

Title

Models used for case-mix adjustment of patient reported outcome measures (PROMs) in musculoskeletal healthcare: A systematic review of the literature.

Authors

R. Burgess*(1,2) , A. Bishop (1) , M. Lewis (1), J. Hill (1).

Affiliations

1. Arthritis Research UK Primary Care Centre, Research Institute for Primary Care & Health Sciences, Keele University, Staffordshire, ST5 5BG.
2. Sandwell and West Birmingham Hospitals NHS Trust, Dudley Road, Birmingham, B18 7QH.

Corresponding Author:

Email: r.m.burgess@keele.ac.uk

Abstract

Title: Models used for **case-mix** adjustment of **patient reported outcome measures (PROMs)** in musculoskeletal healthcare: A systematic review of the literature.

Background: Case-mix adjustment is an established method to take account of variations across cohorts in baseline patient factors, when comparing health outcomes. Although commonplace, there is a lack of evidence as to the most appropriate **case-mix** adjustment model to use to enable fair comparisons of PROM data in musculoskeletal services.

Objectives: To conduct a systematic review summarising evidence of the development, validation, and performance of musculoskeletal case-mix adjustment models, and to make recommendations for future methods.

Data Sources: Searches included; AMED, CINAHL, EMBASE, HMIC, MEDLINE, and grey literature.

Eligibility Criteria: Studies; from **January 1992-May 2017**, English language, musculoskeletal adult population, developing or validating a case-mix adjustment model, using a relevant PROM, and using patient factors feasible for clinical collection.

Data Synthesis: Two reviewers evaluated selected papers. The CASP Cohort Tool was used to assess quality.

Results: Fourteen studies were included; eight US studies on the Focus on Therapeutic Outcomes model (pooled n=546,726 patients (with pre/post treatment data)) and six UK studies related to the UK National PROMs Programme model (pooled n=282,424 patients (with pre/post treatment data)). The majority used retrospective data, restricted to complete datasets. Both US and UK models showed good predictive ability (R² 18-42%). Common model variables were; baseline PROM score, age, sex, comorbidities, symptom duration, and surgical history. Reduced quality scores were mainly due to acceptability of patient recruitment, and completeness and length of patient follow up.

Conclusion: **Significant methodological crossover was found. Further studies are however needed to externally validate and develop models across musculoskeletal settings.**

Contribution of the Paper:

- This systematic review has identified two broad musculoskeletal case-mix adjustment models, **and highlights both the commonalities in case-mix adjustment approaches but also the need for further good quality studies to inform future practice.**
- Effective case-mix adjustment modelling across musculoskeletal clinical pathways of care will allow for further development of performance profiling and benchmarking across musculoskeletal practice, with the aim of improving quality and equity of musculoskeletal healthcare provision.

Key words: case-mix adjustment model, musculoskeletal, patient outcomes, **PROM.**

1 Introduction

2 Routine use of patient reported outcome measures (PROMs) can help patients and clinicians make
3 better decisions, and enable comparisons of providers' performance facilitating quality improvement
4 [1]. For example, the UK National PROMs Programme has successfully raised standards in the area of
5 hip and knee replacement surgery [2]. Patient outcomes are a function of; therapeutic intervention
6 effectiveness, quality of care, patient attributes that affect their response to care (e.g. 'risk factors'),
7 the natural course of a condition and random chance, [3, 4]). Case-mix or risk adjustment (termed
8 case-mix adjustment here for consistency) is a statistical process that aims to account for differences
9 in the mix of patient attributes across definitive patient cohorts, in order to make fair comparisons
10 of the relative effectiveness (outcome) of care provided [3]. For example to enable fair comparisons
11 across different musculoskeletal physiotherapy services it may be appropriate to adjust for
12 population differences in age or symptom duration, as these are known to influence patient
13 outcomes following treatment [5]. Other known patient factors that influence musculoskeletal
14 treatment outcomes include; gender, symptom severity, and impairment type [6]. These patient
15 factors are beyond the control of the treatment provider, unlike provider factors such as the waiting
16 time, clinic setting, or treating clinician, which also influence treatment outcomes [7]. Case-mix
17 adjustment aims to avoid inclusion of provider variables as these variables could remove effects
18 that may be attributable to local quality improvement initiatives, and potentially can adjust out the
19 differences in quality and performance that are being investigated [8]. For example, if one
20 physiotherapy service had treating clinicians of a much higher grade than another, and grade of
21 therapist was adjusted for when examining their respective treatment outcomes, then any variation
22 due to the differing skill-mix between the services would be adjusted out rather than being used to
23 help explain the differences and inform quality improvement initiatives. Most case-mix models
24 therefore only adjust for patient factors to allow for fair inter provider comparisons [8].

25 Within a musculoskeletal context the evidence for case-mix adjustment models to compare inter
26 provider treatment outcomes has not been systematically evaluated, and there has been no
27 previous review of the literature **to the authors' knowledge**. This review therefore aims to
28 summarise the evidence for the development, validation, and performance of musculoskeletal case-
29 mix adjustment models, and make recommendations for future case-mix adjustment methodology.

30 **Methods**

31 This review followed protocol guidance set out within the PRISMA statement [9], and has been
32 registered on the PROSPERO database (CRD42017055948).

33 **Eligibility Criteria:** Inclusion criteria were: studies from January 1992 to May 2017 (**in line with early**
34 **implementers of musculoskeletal PROM collection [10]** and to provide currency **and applicability of**
35 **results**), English language studies (**due to resource limits**), observational cohort studies, adult
36 patients seeking treatment for musculoskeletal conditions, use of a case-mix adjustment model
37 (focus on development, refinement or validation), self-reported treatment outcomes at a follow-up
38 time-point (capturing treatment effect/change), and models adjusting PROMs and including
39 variables feasible for widespread collection (**not using variables such as imaging results that are not**
40 **uniformly collected**). Exclusions were: studies not reporting detailed results, and those not reporting
41 statistical model effectiveness.

42 **Searches:** A search strategy was developed iteratively **with guidance from an experienced systematic**
43 **reviewer, initially conducting test searches for a single database until the refined strategy was**
44 **agreed that amalgamated sets of search terms, reduced individual terms, and exploded terms such**
45 **as 'musculoskeletal' to optimise the balance between search sensitivity and precision [11]. Search-**
46 **terms included key words for; target population, musculoskeletal conditions, outcomes, and**
47 **methodology**. Electronic databases searched were: CINAHL, MEDLINE, EMBASE, AMED and HMIC
48 (see Appendix 1 for search strategy (MEDLINE)) from January 1992 to May 2017. **Grey literature**

49 included searches of NHS Evidence websites of the Department of Health [12] and NICE [13].
50 Additional searches included references and citations of included studies. Seminal authors/research
51 groups were also contacted for all identified case-mix models to ensure latest iterations were
52 included and to identify any additional models.

53 **Selection Process:** One independent reviewer (RB) undertook a preliminary screen of all titles to
54 remove studies clearly and unquestionably excluded from the study. RB then screened all remaining
55 abstracts identified from searches alongside a second reviewer (AB or JH). Two independent
56 reviewers (RB and JH or AB or ML) then read full articles identified to confirm they met the inclusion
57 criteria.

58 **Data Extraction and Quality Assessment:** Information on identified articles was independently
59 entered onto a data extraction form by the two reviewers, with the form reflecting the key themes
60 from the STROBE Checklist [14], and quality assessed using the CASP Cohort Quality Tool [15].
61 Agreement on study inclusion was first discussed between two reviewers. As there were no disputed
62 studies discussion for agreement between all reviewers was not required.

63 A systematic narrative synthesis was conducted, with information presented in table and text format
64 to summarise and explain the history and development of identified case-mix adjustment models,
65 and the overall study findings. A meta-analysis pooling the study data was not possible due to the
66 large methodological diversity (heterogeneity) among studies [11] in patient factors and statistical
67 methods used. For this reason, results were summarised in tables and discussed in detail. Each case-
68 mix adjustment model and their associated studies/papers and statistical methods were presented
69 together for ease of viewing overarching findings.

70 **Results**

71 **Search Results:** Electronic database searches identified 755 articles for consideration with 517
72 remaining after duplicate removal (see Figure 1). Grey literature and additional searching identified

73 a further 12 articles. All **seven experts (or alternative experts from their research group) responded**
74 **and** this identified one additional manuscript that was being prepared for submission that was
75 unable to be included within the review. Following screening, fourteen articles were included (see
76 Figure 1). Two broad case-mix adjustment models were identified; US Focus on Therapeutic
77 Outcomes (FOTO), and UK National PROMs (NPROMs).

78 **Figure 1: Flowchart of Search Results**

79 Eight of the fourteen studies included were undertaken in the US, using data from the FOTO
80 database [5, 6, 16, 17, 18, 19, 16, 17], with four of those authored (primary author) by members of
81 the FOTO Research Advisory Board (FRAB) [5, 6, 17, 20]. The other four were independently led and
82 given access to the FOTO database [16, 18, 19, 21] although two of them were also co-authored by
83 FRAB members [16, 18]. Included study sample sizes ranged from n = 323 [17] to n = 189,088 [5].
84 The pooled sample size across US studies with pre and post treatment data was 546,726.

85 Six of the fourteen included studies were UK based. These included feasibility work for the NHS
86 England NPROMs Programme [22], NPROMs publications [8, 23, 24], and independent researchers
87 using NPROMs data [25, 26]. **All of these studies were only identified following review of the grey**
88 **literature/additional searches as they were all NHS publications or secondary analyses of NHS data.**
89 **Included study sample sizes** ranged from n = 387 [22] to NPROMs data which increased yearly from;
90 2009-10 (n=85,177), 2010-11 (n=95,406), 2011-12 (n=101,454) totalling 282,037 patients [23, 24].
91 The pooled sample size across UK studies with pre and post treatment data was 282,424.

92 Follow up was standardised at six months across UK studies but was non-standardised in US FOTO
93 studies with collection at the end of the treatment episode. All included studies were cohort studies,
94 with three prospectively collecting data [8, 18, 22], and the rest undertaking retrospective analyses
95 of existing datasets. For results detail see Table 1 for quality of included studies, Table 2 for
96 summary of articles included, and Table 3 for summary of model variables within included studies.

97 **Quality Appraisal:** The CASP quality evaluation found that studies were of a good quality (see Table
98 1). There were however consistent sources of bias across studies **within identified areas such as**
99 **patient recruitment and completeness of follow up, which are discussed below.**

100 Key sources of bias across US studies included: Selection-bias due to the exclusion of **a large**
101 **percentage of** participants with missing data (see Table 1). Hart et al [17] for example were only able
102 **to include 323 of 39,529 patients (0.8%) within their routine dataset as only these patients had data**
103 **for all psychosocial measures pertinent to the study, as collecting multiple psychological measures**
104 **was not routine practice. This, however, may have biased their sample to those more likely to be**
105 **psychologically impaired (as acknowledged by the authors).** Three of the eight US studies did
106 however use inverse probability weighting to account for missing data [18, 19, 21]. Four studies
107 compared baseline characteristics between those with missing and complete data to assess
108 likelihood of bias, **broadly concluding that although some differences were found these were**
109 **unlikely to lead to systematic selection biases as missing data included both patients with**
110 **characteristics associated with better and worse outcome [5, 6, 17, 20]. Patients were however also**
111 **limited to those attending clinics using FOTO software so may not be representative of clinics across**
112 **the US (n=4776 clinics currently across the US [10]).** All US studies had non-standardised follow-up
113 outcome assessment time-points with collection at the completion of the individual's treatment
114 episode, both preventing the collection of follow up data for those who ceased attending for
115 treatment and limiting the ability to quantify estimates of efficacy for a given time. Patients with
116 missing follow up data may therefore be 'missing not at random' [27] **having chosen to cease**
117 **attending leading to further potential attrition bias [11]. Resnik and Hart [16] reported that these**
118 **patients were younger and had higher functional status scores and therefore hypothesised that they**
119 **were likely to have ceased attending due to resolution of their symptoms. However, not including**
120 **those with greater chances of improvement as well as the variation in outcome collection timing**
121 **could substantially impact on the case-mix models and their reported predictive abilities [28].**

122 Key sources of bias across UK studies included: Selection-bias due to the exclusion of those with
123 missing data (see Table 1). The study by Browne et al [22] used the SF-36 rule [29] for dealing with
124 missing data, but 25% of eligible patients were excluded due to failure to invite these patients to
125 participate. Due to data linkage between data sources within the NPROMs Programme, unlinked
126 data were also not able to be included in the full analysis, which could again have potentially biased
127 the final patient sample. In 2011/12 116,734 of 247,699 patients who underwent PROMs eligible
128 procedures had complete and linked data (47.13%), this was 63.1% of those who completed baseline
129 PROM data [30]. Whether this impacted on results would depend on whether unlinked or missing
130 data was missing at random [27] or whether this was due to systematic poor administrative
131 processes at certain provider NHS trusts, which is unclear. Follow-up data collection across UK
132 studies was standardised at a six month time-point although baseline data collection occurred both
133 at pre admission clinics and at admission for the surgical procedure, leading to a small source of
134 variation.

135 All included studies used data from clinical databases and were therefore impacted by limitations in
136 controlling the quality of the data and rates of attrition. Most studies reported these limitations
137 reinforcing the issues around the use of clinical data for research purposes. However although
138 acknowledged, these limitations led to a high risk of bias for this domain within included studies
139 [11].

140 **Table 1: Quality Assessment using CASP Cohort Tool**

141 **Table 2: Summary of Included Studies**

142 **Table 3: Summary of Case-mix Adjustment Model Variables**

143 **Model development history:**

144 **US Model:** Early FOTO models made case-mix adjustments using 12 baseline variables as
145 demonstrated by Hart and Connolly [6] (see Table 3) that were found to have a significant effect on

146 discharge functional status (FS). This model predicted 35% of total variance, meaning that 35% of the
147 variance in post treatment outcome could be explained by the model. The three most important
148 patient factors in their model were; baseline FS, age and symptom duration [6], supporting work
149 from Resnik and Hart [16]. FOTO Inc. later moved to a case-mix adjustment model with eight patient
150 factors, aware of the need to balance model performance with data collection feasibility [6], as
151 demonstrated in the paper by Hart et al [5], who looked at the benefit of adding fear avoidance
152 beliefs (FABQ-PA) to the model. Their results demonstrated R2 values of 0.2997 and 0.3010
153 respectively, with and without the inclusion of the FABQ-PA, thus improving model predictive ability
154 but only slightly, and therefore not recommending this variable for model inclusion.

155 **UK Model:** In 2007 Browne et al [22], set out to determine the feasibility of collecting pre and post-
156 operative outcome data from patients undergoing elective surgery, and to develop methods to
157 analyse and present the pooled data from different hospitals. Elective surgeries included five areas,
158 with two of musculoskeletal interest: unilateral hip replacement and unilateral knee replacement.
159 Significant variables within their case-mix adjustment models were baseline PROM score,
160 comorbidities, general health, surgical history, age, and Index of Multiple Deprivation (IMD). Models
161 explained between 24% and 27% of total variance in treatment outcome.

162 Following the feasibility work by Browne et al [22], Coles [8] published the full UK NPROMs case-mix
163 adjustment methodology (see Table 3 for list of variables). Coles [8] describes six orthopaedic
164 models (separate models for each PROM used and for each intervention). Models ranged from 16-20
165 included variables and explained between 23% and 30% of total variance. All models found the
166 patient's baseline score to be highly predictive of outcome, as well as IMD, comorbidities, patients
167 reporting themselves free of a disability (positive impact), and general health.

168 In 2011 increased data was available from the NPROMs collection which aided further model
169 refinement, including changing the variables relating to co-morbidities and then removing general
170 health [23]. Key predictive variables within the updated model were baseline PROM score, disability

171 status, comorbidity of depression, patient needing assistance with questionnaire, and IMD [23]. In
172 2013, an alternative aggregation model (AAM) was proposed by NHS England [31], to further
173 improve model stability. The full model was also updated following the separation out of primary
174 and revision surgery (giving less prediction error). Significant model changes included removing the
175 previous surgery variable and inclusion of some additional patient diagnostic codes. Key variables
176 predicting outcome across updated primary hip and knee models were; baseline PROM score, age,
177 sex, assistance with questionnaire, disability status, comorbidities, ethnicity, diagnostic codes, and
178 IMD [24].

179 **Model validation:**

180 **US Model:** Hart and Connolly [6] used two methods to validate the FOTO case-mix adjustment
181 model. The patient sample was split into two, one to develop the model and one to test the stability
182 of independent variables. 95% confidence intervals for the beta coefficients for all case-mix
183 adjustment variables were similar. In the development sample the predicted discharge FS was very
184 close to the actual discharge FS (average predictive ratio 1.045), although the model slightly over
185 predicted FS in the second testing sample. The paper by Hart et al [5] also carried out a split-half
186 validation method to create a developmental and testing sample. No differences were found
187 between beta coefficients between developmental and testing samples ($p < 0.05$), again suggesting
188 stability within the predictive model [5].

189 **UK Model:** The inception NPROMs paper [8] considered the face validity of the case-mix adjustment
190 models, appropriateness of scale, and direction and stability of the coefficients. The developed
191 model was then tested in a subset of data. Comparisons between datasets and early testing
192 suggested scope for removal of further variables either due to low incidence or volatility. The model
193 for Knee surgery using EQ5D VAS as the outcome showed the only significant difference in samples.
194 This was due to the low incidence of some comorbidities, and lack of specific admission and
195 discharge data. All models showed face validity containing appropriate variables with directionally

196 expected coefficients. Nuttall et al [26] independently reviewed case-mix adjustment of NPROMs
197 data. Mean predicted post-operative scores and mean actual scores were compared using three
198 statistical methods (ordinary least squares (OLS), fixed effects (FE), and random effects (RE) models).
199 They demonstrated that a fixed effects (FE) model performed the best [26].

200 **Model statistical methods:** The majority of studies used a stepwise approach when building a new
201 regression model in order to make the most parsimonious model for clinical practice, and used
202 specific significance levels (0.05 [6], 0.1 [20] and 0.15 [8]) for inclusion/exclusion of independent
203 explanatory variables. Early US and UK models used an ordinary least squares (OLS) multivariate
204 regression method to estimate model power (R²) [6, 8]. Hierarchical models were demonstrated in
205 later papers [19, 21, 27]. UK NPROMs moved to the use of a generalised least squares (GLS) method
206 in 2011 [23]. Support is growing for the use of GLS [23, 26] and hierarchical mixed models [19] that
207 take into account the nature and distribution of the data, including random clinic effects such as
208 clustering (unmeasured factors within clinics that may affect outcome). The majority of latter papers
209 therefore include using a stepwise approach to model development, and a GLS or hierarchical model
210 for statistical analysis.

211 **Model predictive abilities:** Using regression analysis, goodness of fit can be found by calculating R²
212 which is usually expressed as a percentage. It explains the percentage of the variation in the
213 dependent variable (PROM score) that can be explained by its relationship with the independent
214 variables (patient factors) [32]. Predictive ability across US study models ranged from 18-42% [5, 6,
215 16, 17, 18, 19, 20] and in UK models from 23-30% [8, 22, 26], demonstrating moderate to strong
216 predictive ability across models [33].

217 **Discussion:**

218 Table 3 details the patient factor variables used most commonly (those used in 3 or more studies) in
219 included case-mix adjustment models. It can be seen that the most widely used variables across

220 models predicting outcome include: baseline PROM score, comorbidities, surgical history, IMD, age,
221 payer, symptom duration, impairment type, assistance with questionnaire, self-reported disability,
222 gender, and ethnicity. All of these variables are feasible for widespread clinical collection and
223 warrant being considered for inclusion in future musculoskeletal case-mix adjustment modelling.
224 Variables such as exercise history, living alone, FABQ, use of medication, and pain intensity had some
225 limited support but require further investigation before their inclusion can be fully justified. All US
226 studies used the payer variable and all UK studies used the IMD, these two variables may measure a
227 similar construct as payer types have been used as proxy measures for a variety of demographic
228 factors [19, 34].

229 Although there is considerable crossover in variables included within models, there is wide disparity
230 in how variables are collated and entered into regression models, with a mixture of continuous,
231 categorical and binary data. Models also used different outcome tools and different timing of follow-
232 up data collection. This would need to be considered when looking to test, replicate or build upon
233 existing case-mix adjustment models, as when and how predictors and treatment outcomes are
234 measured can have significant effects on model predictive performance [28].

235 **Limitations of the review:** The review focussed on the case-mix adjustment of musculoskeletal
236 PROM data. However, the outcome used within studies was not limited and therefore studies and
237 the predictive performance of models identified cannot be fully compared. Evidence from the UK
238 NPROMs research demonstrates that different variables are necessary dependent on the outcome
239 used [8, 24]. The review also included all healthcare settings including primary, community and
240 secondary care. The limitation of this breadth is again the comparability of included studies, as
241 patients, treatments and outcomes across settings all vary significantly. The review was also limited
242 to English language publications meaning that there may be models reported in languages other
243 than English that have not been included.

244 **Summary of findings:**

245 Two broad case-mix adjustment models have been identified within the review. Neither model
246 however has been externally validated. The two models are distinct in that one model is currently
247 used within a community setting in the US (FOTO), and the other in a UK secondary care surgical
248 setting (NPROMs). Future research is needed to externally validate these existing models within and
249 across musculoskeletal settings and countries, in order to be able to implement these models across
250 healthcare settings.

251 Recommendations for future case-mix adjustment modelling of musculoskeletal PROMs based on
252 the combined study findings are:

- 253 1. Patient factor variables warranting strong consideration for inclusion are: baseline PROM
254 score, age, gender, comorbidities, symptom duration, surgical history, payer, impairment
255 type, IMD, ethnicity, assistance with questionnaire, and self-reported disability.
- 256 2. A stepwise approach to model development is recommended, with significance levels of
257 0.05-0.15 demonstrated within included studies [6, 8, 20].
- 258 3. Statistical methods for consideration include GLS and hierarchical modelling which may be
259 preferential to an OLS method due to accounting for clustering.
- 260 4. Methods need to minimise or account for missing data using structured prospective data
261 collection and statistical methods such as data imputation or inverse probability weighting.
- 262 5. Defined PROM data capture at the start and end of treatment with a standardised follow up
263 time-point is recommended to reduce risk of bias.

264

265 **Conclusion:**

266 Results demonstrate that there is strong evidence to support the use of case-mix adjustment
267 modelling in musculoskeletal practice, and results highlight common areas of overlap between US
268 and UK models, and models used within a community and secondary care setting. These results have
269 been summarised to aid development of case-mix adjustment methodology alongside much needed

270 external validation of existing models, with the aim of optimising case-mix adjustment of
271 musculoskeletal health outcomes. This will allow for effective performance profiling and future
272 benchmarking of musculoskeletal services, both nationally and internationally.

273 **Word Count: 3555**

274 **Tables and Figures:**

275 **Figure 1: Flowchart of Search Results**

276

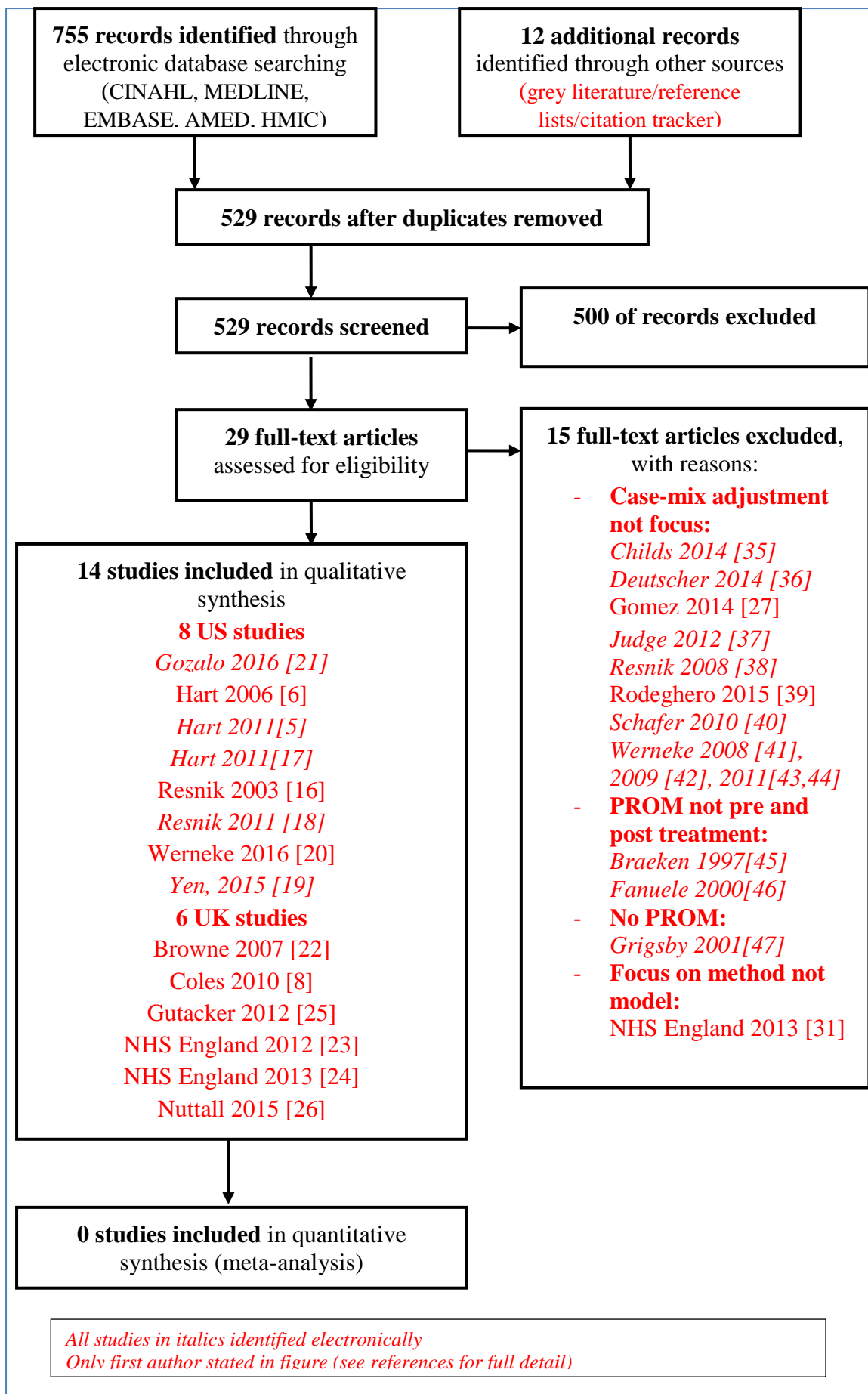


Table 1: Quality Assessment Using CASP Cohort Tool

	CASP Cohort Tool												
Author	Clearly focussed	Recruitment acceptable	Exposure accurately measured	Outcome accurately measured	Identified con-founding	Accounted for con-founding	Subject FU complete enough	Subject FU long enough	Results Precise	Believe results	Applicable results	Fit with other evidence	Complete data
First Author US													
Resnik 2003 [16]	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	
Hart 2006 [6]	Yes	CT	Yes	Yes	Yes.	Yes	Yes	Yes	Yes	CT	No	CT	62%
Hart 2011 [5]	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	62%
Hart 2011 [17]	Yes	No	Yes	Yes	Yes	Yes	No	CT	No	Yes	Yes	CT	0.80%
Resnik 2011 [18]	Yes	No	Yes	Yes	Yes	Yes	No	CT	Yes	Yes	Yes	Yes	44.30%
Yen 2015 [19]	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
Gozalo 2016 [21]	Yes	Yes	Yes	Yes	Yes	Yes	No	CT	Yes	Yes	Yes	Yes	57.20%
Werneke 2016 [20]	Yes	Yes	Yes	Yes	Yes	No	No	Yes	Yes	Yes	Yes	Yes	35%
First Author UK													
Browne 2007 [22]	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	CT	90.2-91.6%
Coles 2010 [8]	Yes	CT	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
DoH 2012 [23]	Yes	CT	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
DoH 2013 [24]	Yes	CT	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
Gutacker 2012 [25]	Yes	CT	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	
Nuttall 2015 [26]	No	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	83.90%
(FU; follow up, CT; Can't tell)													

Table 2: Summary of Included Studies

First Author/s	Design	Setting	Data Sources	Study Size (complete/included datasets)	PROMs	Number of variables	Model R2 (where available)
US Studies							
Resnik and Hart (2003) [16]	Retrospective cohort	Outpatient physical therapy	FOTO	24,276	OHS, SF-12, SF- 36	8	35-42%
Hart and Connolly (2006) [6]	Retrospective cohort	Outpatient therapy	FOTO	189,088	FS	12	35-36%
Hart (2011) [5]	Retrospective cohort	Outpatient therapy	FOTO	49,376	FS	8	30%
Hart (2011) [17]	Prospective cohort	Outpatient therapy	FOTO	257	FS	10 (plus PM)	31% (intake model)
Resnik (2011) [18]	Prospective cohort	Outpatient therapy	FOTO	44,925	FS	8	18-40%
Yen (2015) [19]	Retrospective cohort	Outpatient therapy	FOTO	147,623	FS	7	31% (FE model)
Werneke (2016) [20]	Retrospective cohort	Outpatient physical therapy	FOTO	723	FS	13 (tested in BM)	35% (BM)
Gozaló (2016) [21]	Retrospective cohort	Outpatient therapy	FOTO	90,392	FS	8	
UK Studies							
Browne (2007) [22]	Prospective cohort	Orthopaedic		700	EQ5D Index, OHS, OKS, SF-36	8	24-27%
Coles (2010) [8]	Prospective cohort	Orthopaedic	NPROMs	29759	EQ5D Index, EQ5D VAS, OHS, OKS	16-20 dependent on PROM model	23-30%
NHS England (2012) [23]	Retrospective cohort	Orthopaedic	NPROMs	282,037	EQ5D Index, EQ5D VAS, OHS, OKS	13-15 dependent on tool (some variable items listed & coded separately)	
Gutacker (2012)	Retrospective	Orthopaedic	NPROMs	24,568	EQ5D	7	

[25] NHS England (2013) [24]	cohort Retrospective cohort	Orthopaedic	NPROMs	282,037 (as for NHS England, 2012)	EQ5D Index, EQ5D VAS, OHS, OKS	12 (some variable items listed & coded separately)	
Nuttall (2015) [26]	Retrospective cohort	Orthopaedic	NPROMs	30,555	OKS	10 (some variable items listed & coded separately)	26% (OLS and FE model)

OHSM; Overall health status measure, SF-12; Short Form 12, SF-36; Short Form 36, FS; Functional Status, PM; psychological measure, BM; baseline model, OLS; ordinary least squares, FE; fixed effects, OKS; Oxford Knee Score, OHS; Oxford Hip Score.

Table 3: Summary of Risk-Adjustment Model Variables

	Baseline PROM score	Age	Gender	Comorbidities	Duration of symptoms	Surgical history	Payer	Impairment type/procedure	Index of Multiple Deprivation	Exercise History	Ethnicity	Assistance with questionnaire	Disability	Living alone	Fear Avoidance Beliefs Questionnaire	Use of medication
First Author/s US																
Resnik 2003 [18]	x*	x	x		x*	x	x*			x						
Hart and Connolly 2006 [6]	x*	x*	x		x*	x	x	x		x						x
Hart 2011 [5]	x*	x	x	x*	x*	x	x								x	
Hart 2011 [17]	x*	x	x	x*	x	x*	x*			x					x	x
Resnik 2011 [18]	x	x	x	x	x		x			x						
Yen 2015 [19]	x	x	x	x	x	x	x									
Gozalo 2016 [21]	x*	x	x	x*	x*	x	x*	x							x	
Werneke 2016 [20]	x*	x*	x	x*	x*	x*	x*			x						x
First Author/s UK																
Browne 2007 [22]	x*	x*	x	x*	x	x*			x*							
Coles 2010 [8]	x*	x	x	x*	x	x		x	x*		x	x	x*	x		
NHS England 2012 [23]	x*	x	x	x	x	x		x	x*		x	x*	x*	x		
NHS England 2013 [24]	x*	x*	x*	x*	x			x*	x*		x*	x*	x*	x		
Gutacker 2012 [25]	x	x	x*	x*		x*		x*	x*							
Nuttall 2015 [26]	x	x	x	x		x		x	x		x	x	x			
Note: only variables used in 3 or more studies are included, * marks those identified in studies as most predictive variables																
Resnik et al (2003) * 3 largest predictors																

Hart and Connolly (2006) * 3 largest predictors
Hart et al (2011) * 3 largest predictors
Hart et al (2011) * 4 largest predictors
Resnik et al (2011) baseline model
Yen et al (2015) baseline model (all variables predictive)
Gozalo et al (2016) * 4 largest predictors
Werneke et al (2016) * 6 significant 'patient factor' predictors (retained in model)
Browne et al (2007) * 5 largest predictors (not including GH)
Coles (2010) * 4 largest predictors across models (not including GH)
NHS England (2012) * 4 most predictive across models (not including depression)
NHS England (2013) * 9 variables retained across primary hip/knee models
Gutacker et al (2012) * 5 largest predictors
Nuttall et al (2015) 10 significant variables included in model (not including length of stay)

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Appendix 1:

Search Results:

#	Database	Search term	Results
1	Medline	(physiotherap*).ti,ab	20170
2	Medline	("physical therap*").ti,ab	17332
3	Medline	(rheumatolog*).ti,ab	27857
4	Medline	(Orthopaedi*).ti,ab	32882
5	Medline	(Orthopedi*).ti,ab	35796
6	Medline	(Chiropract*).ti,ab	5047
7	Medline	(Osteopath*).ti,ab	4747
8	Medline	(rehabilitat*).ti,ab	132634
9	Medline	exp "PHYSICAL THERAPY MODALITIES"/	198318
10	Medline	REHABILITATION/	189286
11	Medline	exp "MUSCULOSKELETAL MANIPULATIONS"/	14266
12	Medline	(1 OR 2 OR 3 OR 4 OR 5 OR 6 OR 7 OR 8 OR 9 OR 10 OR 11)	539790
13	Medline	(low* ADJ back).ti,ab	27483
14	Medline	(cervical).ti,ab	184992
15	Medline	(spine).ti,ab	93636
16	Medline	(spinal).ti,ab	225643
17	Medline	(hip).ti,ab	110924
18	Medline	(knee).ti,ab	109237
19	Medline	(shoulder).ti,ab	52204

20	Medline	(Musculoskeletal).ti,ab	37510
21	Medline	SCIATICA/	4718
22	Medline	exp "BACK PAIN"/	32951
23	Medline	exp SPINE/	124297
24	Medline	HIP/	10837
25	Medline	exp "HIP JOINT"/	23967
26	Medline	exp "KNEE JOINT"/	50054
27	Medline	KNEE/	12391
28	Medline	SHOULDER/	11036
29	Medline	"SHOULDER JOINT"/	16237
30	Medline	SHOULDER/	11036
31	Medline	exp "MUSCULOSKELETAL PAIN"/	2627
32	Medline	exp "MUSCULOSKELETAL SYSTEM"/	1336749
33	Medline	exp "MUSCULOSKELETAL DISEASES"/	988774
34	Medline	(13 OR 14 OR 15 OR 16 OR 17 OR 18 OR 19 OR 20 OR 21 OR 22 OR 23 OR 24 OR 25 OR 26 OR 27 OR 28 OR 29 OR 30 OR 31 OR 32 OR 33)	2410888
35	Medline	(Baseline variabl*).ti,ab	36869
36	Medline	(Characteristic*).ti,ab	1080307
37	Medline	(demographic*).ti,ab	218641
38	Medline	(prognostic indicat*).ti,ab	40056
39	Medline	(predictor*).ti,ab	280753
40	Medline	exp "POPULATION CHARACTERISTICS"/	7252956

41	Medline	FORECASTING/	76553
42	Medline	(35 OR 36 OR 37 OR 38 OR 39 OR 40 OR 41)	8067345
43	Medline	(Patient Recorded Outcome Measure*).ti,ab	2458
44	Medline	(PROM).ti,ab	1835
45	Medline	(effectiveness).ti,ab	337302
46	Medline	("Change score*").ti,ab	2984
47	Medline	("Health gain*").ti,ab	1399
48	Medline	("Functional status*").ti,ab	20277
49	Medline	(43 OR 44 OR 45 OR 46 OR 47 OR 48)	364094
50	Medline	(case mix adjustment).ti,ab	946
51	Medline	(case-mix adjustment).ti,ab	934
52	Medline	("risk adjust*").ti,ab	6856
53	Medline	("regression analys*").ti,ab	200297
54	Medline	"RISK ADJUSTMENT"/	2594
55	Medline	exp "REGRESSION ANALYSIS"/	347144
56	Medline	(50 OR 51 OR 52 OR 53 OR 54 OR 55)	489201
57	Medline	(12 AND 34 AND 42 AND 49 AND 56)	401
58	Medline	(12 AND 34 AND 49 AND 56)	425
59	Medline	(mortalit*).ti,ab	578260
60	Medline	(random* ADJ2 trial*).ti,ab	253649
61	Medline	(59 OR 60)	804076
62	Medline	57 NOT 61	293

63	Medline	58 NOT 61	313
64	Medline	62 [DT 1992-2017] [Human age groups Young adult OR Adult OR Middle Aged OR Aged OR Aged,80 and over] [Languages English]	246
65	Medline	63 [DT 1992-2017] [Human age groups Young adult OR Adult OR Middle Aged OR Aged OR Aged,80 and over] [Languages English]	252