patients were included. The study
89 methodology was classified according to Mathes and Pieper (2017) ⁴².

90 Two reviewers (ADP, GDC) screened independently titles and abstracts. Duplicates were
91 removed and full texts of studies considered eligible were reviewed independently. Any
92 disagreements for inclusion were discussed between reviewers and, if unresolved, with the
93 senior experienced author.

94

95 Data extraction

96 Two reviewers extracted relevant data about demographics, type of implants used, cement type,
97 definition of RLLs and radiographic evaluation system. Numbers reported for each group (n)
98 in the analysis refer to numbers of TKAs rather than number of patients.

99

100 Data analysis – Statistical analysis

101 The rate of RLLs reported post-operatively was the primary outcome. The rates of aseptic
102 loosening and rates of revision due to loosening (as reported by research studies and national
103 joint registries) were the secondary outcomes. For each study, post-operative RLLs, loosening
104 rates and revision rates were reported as absolute numbers and rates. Any statistically
105 significant difference between groups of comparison was calculated and reported ($p < 0.05$).
106 Risk ratios and 95% confidence intervals (CIs) were calculated for both primary and secondary
107 outcomes and combined in a random-effects model meta-analysis²². Heterogeneity was
108 assessed using τ^2 , I^2 , Q and P values. Data were analysed with Comprehensive Meta-analysis
109 version 2 (Biostat).

110

111 Assessment of methodological quality of studies and quality of evidence

112 The Cochrane Risk of Bias Tool for randomised controlled trials (RCTs)³⁰, Newcastle-Ottawa
113 scale (NOS) for prospective cohort studies⁶⁴, and the revised and validated version of
114 Methodological Index for Non-Randomised Studies (MINORS) for the retrospective
115 comparative studies⁵⁸ were used. Grading of Recommendations, Assessment, Development,
116 and Evaluation (GRADE) approach was used to assess the quality of evidence of the review²⁷.

117 **RESULTS**

118 Findings of the database searches

119 4,910 records were identified by title, 12 of which met the inclusion criteria^{8, 26, 32, 36, 37, 40, 51,}
120 ^{57, 59-62}. **Figure 1** shows the Preferred Reporting Items for Systematic reviews and meta-
121 analyses (PRISMA) flow diagram⁴⁶.

122

123 Characteristics of included studies

124 **Table 1** summarises the characteristics of included studies^{8, 26, 32, 36, 37, 40, 51, 57, 59-62}. The total
125 number of TKAs included was 3,869 (2,600 ATTUNE TKAs, 1,269 other systems). Five
126 studies that had a control group for comparison had no significant difference of age, gender,
127 and BMI between groups^{8, 36, 37, 51, 60}. The mean age of patients having an ATTUNE TKA was
128 69.6 years with 894 males and 1,636 females. All studies used the original design of the
129 cemented ATTUNE TKA system. All studies reported on post-operative RLLs either on tibia
130 and/or femur. Most studies reported a mean follow-up of about 2 years, but with variation in
131 their range of follow-up from 3 months to 5.4 years; this didn't allow subgroup analysis
132 according to length of follow-up (**Table 1**).

133

134 Radiographic outcomes: Radiolucent lines

135 The definition of RLLs and the radiographic evaluation system utilised are shown in **Table 2**.
136 The systems used were the Knee Society Radiographic Evaluation System and Methodology
137 (KSRESM) (**Figure 2a**)²³, and the Modern Knee Society Radiographic Evaluation System and
138 Methodology (MKSRESM) (**Figure 2b**)⁴⁴. One study defined as radiolucency any medial
139 tibial bone resorption on AP and lateral radiographs and classified it using a novel classification
140 system. Data from this referring to RLLs at the implant cement interface were extracted⁵⁹.

141

142 Results are summarised in **Table 3**. Four studies with a control group showed higher rates of
143 RLLs, predominantly tibial or overall, for the ATTUNE groups^{8, 36, 37, 60}; with two
144 demonstrating a significant difference^{37, 60}. Two studies reported no RLL for the ATTUNE
145 group in either the tibia or femur (mean follow-up 2 years)^{51, 62}. Three studies reported on
146 progression of RLLs^{36, 37, 57}, with two studies showing no progression of the reported RLLs^{36,}
147 ⁵⁷. One reported that medial tibia RLLs were progressive: increasing from 17% for the
148 ATTUNE group at 2 weeks follow-up to 42% at 2 years follow-up³⁷. One study compared
149 patients in the ATTUNE group that had RLLs with those without RLLs³². BMI was associated
150 with increased rates of RLLs (p=0.003), with an increase of one unit of BMI increasing the
151 odds of RLL by 8%. There was no difference in implant constraint (p=0.818), cement type
152 (p=0.340), patella resurfacing (p=0.286), age (p=0.984), and sex (p=0.376) between those with
153 and without RLLs.

154

155 **Meta-analysis**

156

157 Prevalence of RLL in the ATTUNE® groups (Table 4)

158 All studies, (1,858 ATTUNE® TKAs), examined the prevalence of RLLs either tibial, femoral
159 or overall (any tibial or femoral), with 3 studies reporting on RLL if ≥ 2 mm or progressive^{8,}
160 ^{36, 62}. Meta-analysis of 10 studies (n=1,558) showed a prevalence of 21.4%% (95%CI: 12.7-
161 33.7%) for any RLL (tibial or femoral) overall^{8, 26, 32, 36, 37, 40, 51, 57, 60, 62}.

162

163 RLLs - Sub-group analysis (CR, PS, Fixed-bearing implants) (Table 4)

164 There was heterogeneity in the characteristics of the ATTUNE TKA implant types, such as
165 CR/PS, fixed/mobile bearing, patella resurfaced/not and type of cement used. Meta-analysis
166 showed a prevalence of 27.4% (95%CI: 13.4-47.9%) for any RLL (tibial or femoral) overall
167 for the CR type (either fixed or mobile-bearing)^{8, 37, 57}, and 29.9% (95%CI: 15.6-49.6%) for

168 the fixed-bearing type (either CR or PS) ^{26, 32, 36, 37, 40, 57}. The rest of the meta-analysis results
169 are summarised in **Table 4**.

170

171 Meta-analysis was also performed to compare the reported tibial versus femoral RLLs. Meta-
172 analysis of 4 studies (n=636) reporting on both tibial and femoral RLLs showed no significant
173 difference between rates of tibial and femoral RLLs in the ATTUNE group (estimated OR:
174 0.845; 95%CI: 0.461-1.548, P=0.586; heterogeneity: tau²=0.183, I²=56.084, Q=6.831,
175 P=0.077) ^{8, 26, 36, 60}.

176

177 RLLs - Comparison with control group

178 Meta-analysis (6 studies) compared RLLs of the ATTUNE® TKA with a variety of other
179 systems (PFC Sigma®, Vanguard®, PERSONA®, LCS®) ^{8, 36, 37, 57, 60}. One study (n=200)
180 reported no RLL in either group ⁵¹. In meta-analysis methodology, studies with zero events are
181 discarded, hence this study was excluded. Meta-analysis of the remaining 5 studies (1,228
182 TKAs) showed a significantly higher rate of any RLL (tibial or femoral) overall (estimated OR:
183 2.841; 95%CI: 1.219-6.623, P=0.016; heterogeneity: tau²=0.705, I²=80.805, Q=20.838,
184 P<0.001, **Figure 3**) in the ATTUNE group as compared to the control. When excluding two
185 studies reporting only on RLLs ≥ 2mm ^{8, 36}, the odds ratio was even higher (estimated OR:
186 4.258; 95%CI: 1.271-14.261, P=0.019). Meta-analysis of 2 studies (n= 603 TKAs) comparing
187 the ATTUNE® with the PFC Sigma® showed a significantly higher rate of any RLL (tibial or
188 femoral) overall in the ATTUNE group as compared to the PFC group (estimated OR: 7.039;
189 95%CI: 4.298-11.526, P<0.001; heterogeneity: tau²=0.001, I²=0.001, Q=0.298, P=0.585) ^{37, 60}.

190

191 Loosening rates (Table 5)

192 Studies reporting on loosening rates of the ATTUNE TKA and their demographics are shown
193 in **Table 5**. It is of note that there was substantial variation in the loosening rates reported
194 between studies, varying from 0-10.2%. Meta-analysis of 6 studies showed an overall reported
195 loosening rate of 1.2% (95%CI: 0.2-6.3%) (heterogeneity: tau²=6.092, I²=93.273, Q=29.731,
196 P<0.001) ^{26, 36, 40, 57, 60, 61}. Meta-analysis of 3 studies reporting on loosening rates with fixed-
197 bearing components showed an overall reported loosening rate of 2.4% (95%CI: 0.2-25.5%)
198 (heterogeneity: tau²=4.605, I²=91.283, Q=22.942, P<0.001) ^{26, 40, 57}. Meta-analysis of 3 studies
199 reporting on loosening rates with PS components showed a rate of 1.5% (95%CI: 0.1-22.6%)
200 (heterogeneity: tau²=3.936, I²=93.702, Q=79.394, P<0.001) ^{26, 40, 59}.

201

202 Revision due to loosening (Table 5)

203 There was substantial variation between studies in the reported revision due to loosening rates,
204 from 0-16.3% (Table 5). Meta-analysis of 6 studies reporting on revision due to loosening
205 showed an overall rate of 0.9% (95%CI: 0.2-5.1%) (heterogeneity: $\tau^2=3.587$, $I^2=93.131$,
206 $Q=72.789$, $P<0.001$)^{26, 40, 59-62}.

207

208 Seven national joint registries reporting on the ATTUNE® knee were identified and assessed
209 for revision rates due to loosening (UK, Australia, New Zealand, Swedish, German, Dutch,
210 Swiss)^{1-3, 5, 48, 53, 54}. Although these reported on overall revision rates of the ATTUNE TKA,
211 none reported specifically on revision due to loosening. The overall revision rates are shown
212 in Table 6. Only three presented results on cemented implants in isolation^{1, 3, 4}, with the rest
213 reporting revision for all fixation types. In the three that reported on cemented in isolation, 5-
214 year revision rates varied from 2.6 to 5.9%, whilst for all fixation types reported rates varied
215 from 1.37 to 6.3%.

216

217 **Assessment of methodological quality of the studies and quality of evidence**

218

219 The RCT had “low risk of bias”³⁰, having adequate sequence generated, concealed allocation
220 and blinding of participants without any other source of bias³⁷. Both prospective studies scored
221 the highest score of 9 stars in the assessment (Table 7). The average MINORS score of the 9
222 retrospective studies was 17 (Table 8). The quality of evidence (GRADE approach) was “low”
223²⁷.

224

225 **DISCUSSION**

226

227 Our meta-analysis showed high rates of overall tibial or femoral RLLs for the cemented
228 original version of the ATTUNE TKA. The rate of RLLs was estimated at 21.4% for all implant
229 types but was even higher for certain subgroups (27.4% for the CR type, and 29.9% for the
230 fixed-bearing type). Analysis of studies comparing RLLs of the ATTUNE versus other knee
231 systems showed that the odds of having RLL was 2.8-fold higher with the ATTUNE when any
232 RLL was considered or 4.3-fold higher when RLLs ≥ 2 mm were considered. Comparison of
233 the ATTUNE® with the PFC Sigma® showed that the odds of having RLL was 7-fold higher
234 with the ATTUNE. Rates of component loosening or revision for loosening reported within
235 published studies were much lower. Overall, these rates are estimated at 1.2% and 0.9%

236 respectively, however, reported rates varied significantly (0 to 16.3%) between studies. There
237 is no registry data reporting specifically on revision due to loosening, but ‘all-cause’ 5-year
238 revision rates for the cemented ATTUNE vary from 2.6 to 5.9% between registries ^{2, 6, 48}.

239
240 RLLs in TKA may be related to multiple mechanisms ⁷. Early radiolucency has been attributed
241 to component design and constraint, malalignment, surface roughness of the tibial component,
242 cement type, and cementation techniques ^{39, 56}. Late radiolucency around a cemented tibial
243 component has been associated with PE wear and osteolysis or stress shielding related to the
244 component material and design^{24, 25, 41}. Stress shielding is influenced by the tibial tray material
245 and thickness as well as stem length and geometry ^{24, 41, 55}. Patient factors, such as age, BMI or
246 activity level, have also been linked to tibial component radiolucency ^{9, 56}.

247
248 Several mechanisms have been postulated to explain the high rate of RLLs noted in the
249 ATTUNE®. A retrieval analysis examining ATTUNE implants compared with titanium PFC
250 Sigma and CoCr PFC Sigma showed no evidence of cement remain on any of the ATTUNE
251 trays ¹⁷. This was felt possibly related to tibial tray design, in particular the absence of separate
252 cement pockets/grooves in the backside surface as well as the higher stem surface roughness
253 in the ATTUNE. The ATTUNE® tibial tray also has a patented central locking mechanism
254 claiming to provide more secure fixation with less backside micromotion ¹⁶. However, a
255 comparative retrieval analysis showed that TKA designs with central locking trays had
256 significant less cement cover compared with peripheral locking trays; the PE inserts in the
257 central locking systems had a characteristic pattern of deformation of their outer edges, which
258 could increase the localized frictional torque and lead to debonding of the tray from the cement
259 mantle ¹¹. A further possibility is that the different design and instrumentation of the ATTUNE
260 system leads to inadequate cement mantle in comparison with its predecessors, with recent
261 reports showing that excessive press fit may lead to incomplete seating or tilting of the tibial
262 component especially in hard and uneven sclerotic bone ³⁵. Another factor attributed to tibial
263 loosening is stress shielding. The ATTUNE system uses a thick CoCr tibial baseplate and there
264 are reported series suggesting that medial tibial bone resorption is common with the ATTUNE,
265 presenting in various locations and severities around the baseplate ⁵⁹.

266
267 Cement debonding at the tibial cement-implant interface has been related to cement type and
268 cementation technique in modern TKA^{7, 19, 45, 39}. High-viscosity (H-V) cement reaches the
269 dough phase more quickly and it is popular in TKA, however, there are reports linking H-V

270 cement with possible debonding at the implant-cement interface ^{7, 14, 39}. In our review, a
271 standard H-V cement (Palacos R+G, Heraeus Medical, Germany) was used in six of the studies
272 ^{8, 26, 32, 37, 57, 60}; with one study using a fast-setting H-V cement in some TKAs (CMW-1, DePuy,
273 CMW, UK) ³².

274

275 In 2017 DePuy launched a modification of the tibial component (Attune S+) incorporating
276 backside grooves which may facilitate cement interdigitation and improve fixation
277 performance ³⁴, but an estimated 600,000 TKAs were implanted before this design change ¹⁶.
278 Furthermore, the rest of the design features remained the same and there is, yet, little clinical
279 evidence that these changes have influenced the rates of RLL.

280

281 Radiolucencies are recognised following most cemented TKA designs and 3 studies in our
282 analysis have compared the ATTUNE® and PFC Sigma® systems with regards to RLLs ^{37, 51,}
283 ⁶⁰. Two of them showed a significantly higher rate of RLLs (both overall and especially at the
284 medial tibia implant-cement interface) in the ATTUNE as compared to the PFC ($p < 0.001$) ^{37,}
285 ⁶⁰, and with RLLs being progressive up to the 2 year follow-up in one of these studies ³⁷.

286

287 Radiolucencies in TKA may be a surrogate marker of aseptic loosening. Loosening is likely to
288 be a progressive process and early RLLs may be a herald of failure at a later stage. Aseptic
289 loosening is the principal cause for early and late revisions, accounting for one third of implant
290 failures in TKA so understanding the rates of RLLs in the ATTUNE TKA and their clinical
291 significance may help guide surgical practice.

292

293 Our results show that despite the high rate of RLLs observed with the original ATTUNE
294 system, the reported rates of loosening within published studies are low. Although, no registry
295 data are available that report specifically on revision due to loosening, in most registries overall
296 revision rates are also low. Overall revision rates of the ATTUNE knee as reported by registries
297 may reasonably be used as an indicator of revision rates for aseptic loosening, unless there
298 were other causes of revision which have lower rates with the ATTUNE. Thus, the clinical
299 significance of high rates of postoperative RLLs in the ATTUNE remains unclear. The
300 observed discrepancy with high rates of RLLs but low reported rates of component loosening
301 or revision may signify that RLLs are not clinically important in the ATTUNE system.
302 Alternatively, it is possible that RLLs are clinically important but for other reasons their rate
303 of occurrence is not mirrored by loosening and revision rates.

304

305 It is reasonable to expect that rates of RLLs are higher than those of aseptic component
306 loosening which in turn are expected to be higher than revision rates. RLLs do not necessarily
307 equate to loosening and component loosening may not lead to revision surgery. Furthermore,
308 diagnosis of early component loosening in the absence of overt clinical features or significant
309 radiological features such as implant migration or substantial bone loss can be difficult. This
310 diagnosis may be made intra-operatively at the time of revision, but may also be relevant to the
311 substantial proportion of patients who continue with unexplained pain following TKA ¹⁰. In
312 line with such diagnostic challenges, Bonutti et al. reported that 15 patients revised for
313 ATTUNE tibial loosening had developed increasing pain with initiation of weight bearing and
314 loss of active ROM following an initial symptom-free period ¹³. They also reported that all
315 these patients had tenderness on palpation of the medial and lateral part of the tibial plateau
316 and their plain radiographs showed radiolucencies, but they didn't report the presence of overt
317 radiographic evidence of loosening or bone loss. Similar clinical findings of pain and localised
318 tenderness at or just below the joint line were also reported more recently by Murphy et al ⁴⁷
319 in 3 cases of early aseptic failure of the tibial component-cement interface in the ATTUNE
320 prosthesis.

321

322 Even if component aseptic loosening is clear, it is likely that some if not most revisions for this
323 are only carried out when the patient becomes significantly symptomatic. Patients with minor
324 symptoms and no significant bone loss may be monitored rather than proceeding with revision.
325 Assuming this is correct, there will always be a lag between the early stages of a loose
326 component and the reported rates of revision surgery. Moreover, in many healthcare settings
327 such as the UK's National Health System (NHS), there is a further lag between making a
328 decision to carry out revision surgery and actually performing the procedure, with evidence
329 this effect is exacerbated by the backlog due to the COVID-19 pandemic ^{15, 28}.

330

331 Although the overall reported loosening and revision rates for the original ATTUNE knee are
332 low, it is notable that there is substantial variation in reported loosening rates between research
333 studies (0 to 16.3%), as well as in overall revision rates reported by registries (2.6% at 5 years
334 in the Australian registry to 5.9% at 5 years in the German registry) ^{48, 53}. This variation allied
335 to high rates of RLLs, warrants further investigation to fully determine if there is more concern
336 with specific component/design, surgical or cementation technique or patient characteristics.

337 This is also important as registries do not allow clarification of the multiple combinations of
338 an implant and the revision rates for such combinations cannot be easily reviewed ⁴⁹.

339

340 Our study has several limitations. Firstly, the quality of evidence was limited with only one
341 RCT and two prospective cohort studies available ^{37, 51, 57}, the rest being retrospective, and
342 some with no control group. Another limitation was the heterogeneity in the specifics of the
343 ATTUNE® TKA implant with differences in the type of components or cement used. In 4
344 studies that had a control group, the TKA system used as control varied between studies, but,
345 despite this, there was a relative consistency in the findings. We feel this is a valid comparison
346 as it helps demonstrate how the ATTUNE TKA system is performing against a general
347 population of other TKAs performed by the same surgeons, using similar techniques, in similar
348 patient populations. Radiographs can assess RLLs but the technique must follow standard
349 guidelines and fluoroscopic positioning with the beam parallel to the tibia and the components
350 ¹⁸. However, this is operator dependent, and it is difficult to ensure a reproducible technique
351 was used in the analysed studies. Follow-up in most studies was at least 2 years but there was
352 variation in this range and insufficient data to stratify risk of RLLs according to length of
353 follow-up.

354

355 The authors believe that despite our study limitations, the original design of the cemented
356 ATTUNE® TKA system is associated with a high rate of RLLs both on the tibia and femur,
357 but it remains unclear specifically which components or bearings are most at risk of this. Whilst
358 we draw attention to this finding we are also unclear of its clinical significance. Longer follow-
359 up studies and data are needed to determine the clinical relevance of the increased rate of RLLs
360 with the original ATTUNE® implant and until such evidence is available, we recommend close
361 surveillance for all patients with this implant.

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Table 1. Characteristics of all included studies in the systematic review.

Lead author (Year of publication)	Study design (Level of Evidence, Country)	No. of patients (TKAs)	Patient groups (TKA designs, cement used) Group 1: ATTUNE Group 2: Control	Gender (M:F)	Age (years) Mean (range)	Follow-up (months)
Kaptein (2020) ³⁷	RCT (I, Netherlands)	74 (74)	Group 1 (n=38) ATTUNE® CR Fixed Palacos R+G Group 2 (n=36) PFC Sigma® CR Fixed Palacos R+G	Group 1: 18M:20F Group 2: 11M:25F	Group 1: 69±9.5 Group 2: 68±8.2	<u>ATTUNE</u> 24 <u>Control</u> 24
Robinson (2021) ⁵⁷	Prospective cohort (II, UK)	192 (192)	Group 1 (n=96) ATTUNE® CR Fixed Group 2 (n=96) PFC Sigma® CR (n=41) Vanguard® CR (n=55) Fixed Palacos R+G	Group 1: 51M:45F Group 2: 34M:62F NSD	Group 1: 70.6 Group 2: 68.1 P=0.88	<u>ATTUNE</u> 24 <u>Control</u> 24
Ranawat (2017) ⁵¹	Prospective cohort (II, USA)	200 (200)	Group 1 (n=100) ATTUNE® PS 61 fixed / 39 RP Group 2 (n=100) PFC Sigma PS 83 fixed / 17 RP Cement type not specified	Group 1: 33M:67F Group 2: 29M:71F P=0.54	Group 1: 71±7.3 Group 2: 70.1±7.4 P=0.4	<u>ATTUNE</u> Mean: 22.8 (95% CI: 21.6-22.8) <u>Control</u> Mean: 24 (95% CI: 21.6-22.8)
Lachiewicz (2021) ⁴⁰	Retrospective cohort (III, USA)	624 (677)	Group 1 (n=154, 166 TKAs) ATTUNE® PS Fixed, cement: DePuy SmartSet HV: 71 (43%) DePuy SmartSet MV: 77 (46%) Simplex P MV: 18 (11%) Group 2 (n=470, 511 TKAs) Various manufacturers DePuy SmartSet HV: 20 (4%) Simplex-P MV: 492 (96%)	Group 1: 135M:19F Group 2: 419M:51F P=0.784	Group 1: 63.8±8.2 (44-85) Group 2: 64.6±7.7 (43-88) P=0.271	<u>ATTUNE</u> Mean: 23.7±12.4 Range: 6-67 <u>Control</u> Mean: 25±16.8 Range: 10-75

Behrend (2020) ⁸	Retrospective cohort (III, Switzerland)	291 (291)	Group 1 (n=100) ATTUNE® CR Group 2 (n=191) LCS® CR Mobile Palacos R+G	Group 1: 52M:48F Group 2: 85M:106F P=0.22	Group 1: 71±10 (45-89) Group 2: 70±10 (44-91) P=0.68	<u>Both groups</u> Mean: 13.5 Range: 10-21
Jin (2020) ³⁶	Retrospective cohort (III, Korea)	142 (142)	Group 1 (n=68) ATTUNE® PS Group 2 (n=74) PERSONA® PS Fixed Simplex P	Group 1: 9M:59F Group 2: 14M:60F P=0.36	Group 1: 69.7±5.9 Group 2: 67.9±7.3 P=0.44	<u>ATTUNE</u> Mean: 28.4±12.6 <u>Control</u> Mean: 29.1±13.2
Staats (2019) ⁶⁰	Retrospective cohort (III, Austria)	529 (529)	Group 1 (n=276) ATTUNE® 22PS/254CR, 255 fixed / 21 mobile Group 2 (n=253) PFC Sigma® 38PS/215CR Mobile Palacos R+G	Group 1: 103M:173F Group 2: 105M:148F p>0.05	Group 1: 69±9 Group 2: 68±10 p>0.05	<u>ATTUNE</u> Mean: 19±7 <u>Control group</u> Mean: 25±11
Torino (2022) ⁶¹	Case-series (IV, USA)	668 (742)	ATTUNE® CR/PS Fixed or mobile Cement: various types	260M:408F	70.3±9.8	<u>ATTUNE</u> Mean: 42±16.8
van Loon (2021) ⁶²	Case-series (IV, USA)	200 (200)	ATTUNE® RP 115CR/85PS Cement type not specified	74M:126F	65.4±7.8 (41-78)	<u>ATTUNE</u> 24 months
Hoskins (2020) ³²	Case-series (IV, Australia)	112 (122)	ATTUNE® 121 fixed: 9PS/112CR, 1 RP	38M:74F	71.2 (44-89)	<u>ATTUNE</u> Mean: 21 Range: 3-51
Song (2020) ⁵⁹	Case-series (IV, Italy)	500 (500)	ATTUNE® PS Cement type not specified	32M:468F	71.3±7.3	<u>ATTUNE</u> Mean: 40.8±19.2
Giaetta (2019) ²⁶	Case-series (IV, Italy)	185 (192)	ATTUNE® PS Fixed Palacos R+G	89M:129F	70.3±6.52 (43-85)	<u>ATTUNE</u> Mean: 37.9±13.9 Range: 12-64.8

n: number of patients, **TKA:** total knee arthroplasty, **PS:** posterior-stabilised, **CR:** cruciate-retaining, **RP:** rotating-platform, **PFC:** Press-Fit Condylar, **NR:** not reported, **NA:** not applicable, **UK:** United Kingdom **ATTUNE®**, **PFC Sigma®**, **LCS®:** DePuy Synthes, Warsaw, IN, USA. **Vanguard®**, **PERSONA®:** Zimmer Biomet, Warsaw, IN, USA

Table 2. Definition of radiolucency lines (RLL) and radiographic evaluation system in all included studies.

Lead Author (Year)	Definition of RLL	System used for radiographic evaluation (number of assessors)
Kaptein (2020) ³⁷	RLL (tibia) at the implant-cement interface on AP/Lat long-leg standing radiographs.	MKSRESM (2)
	RLL (tibia) either at implant-cement or cement-bone interface on AP/Lat standing radiographs. Reported on both ≥ 2 mm in depth or progressive pattern (significant) and on < 2 mm in depth (non-significant). RLL at implant-cement interface included in analysis.	KSRESM (2)
Ranawat (2017) ⁵¹	RLL (tibia and femur) at implant-cement interface on weight-bearing AP, Lat and 30° merchant view + AP long-leg standing view.	KSRESM (2)
Lachiewicz (2021) ⁴⁰	RLL (tibia) at implant-cement interface on AP/Lat standing radiographs	MKSRESM (2)
Behrend (2020) ⁸	RLL (tibia and femur) at implant-cement interface on AP/Lat radiographs. Documented if ≥ 2 mm in a progressive pattern	MKSRESM
Jin (2020) ³⁶	RLL (tibia and femur) at implant-cement interface on AP/Lat radiographs. Documented if ≥ 2 mm or progressively enlarging RLL was found in any zone in AP/Lat views	KSRESM (2)
Staats (2019) ⁶⁰	RLL (tibia and femur) either at implant-cement or cement-bone interface on AP/Lat standing radiographs. Documented if detected on two serial radiographs	MKSRESM (2)
	RLL (tibia and femur) ≥ 2 mm in depth on AP/Lat standing radiographs	No system reported
Hoskins (2020) ³²	RLL (tibia and femur) at implant-cement interface (AP/Lat radiographs). Classified as partial or complete.	MKSRESM
Song (2020) ⁵⁹	Medial tibial bone resorption was evaluated. Progression according to change in size of bone resorption area, defined as no progression when change in size was less than 2mm.	Own classification system of bone resorption (2)
Giaretta (2019) ²⁶	RLL (tibia and femur) at implant-cement interface on AP/Lat standing radiographs	MKSRESM

RLL: radiolucency lines, **AP:** anteroposterior view, **Lat:** lateral view, **KSRESM:** Knee Society Radiographic Evaluation System²³,

MKSRESM: Modern Knee Society Radiographic Evaluation System⁴⁴

Table 3. Radiolucency lines reported post-operatively in all studies included in the systematic review.*

Lead author (Year)	Type of prosthesis Radiographic evaluation	Tibial RLL (knees) in ATTUNE®	Tibial RLL (knees) in Control	Femoral RLL in ATTUNE®	Femoral RLL in Control	Knees with RLL overall in ATTUNE	Knees with RLL overall in Control	Statistical analysis (ATTUNE vs Control)
Kaptein (2020) ³⁷	ATTUNE vs PFC CR MKSRESM	16 (16) <u>AP</u> Z1: 14 (42%) Z2: 2 (6%)	4 (3) <u>AP</u> Z1: 3 (8.6%) Z2: 1 (2.8%)	NR	NR	16/33 (48%)	3/35 (8.6%)	Tibial/Overall RLL: P=0.002
Robinson (2021) ⁵⁷	ATTUNE vs PFC or Vanguard CR KSRESM	28 (26) <u>AP</u> Z1: 6 (23%) Z4: 2 (7.7%) <u>Lat view</u> Z1: 2 (7.7%) Z2: 2 (7.7%) Z3: 16 (61.5%)	29 (20) <u>AP</u> Z1: 7 (24%) Z3: 1 (3%) Z4: 3 (10%) <u>Lat</u> Z1: 6 (21%) Z2: 2 (7%) Z3: 9 (31%)	NR	NR	26/96 (27%)	20/96 (21%)	Tibia/Overall RLL: P=0.42
Ranawat (2017) ⁵¹	ATTUNE vs PFC PS KSRESM	0/100	0/100	0/100	0/100	0/100	0/100	No difference
Lachiewicz (2021) ⁴⁰	ATTUNE vs various PS MKSRESM	182 (110) <u>AP</u> Z1: 26 (16%) Z2: 14 (8%) <u>Lat</u> Z1: 1 (1%) Z2: 8 (5%) Z3: 3A: 49 (30%) 3P: 28 (17%) Z5: 26 (16%)	NR	NR	NR	110/166 (66%)	NR	NA
Behrend (2020) ⁸	ATTUNE vs LCS CR MKSRESM	2 (1) <u>AP</u> Z1: 1 (1%) Z2: 1 (1%)	6 (5) <u>AP</u> Z1: 2 (1%) Z2: 4 (2.1%)	15 (14) <u>Lat view:</u> Z1: 1 (1%) Z2: 12 (12%) Z3A: 1 (1%) Z3P: 1 (1%)	22 (18) <u>Lat view:</u> Z1: 6 (3.1%) Z2: 15 (7.9%) Z3A: 0 Z3P: 1 (0.5%)	14/100 (14%)	18/191 (9.4%)	Tibial RLL: P=0.428 Femoral RLL: P=0.236 Overall RLL: NSD
Jin (2020) ³⁶	ATTUNE vs PERSONA PS KSRESM	8 (4) <u>AP</u> Z1: 4 (5.9%) Z2: 4 (5.9%)	8 (4) <u>AP</u> Z1: 4 (5.4%) Z2: 4 (5.4%)	6 (3) <u>Lat view:</u> Z1: 3 (4.4%) Z4: 3 (4.4%)	3 (2) <u>Lat view:</u> Z1: 2 (2.7%) Z4: 1 (1.4%)	5/68 (7%)	4/74 (5%)	Tibial RLL: p=0.98 Femoral RLL: p=0.99 Overall RLL: P=0.98

Staats (2019) ⁶⁰	ATTUNE (22PS/254CR) vs PFC (38PS/215CR) MKSRESM	<u>AP</u> 38 (37) Z1: 26 (9%) Z2: 6 (2%) <u>Lat</u> 68 in 56 knees (20.3%) Z1: 6 (2%) Z2: 3 (1%) Z3: 3A: 44 (16%) 3P: 12 (4%) Z5: 3 (1%)	<u>AP</u> 11 (10) Z1: 8 (3%) Z2: 3 (1%) <u>Lat</u> 6 in 6 knees (2.4%) Z1: 0 Z2: 0 Z3: 3A: 3 (1%) 3P: 0 Z5: 3 (1%)	40 (40) <u>Lat view:</u> Z1: 3 (1%) Z2: 33 (12%) Z3: 1	6 (5) <u>Lat view:</u> Z1: 0 Z2: 6 (2%) Z3: 0	97/276 (35%)	19/253 (7.5%)	Tibial RLL: P<0.001 Femoral RLL: P<0.001 Overall RLL: P<0.001
van Loon (2021) ⁶²	ATTUNE RP 115CR/85PS (no control)	0/191	NA	0/191	NA	0/191	NA	NA
Hoskins (2020) ³²	ATTUNE (9PS/112CR) (no control) MKSRESM	<u>AP</u> Z1: 28 (23%) Z2: 28 (23%) <u>Lat</u> Z1: 16 (13%) Z2: 14 (53.8%) Z3: 3A: 0 3P: 1 (3.4%)	NA	<u>Lat view:</u> Z1: 9 (7%) Z2: 0 Z3: 3A: 2 3P: 2 Z5: 17 (14%)	NA	29/122 (23.8%)	NA	NA
Song (2020) ⁵⁹	ATTUNE PS (no control)	21/500 (4.2%) <u>Under medial tibial baseplate</u> UT1: 31 (19.2%) UT2: 10 (2%)	NA	NA	NA	96/500 (19.2%)	NA	NA
Giaretta (2019) ²⁶	ATTUNE PS (no control) MKSRESM	25/192 (13%) <u>AP</u> Any zone: 25 (13%) <u>Lat</u> Any zone: 17 (8.8%)	NA	23/192 (12%) <u>Lat</u> Any zone: 23 (12%)	NA	43/192 (22.4%)	NS	NA

TKA= total knee arthroplasty, PS: posterior-stabilised, CR: cruciate-retaining, RP: rotating-platform, PFC: Press-Fit Condylar, RLL: radiolucency lines, AP: anteroposterior view, Lat: lateral view, Z: zone, NA: not applicable, NR=not reported, NSD=no significant difference, p<0.05: significant, MKSRESM: Modern Knee Society Radiographic Evaluation System ⁴⁴, KSRESM: Knee Society Radiographic Evaluation System ²³, ATTUNE®, PFC Sigma®, LCS®: DePuy Synthes, Warsaw, IN, USA. PERSONA®: Zimmer Biomet, Warsaw, IN, USA

*The numbers in total in each box refer to the numbers of knees which had at least one RLL.

Table 4. Prevalence (estimated rate) for any radiolucency lines in the ATTUNE® groups reported in medial tibia, tibia, femur and overall

RLL (TKA design)	No. of studies (TKAs)	Estimated rate - OR (95%CI)	Estimated rate - OR (95%CI) (excluding the 3 studies reporting on RLL ≥ 2mm) ^{8, 36, 62}	Heterogeneity			
				τ^2	I ²	Q value	P value
Tibia and/or femur overall (fixed)	6 (682)	29.9% (95%CI: 15.6-49.6%)	36.3% (19.6%-57.2%)	1.020	95.182	103.778	P<0.001
Tibia and/or femur overall (CR)	3 (234)	27.4% (13.4-47.9%)	NA	0.535	86.831	15.187	P=0.001
Tibia and/or femur overall (any)	10 (1,558)	21.4% (95%CI: 12.7-33.7%)	31% (95%CI: 19.2-46%)	0.818	93.708	143.042	P<0.001
Tibia AP (fixed)	5 (560)	27.4% (95%CI: 10.1-55.8%)	36.1% (95%CI: 13.7%-66.8%)	1.794	96.650	119.392	P<0.001
Tibia AP (CR)	3 (234)	18.5% (5.1-49.2%)	NA	1.338	89.688	19.395	P<0.001
Tibia AP (PS)	4 (526)	11.7% (1.8-48.8%)	NA	3.623	97.593	124.653	P<0.001
Tibia AP (any)	9 (1,236)	11.3% (95%CI: 4.5-25.6%)	22.1% (95%CI: 8.7-45.9%)	1.913	95.913	195.721	P<0.001
Medial tibia AP (fixed)	5 (490)	15.8% (95%CI: 8.4-28%)	19% (95%CI: 10-33.1%)	0.562	85.953	28.476	P<0.001
Medial tibia AP (CR)	3 (234)	8.4% (95%CI: 1.0-45.4%)	NA	3.388	93.149	29.193	P<0.001
Medial tibia AP (PS)	4 (834)	8.4% (95%CI: 4.3-15.5%)	NA	0.313	77.971	13.618	P=0.003
Medial tibia AP* (any)	10 (1,666)	9.1% (5.4-15.1%)	12.8% (95%CI: 7.6-20.7)	0.586	86.737	67.859	P<0.001
Tibia Lat (any)	5 (838)	3.8% (95%CI: 1.1-12.1%)	5.6% (95%CI: 1.7-16.7%)	1.447	88.923	36.110	P<0.001
Femur Lat (any)	6 (936)	8.9% (95%CI: 5.1-15%)	11.5% (95%CI: 6.6-19.5%)	0.295	72.982	18.506	P=0.002

RLL: radiolucency lines, **OR:** odds ratio, **95%CI:** 95% Confidence Interval, **p<0.05:** significant, **NA:** not applicable, **TKAs:** total knee arthroplasties, **AP:** anteroposterior view, **Lat:** lateral view, **PS:** Posterior-stabilised, **CR:** cruciate-retaining,

*Medial tibia (AP): included one study which defined as radiolucency any medial tibial bone resorption, but only radiolucencies reported for zones of medial tibial baseplate included⁵⁹

Table 5. Demographics and outcomes (loosening and revision rates) from studies included in the systematic review.

Lead Author (Year)	TKA design	Follow-up (months) Mean (range)	Number of ATTUNE TKAs	Loosening	Revision overall	Revision due to loosening
Robinson (2021) ⁵⁷	Fixed CR	24	96	0	NR	NR
Lachiewicz (2021) ⁴⁰	Fixed PS	Mean: 23.7±12.4 (6-67)	166	17	31*	27*
Jin (2020) ³⁶	Fixed PS	Mean: 28.4±12.6	142	0	NR	NR
Staats (2019) ⁶⁰	Fixed + mobile CR/PS	Mean: 19±7	276	0	3	0
Van Loon (2021) ⁶²	Mobile-CR/PS	Mean: 24	200	NR	1	0
Song (2020) ⁵⁹	PS	Mean: 40.8 (2-5)	500	NR	2	0
Giaretta (2019) ²⁶	Fixed PS	Mean: 37.9 (12-64.8)	228	2	2	2
Torino (2022) ⁶¹	Fixed + mobile	Mean: 42	742	10	18	10

TKA: total knee arthroplasty, **CR:** cruciate-retaining, **PS:** posterior-stabilised, **NR:** not reported
 All were based on radiological findings, with one based on radiological and clinical characteristics ⁴⁰.
 *Including 12 TKAs awaiting revision.

Table 6. Overall revision rates of the ATTUNE TKA reported in National Joint Registries.

NJR (Year)	ATTUNE TKAs (n)	Revisions (n)	Reported revision	Revision rate 1 year (95%CI)	Revision rate 2 years (95%CI)	Revision rate 3 years (95%CI)	Revision rate 4 years (95%CI)	Revision rate 5 years (95%CI)	Revision rate 6 years (95%CI)
UK (2022) ⁴⁸	FB (all fix): 33,769 MB (all fix): 5770	NR	Cumulative	<u>FB (all fix)</u> 0.39 (0.32-0.46) <u>MB (all fix)</u> 0.26 (0.16-0.45)	NR	NR	NR	<u>FB (all fix)</u> 2.06 (1.88-2.27) <u>MB (all fix)</u> 1.37 (1.03-1.83)	NR
Australia (2022) ¹	Cement CR: 20,427 PS: 10,431	CR: 473 PS: 206	Cumulative	<u>CR cement</u> 0.9 (0.9-1.0) <u>PS cement</u> 0.9 (0.7-1.1)	NR	NR	NR	<u>CR cement</u> 3.1 (2.8-3.4) <u>PS cement</u> 2.6 (2.3-3.0)	NR
New Zealand (2022) ⁵⁴	All fix: 35,148	All fix: 193	Rate/100 component years	0.549 (0.474-0.632)	NR	NR	NR	NR	NR
Sweden (2020) ⁵³	All fix: 115	NR	Overall relative risk	0.88 (0.12-6.27)	NR	NR	NR	NR	NR
Germany (2021) ²	CR FB cement 5,802 CR MB cement 1,417 PS FB cement 1,362 PS MB cement 417	NR	Revision probability	<u>CR FB cement</u> 1.6 (1.3-2.0) <u>CR MB cement</u> 1.4 (0.9-2.2) <u>PS FB cement:</u> 2.5 (1.7-3.6) <u>PS MB cement:</u> 1.0 (0.4-2.8)	NR	<u>CR FB cement</u> 3.1 (2.6-3.7) <u>CR MB cement</u> 2.8 (1.9-3.9) <u>PS FB cement:</u> 4.0 (3.0-5.5) <u>PS MB cement:</u> 1.4 (0.6-3.3)	<u>CR FB cement</u> 3.2 (2.7-3.8) <u>CR MB cement</u> 3.2 (2.2-4.6) <u>PS FB cement:</u> 5.6 (4.1-7.6) <u>PS MB cement:</u> 1.4 (0.6-3.3)	<u>CR FB cement</u> 3.6 (2.9-4.4) <u>CR MB cement</u> 3.6 (2.9-4.4) <u>PS FB cement:</u> 5.9 (4.3-8.1) <u>PS MB cement:</u> NR	<u>CR FB cement</u> 3.6 (2.9-4.4) <u>CR MB cement</u> 3.6 (2.9-4.4) <u>PS FB cement:</u> 3.6 (2.9-4.4) <u>PS MB cement:</u> NR
Netherlands (2022) ³	Cement: 3,261	23	Cumulative	0.5 (0.2-0.8)	NR	2.4 (1.7-3.2)	NR	3.2 (2.2-4.1)	NR
Switzerland (2021) ⁶	All fix: 18,286	NR	Cumulative	1.7 (1.5-1.9)	NR	NR	5.7 (5.3-6.1)	6.3 (5.9-6.8)	6.9 (6.3-7.4)

Switzerland (2022) ⁵	<u>All fix</u> CR FB: 2,677 CR MB: 4,753 PS FB: 2,224 PS MB: 3,246	CR FB: 2,677 CR MB: 4,753 PS FB: 2,224 PS FB: 3,246	Adjusted revision rate	NR	<u>CR FB:</u> 2.8 (2.2-3.5) <u>CR MB:</u> 4.2 (3.7-4.9) <u>PS FB:</u> 2.9 (2.3-3.7) <u>PS MB:</u> 3.7 (3.1-4.4)	NR	NR	NR	NR
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NJR: National Joint Registry, **TKA:** total knee arthroplasty, **n:** number, **UK:** United Kingdom, **CR:** cruciate-retaining, **PS:** posterior-stabilised, **FB:** fixed-bearing, **MB:** mobile-bearing, **fix:** fixation, **NR:** not reported.

***Rate/100 component years:** Equivalent to the yearly revision rate expressed as a percent and is derived by dividing the number of prostheses revised by the observed component years multiplied by 100.

****Adjusted revision rate:** Revision rate adjusted for effects of mortality and emigration.

Table 7. Risk of bias for prospective cohort studies using the Newcastle-Ottawa Scale (NOS) ⁶⁴.

Lead author (Year)	Representativeness of cohort	Selection of non-exposed cohort	Ascertainment of exposure	Demonstration of that outcome was not present at start of study	Comparability of cohorts	Assessment of outcome	Follow up long enough for outcomes to occur	Adequate of follow-up of cohorts	NOS score
Robinson (2021) ⁵⁷	Somewhat representative*	Drawn from same community as the exposed cohort*	Secure record*	Yes*	Study control for post-op radiolucencies* Study controls for gender, age, BMI, side, pre-op deformity*	Independent blind assessment*	Yes*	Subject lost to follow-up unlikely to introduce bias – small number lost*	9
Ranawat (2017) ⁵¹	Somewhat representative*	Drawn from same community as the exposed cohort*	Secure record*	Yes*	Study control for post-op radiolucencies* Study controls for gender, age, BMI, side, clinical outcomes, ROM*	Record linkage*	Yes	Subject lost to follow-up unlikely to introduce bias – small number lost*	9

BMI: body mass index, **ROM:** range of motion

A study can be awarded a maximum of 1 star for each question and a maximum of 2 stars for comparability of cohorts. The more stars a study was awarded, the lower was the risk of bias.

Threshold for “Good quality”: 3 or 4 stars in selection domain AND 1 or 2 stars in comparability domain AND 2 or 3 stars in outcome/exposure domain.

The asterisks represent stars.

Table 8. Assessment of methodological quality of the non-randomised retrospective studies (MINORS criteria) ⁵⁶.

Criteria	Torino (2022) ⁶¹	van Loon (2021) ⁶²	Behrend (2020) ⁸	Jin (2020) ³⁶	van Loon (2021) ⁶²	Staats (2019) ⁶⁰	Hoskins (2020) ³²	Song (2020) ⁵⁹	Giaretta (2019) ²⁶
A clearly stated aim	2	2	2	1	2	2	2	2	2
Inclusion of consecutive patients	0	0	0	0	0	0	0	2	2
Prospective data collection	0	2	2	0	2	0	2	2	0
Endpoints appropriate to the study aim	2	2	2	2	2	2	1	2	2
Unbiased assessment of the study endpoint	1	1	2	2	1	2	1	2	1
Follow-up period appropriate to the study aim	2	2	2	2	2	2	2	2	2
Loss to follow-up <5%	1	2	2	1	2	2	2	2	1
Prospective calculation of the study size	0	0	2	0	2	2	0	2	0
Adequate control group	0	0	2	2	0	2	0	0	0
Contemporary group	2	2	2	2	2	2	2	2	2
Baseline equivalence of groups	2	0	2	2	0	2	0	0	0
Adequate statistical analysis	2	2	2	2	2	2	1	2	1
TOTAL	14	15	22	16	17	20	13	22	13

MINORS, Methodological Index for Non-randomized Studies ⁵⁶.

The items are scored 0 (not reported), 1 (reported but inadequate) or 2 (reported and adequate).

Maximum possible score being 24 for comparative studies.