

Relph, Nicola, Herrington, Lee and Tyson, Sarah (2014) The effect of ACL injury on knee proprioception: a meta-analysis. *Physiotherapy*, 100 (3). pp. 187-195.

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Physiotherapy

Elsevier Editorial System(tm) for

Manuscript Draft

Manuscript Number:

Title: The Effects of ACL Injury on Knee Proprioception: A Meta-Analysis

Article Type: Systematic Review

Keywords: Anterior Cruciate Ligament (ACL), Knee proprioception, Joint position sense, Threshold to detect passive motion

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Manuscript Region of Origin: UNITED KINGDOM

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Wednesday 6th March 2013

Dr Michele Harms,
St George's,
University of London and Kingston University,
London, UK

Dear Dr Harms,

Please find enclosed our article entitled "*The effect of ACL injury on knee proprioception: A Meta-Analysis*". This paper is a meta-analysis considering current studies on knee proprioception following ACL injuries. We think the paper meets Physiotherapy's scope and aims to provide information on the advances of clinically relevant characteristics of the knee joint following injury. I can confirm this article is of original material, i.e. has not been submitted elsewhere for publication or has been published elsewhere.

Yours sincerely,

Nicola Relph. MSc.

Enclosure: Article.

The Effects of ACL Injury on Knee Proprioception: A Meta-Analysis

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KEY WORDS: Anterior Cruciate Ligament (ACL), Knee proprioception, Joint position sense,
Threshold to detect passive motion.

WORDCOUNT: 3294

Background It is suggested the anterior cruciate ligament (ACL) plays a significant role in knee proprioception, however, the effect of ACL injury on knee proprioception is unclear. Studies utilising the two most common measurement techniques, joint position sense and threshold to detect passive motion, have provided evidence both for and against a proprioceptive deficient following ACL injury.

Objective The objective of the study was to undertake a meta-analysis investigating the effects of ACL injury, treated conservatively or by reconstruction, on proprioception of the knee, measured using joint position sense and/or threshold to detect passive movement techniques.

Data Sources Seven databases were searched from their inception to December 2011 using the subject headings 'anterior cruciate ligament, proprioception, postural sway, joint position sense, balance, equilibrium or posture' to identify relevant studies.

Eligibility criteria PRISMA guidelines were followed. Studies that investigated the effect of ACL injury on either knee joint kinaesthesia or position sense were included in this review.

Data extraction and synthesis Two reviewers independently extracted data using a standardised assessment form. Comparisons were made using a fixed effect model with an inverse variance method using Review Manager Software (V5.1).

Results Patients with ACL injury have poorer proprioception than people without such injuries (SMD = 0.35°; P= 0.001 and SMD = 0.38°; P=0.03) when measured using joint position sense and threshold to detect passive motion techniques respectively. Patients had poorer proprioception in the injured than uninjured leg (SMD = 0.52°; P<0.001) and the proprioception of people whose ACL was repaired was better than those whose ligament was left unrepaired (SMD = -0.62°; P<0.001).

Limitations Heterogeneity of measurement techniques and lack of psychometric details.

Conclusion ACL injuries may cause knee proprioception deficits compared to uninjured knees and control groups. Although differences were statistically significant, the clinical significance of findings can be questioned.

1 **The Effects of ACL Injury on Knee Proprioception: A Meta-Analysis**

2 **Introduction**

3 The anterior cruciate ligament (ACL) controls knee movements in six directions; three
4 rotations and three translations and thus is critical for stable lower extremity movement [1].
5 The ligament's main role in knee joint stability is to prevent excessive anterior translation
6 (forward movement) of the tibia in relation to the femur and help direct the 'screw-home'
7 mechanism which occurs during femoral and tibial rotation into full knee extension [2]. The
8 ACL is also thought to play a significant role in knee proprioception [2]. Proprioception is a
9 component of the somatosensory system which plays a critical role in normal human
10 performance [2-4] Its main role is to provide afferent information on the position and
11 movements of a joint. In the ACL, 1% of its total area [5] is made up of three types of
12 proprioceptive receptors; pacinian capsules, ruffini nerve endings and golgi tendon organs
13 [6] and each has specific role. The pacinian capsules adapt rapidly to low degrees of joint
14 stress, are sensitive to rapid changes in accelerations, and are therefore classified as
15 dynamic receptors [7]. Whereas, ruffini nerve endings and golgi tendon organs are slow
16 adapting with a high threshold to stress and are believed to provide information on the
17 position of the knee joint [7].

18 Injuries to the ACL are career threatening for sports professionals and even when
19 rehabilitation is completed, secondary injury problems, such as osteoarthritis are common
20 [8,9]. It has long been thought that such ACL injuries can be detrimental to proprioception of
21 the knee which may lead to abnormal movement patterns which are a mechanism for further
22 injuries and long-term secondary problems [9]. However, research in to the effects of ACL
23 injury on knee proprioception has yielded conflicting results [10]. Therefore, our aim was to
24 undertake a systematic review to investigate the effects of ACL injury, whether treated
25 conservatively or by reconstruction, on proprioception of the knee. The two most common
26 proprioception measurement techniques [11]; joint kinaesthesia (threshold to detect passive

27 motion (TTDPM)) and joint position sense (JPS) were considered. Joint position sense (JPS)
28 involves passively moving a joint to a target angle, then the patient actively reproduces this
29 angle [11]. Joint kinaesthesia traditionally measures the passive movement of a joint before
30 movement is detected, called a threshold to detect passive motion (TTDPM). This involves
31 asking the patient to indicate the first instance they perceive motion of the joint [11].

32 The aim of this review was to assess knee proprioception deficits following ACL injury
33 whether treated conservatively or by reconstruction using JPS and TTDPM measurement
34 techniques. The following null hypotheses were formulated.

- 35 • there are no difference in proprioception between ACL injured legs and the contra-
36 lateral uninjured leg;
- 37 • there are no difference in proprioception between ACL injured legs and the leg of an
38 external control participant;
- 39 • there are no difference in the proprioception of people with a reconstructed ACL
40 injury (ACL-R) and those whose ACL has not been reconstructed; so-called ACL-
41 deficient (ACL-D)

42 **Methods**

43 *Protocol*

44 No review protocol exists for a descriptive data meta-analysis. The PRISMA guidelines on
45 meta-analysis were followed (<http://www.prisma-statement.org/statement.htm>).

46 *Eligibility Criteria*

47 Observational studies testing proprioception of the knee following ACL injury (conservatively
48 managed or reconstructed). Adults (over 16 years) with an ACL injury confirmed by
49 arthroscopy and/ or MRI and/ or clinical test (Lachman's test, the pivot shift test or
50 measurement using a knee arthrometer), including participants with ACL injuries combined

51 with meniscus and/ or collateral ligament damage. The primary outcome measure was
52 proprioception measured by mean angle of error in degrees. This took two forms. Studies
53 measuring knee kinaesthesia used the TTDPM method where the mean angle of error was
54 defined as *the difference in degrees from initiation of motion and the participant's perception*
55 *of motion*. Studies measuring JPS utilised an index angle matching method in which the
56 mean angle of error was defined as *the difference in degrees between the target angle and*
57 *the angle reproduced by the participant*. The type of control measure (the participant's
58 contra-lateral leg or the leg of an external matched control) was also collected.

59 *Information Sources, Search Strategy*

60 One researcher completed the search. The following electronic databases were accessed
61 from their inception to December 2011: AMED, CINAHL, PubMed, Medline, PeDro, Sports
62 Discus and the Cochrane Library. Primary journals; The Knee, American Journal of Sports
63 Medicine and the British Journal of Sports Medicine were also manually searched, as were
64 the reference lists of all selected studies. Key terms were: anterior cruciate ligament,
65 proprioception, postural sway, joint position sense, balance, equilibrium or posture. Limits of
66 the search were: English language studies (none of the researchers spoke foreign
67 languages), human studies, adult participants and peer reviewed published full access
68 articles. Unpublished literature and trial registries of current studies were not included in the
69 search.

70 *Study selection*

71 The search results were merged using reference management software (Endnote 9.0) and
72 duplicates removed. The titles and abstracts were screened and articles which obviously did
73 not meet the selection criteria removed. The full text of the remaining studies was then
74 checked against the selection criteria. Studies with missing outcome measure data were
75 excluded at this stage.

76 *Risk of Bias in individual Studies*

77 The methodological quality of the studies that met the selection criteria was appraised by
78 two of the research team independently to identify studies that had a low risk of bias. The
79 quality assessment tool was based on that previously developed and used by the authors
80 [12] but adapted to evaluate the factors that would introduce bias into this analysis
81 (Appendix 1). The factors were: confirmation of the ACL injury (up to three points),
82 population representation including classification of injury group and details of previous
83 and/or concurrent injury (up to 19 points), representation of the sample (up to five points),
84 homogeneity of participants (up to 13 points), sample size (up to 25 points), study design (up
85 to four points), assessor blinding (up to five points) and statistical analysis (up to 14 points).
86 'Description of the sample' assessed whether details of age, gender, pre-injury levels of
87 activity, previous injury to damaged knee, concurrent damage to injured knee, concurrent
88 damage to ankle and/ or hip joint on the injured side, injury to the contra-lateral side and
89 participation in a rehabilitation programme were noted. 'Statistical analysis' included whether
90 details of the reliability and sensitivity of the measurement tools were noted. This gave a
91 total of 88 points. The methodological quality scores were arbitrarily grouped as 'poor' (a
92 score of less than 29/88), 'moderate' (a score of 30-58/88) or 'good' (a score of 59+/88).
93 Studies of moderate to good quality (that is, 30–88/88) were selected as providing data of
94 sufficient low risk of bias to enter in to the meta-analysis. Two reviewers appraised the
95 literature. For the selected studies, the following data were extracted by one reviewer: the
96 number of participants, mean angle of error measured using TTDPM and/ or JPS methods
97 and accompanying standard deviation values to include in the meta-analysis and the
98 following comparisons were made:

99 For joint position sense data:

- 100 • ACL injured leg versus contra-lateral leg control
- 101 • ACL injured leg versus external control leg

- 102 • Patients with a reconstructed ACL versus patients with a deficient ACL

103 For data on the threshold to detect passive motion:

- 104 • ACL injured leg versus contra-lateral leg control
- 105 • ACL injured leg versus external control leg

106 The comparisons were made using a fixed effect model with an inverse variance method
107 and presented as forest plots using Review Manager Software (version 5.1). Standard mean
108 difference between groups measured the effect size. Heterogeneity between comparable
109 trials was tested using the chi squared test (level of significance = $p < 0.10$ Higgins & Green,
110 2008). Heterogeneity was further tested using I^2 percentages to consider the impact
111 potential heterogeneity would have on the meta-analysis.

112 **Results**

113 *Study Selection*

114 The initial search strategy yielded 3076 articles, 2737 of which did not relate to the research
115 question. Screening of the titles and abstracts of the remaining 339 articles revealed that
116 290 did not fully meet the inclusion criteria; the main exclusion factor was the use of
117 techniques to measure proprioception other than TTDPM and/or JPS. A further 43 articles
118 were excluded following the evaluation of methodological quality as they provided 'poor'
119 quality data with a high risk of bias and/or had missing or inadequate outcome data. The
120 main reasons for missing data were that median data were presented instead of mean data
121 [13,14,15] or measures of the variability of the data (standard deviation) were missing [16].
122 This left six studies which were selected for inclusion in the meta-analysis. The flow chart
123 detailing the selection process is shown in Figure 1.

124

125 *Study Characteristics*

126 Six studies involving 191 ACL injured patients were selected (Table 1). Sixty-one
127 participants were ACL deficient and 130 had had an ACL reconstruction. There were 82
128 healthy controls from five studies [17-21]. The participants' contralateral leg was used as the
129 control in four studies [18,19, 21,22]. Confirmation of ACL injury was provided by
130 arthroscopy or MRI in five studies [17-20, 21]. Only Barrack *et al.*, [17] stated a Lachman's
131 Test and Pivot Shift test had been used in addition to the arthroscopy. Mir *et al.*, [21] did not
132 report how the ACL injury had been confirmed. An autograft using the patella tendon was the
133 most common surgery used to reconstruct the ACL [18-20] but, none of the included studies
134 assessed laxity before and after surgery. Angoules *et al.*, [22] was the only study to use the
135 same surgeon for every reconstruction to minimise surgical skill as a confounder. Mir *et al.*
136 [21] and Angoules *et al.*, [22] stated the type and number of surgical complications. None of
137 the patients in the included studies had previous ACL injury to the injured knee. One [19],
138 stated ACL patients had concurrent damage to other structures in the knee during the ACL
139 injury. A rehabilitation programme had been completed by patients in four studies [17, 19,
140 21,22].

141 All six selected studies were of moderate quality (Table 2). Most recruited a convenience
142 sample [17, 19, 20, 22] or did not state how their participants were recruited [18, 21]. Five
143 studies matched the injured patients to controls by age [17-21] and four matched by gender
144 [18-21]. None justified the sample size with a power calculation or the minimal detectable
145 difference of the measurement tool. Two studies [17, 22] blinded assessors to the type of
146 participant.

147 Generally the statistical analysis in the selected studies lacked important (Table 2). Only two
148 [21,22] reported whether the data was normally distributed and hence justified the use of
149 parametric statistical testing. Most used 'home-made' measurement devices prepared
150 specifically for the study but the reliability and sensitivity were infrequently reported.

151 During analysis, data from the external control subjects and ACL patients in some studies
152 were used in several comparisons, for example if a control group was compared to ACL-D
153 and ACL-R patients or if the same ACL patients were measured from two different starting
154 positions [18, 21]. Unfortunately the RevMan software did not allow us to stipulate the actual
155 control and patient number values. However this number is clearly noted as a footnote to the
156 affected figures and should be considered when analysing the comparison data.

157 *Synthesis of results*

158 Effects of ACL injury on proprioception - Joint Position Sense Studies

159 Five studies compared the injured leg to the participant's un-injured leg (n=170) as the
160 control [18-22]. The pooled standard mean difference of mean angle of error was 0.52° (95%
161 CI 0.41 to 0.63; P<0.001; I² = 63%) indicating that the un-injured leg had a lower mean angle
162 of error (better joint position sense) compared to the injured leg (Figure 2). Four studies
163 compared the injured legs (n=140) to an external control (n=104) [18-20, 22]. The pooled
164 standard mean difference of the mean angle of error was 0.35° (95% CI 0.14 to 0.55; P=
165 0.001; I² = 78%) indicating that the control group had better joint position sense than ACL
166 patients (figure 3). Three studies compared ACL reconstructed (n=116) and ACL deficient
167 legs (n=100) [18, 20, 22]. The pooled standard mean difference of the mean angle error (°)
168 was -0.62° (95% CI -0.76 to -0.48; P<0.001; I² = 42%) indicating that ACL reconstructed
169 patients had significantly better joint position sense (figure 4).

170 Effects of ACL injury of proprioception - Threshold to Detect Passive Motion Studies

171 Two studies compared the injured leg (n=71) with the un-injured (n=71) leg in ACL patients
172 [17,20]. The pooled standard mean difference of mean angle error was 0.02° (95% CI -0.32
173 to 0.35; P= 0.91; I² = 61%) indicating no difference. These studies also compared ACL
174 injured legs (n=71) to external control legs (n=30) which showed a difference in mean angle
175 error of 0.38° (95% CI 0.04 to 0.72; P= 0.03; I² = 73%) indicating that the external control
176 group had a significantly lower mean angle of error than the injured leg group (figure 5).

177 Joint position sense studies and threshold to detect passive motion studies both indicated
178 differences between injured leg and external controls. However, only data collected using
179 the JPS method detected proprioception differences between injured and non-injured legs.

180 **Discussion**

181 This review examined the effect of ACL injury on proprioception, in terms of joint position
182 sense and threshold to detect passive motion. The results indicate that there are statistically
183 significant differences in the proprioception, in terms of JPS acuity and threshold to detection
184 of movement, of patients with ACL injury in that they have poorer proprioception than people
185 without such injuries and poorer proprioception in the injured than uninjured leg. The
186 proprioception of people whose ACL was reconstructed was statistically significantly better
187 than those whose ligament is left unreconstructed (ACL- deficient). These differences are
188 seen whether the comparator group is a patient's uninjured leg, or a control group of people
189 with no injuries; suggesting that either can be used as a control group in future research.
190 The differences were seen most clearly when joint position sense was measured but was
191 less consistent when threshold to detect passive motion measurement techniques were
192 used.

193 It is thought that mechanoreceptors in the ACL provide afferent information on the relative
194 position and movement of the knee joint [3, 7, 23, 24] and that ACL injury impairs
195 proprioception through disruption to the transmission of this sensory information [5]. Our
196 results give some support to this belief. However, although statistically significant, the
197 differences found were very small (less than one degree) which is unlikely to be clinically or
198 functionally important. A proprioceptive deficit of at least 5 degrees is thought to be the
199 minimum to indicate a clinically important difference [25] although there is little evidence to
200 support, or refute, this value.

201 The discrepancy between the statistical and functional significance of the differences found
202 may be because the proprioception measurement techniques used were insufficiently

203 accurate to reliably detect clinically significant differences between groups [11]. None of the
204 trials in the current analysis included information on the reliability, sensitivity, measurement
205 error of the measurement techniques used. Hence it is possible that the differences found
206 are due to measurement error and/or the measurement techniques were insufficiently
207 sensitive to detect clinically significant differences. Another explanation is that the
208 comparisons were under-powered because the sample was too small, (none of the included
209 studies calculated sample size using power estimations). However our pooled analysis
210 involved nearly 200 patients and the 95% confidence intervals of the comparisons made
211 were small, indicating that a lack of power was not an issue. Further researcher is needed
212 to evaluate the sensitivity and reliability of techniques to measure proprioception at the knee,
213 before they can meaningfully be used as an evaluation tool.

214 A more likely, but controversial, explanation for our results is that ACL injury may not have a
215 major impact on proprioception at the knee. This support's the view that muscle, rather than
216 ligaments, provide the primary afferent information in the sensorimotor system [10], which is
217 not a surprise given that only 1% of the ACL total area is made up of proprioceptive
218 receptors [5] and that receptors are often still deficient six months after reconstructive
219 surgery [5]. It may, to some degree, also explain the inconclusive evidence for reconstructive
220 surgery and conservative (non-surgical) rehabilitation [10,26,27] some patients 'cope' with
221 an ACL-deficiency and have an apparently stable knee even after complete rupture, while
222 others do not 'cope' despite reconstructive surgery and apparent stability [5,12,10,26]. Joint
223 stability relies on synergy between muscles and ligaments [1, 2, 28, 29]. Once the ligament
224 is damaged, patients may adapt by using proprioceptive information from the muscles to a
225 great extent to compensate for the lack of information from the ligament. This may explain
226 why some patients cope better with ACL injury (however it is managed) than others [12]:
227 some may be more able to make that adaptation than others. Rehabilitation can improve
228 proprioception and joint stability in patients with and without reconstruction [19,27] the
229 mechanism being an adaptation to use increased proprioceptive information from the

230 muscles or other ligaments, rather than restoring proprioception through the ACL per se.
231 Further research is needed to test this hypothesis further and to the clinical significance of
232 knee proprioception deficits.

233 We found greater differences in joint position sense (JPS) than studies using TTDPDM.
234 TTDPDM techniques may be insufficiently sensitive to detect the responses of rapid receptors
235 such as the pacinian capsules in the ACL [5] as measurements incorporate the participants'
236 reaction time, which is unrelated to their injury. JPS methods may be more sensitive by
237 measuring the slower responses of the ruffini nerve endings and golgi tendon organs [24] as
238 they allow the conscious perception of joint motion and position.

239 A limitation of this meta-analysis is that all data collection was retrospective, which inevitably
240 means that pre-injury proprioception is unknown. It is possible that the patients who suffered
241 injuries had poorer proprioception which predisposed them to injury. Large scale normative
242 studies are needed to give insight into the distribution of proprioception abilities across the
243 population and whether this predisposes people to ACL injury. Such studies should consider
244 a measurement technique that explores the full range of knee motion and direction using
245 large sample sizes that represents the complete ACL patient population and normative data
246 on proprioception ability.

247 Heterogeneity of variance was greater than the recommended level of 50% [30] in all but
248 one comparison; this may be due to variability in the recruitment strategies across studies.
249 The time since injury when proprioception was measured ranged from 12 days [19] to over
250 two years [20] and the use of rehabilitation programmes was not consistent. The high I^2
251 levels may indicate that ACL injury had effects other than proprioception deficits [30] such as
252 kinematic adaptations [31] and movement variability [32]. Highly varied measurement
253 techniques were also evident, which is a limitation that hampers further analysis [10]. In this
254 analysis, three different pieces of measuring equipment and varied knee movements, in
255 terms of direction and speed of motion, were used. Proprioception increases towards the

256 extremes of range of movement to protect the joint from injury [5, 33], thus studies that do
257 not include measurements across the whole range of movement may either under- or over-
258 estimate knee proprioception. These inconsistent methods of measuring proprioception
259 could have contributed to the high levels of heterogeneity in the current analysis.

260

261 **Conclusions**

262 This review examined the effect of ACL injury on proprioception, in terms of joint position
263 sense and threshold to detect passive motion. The results indicate that patients with ACL
264 injury may have poorer proprioception than people without such injuries and poorer
265 proprioception in the injured than uninjured leg. The proprioception of people whose ACL is
266 reconstructed may be better than those whose ligament is left unreconstructed (ACL-
267 deficient). These differences are seen whether the comparator group is a patient's uninjured
268 leg, or a control group of people with no injuries; suggesting that either can be used as a
269 control group in future research.

270

271 There are no conflicts of interest.

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391 **Appendix 1 – Scoring System**

392

Authors	
Article Title	
Source	
Years/Volume/Pages	
Institute affiliation & Contact address	

393

394

395 Do not proceed if one of the following six categories is not adhered to:-

396

	Yes
Human Study	
English Language	
All participants adults / teenagers	
Were all subjects ACL deficient and/or reconstructed or acting as a healthy control group?	
Were ACL participants categorised into ACL-D, ACL-R or ACL-R pre and post op?	
Was at least one OM a direct measure of proprioception, either TTDPM or JPS?	

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POPULATION

A. Confirmation of ACL Deficiency

Was ACL deficiency confirmed by:

	Score
Not stated	0
Arthroscopy or MRI OR clinical examination using Lachmans, pivot shift test or knee arthrometer	1
Arthroscopy or MRI AND clinical examination using Lachmans, pivot shift test or knee arthrometer	3

B. Representation of Population

Were the ACL participants classified into -

	Score
A sub-group of deficient or reconstructed patients recruited (e.g. those who are undergoing or have completed rehab or copers/ non-copers/ adapters, or limited by age, sex, activity)	1
ACL deficient or ACL reconstructed groups only	3
People with all types of ACL problem (deficient and reconstructed)	5

419 Were ACL-R classified according to:

420

	Yes	No
Type of surgery stated	1	
Type and number of complications stated	1	
Same surgeon for every ACL-R participant	1	
Assessment of laxity pre and post surgery	1	

421

422 Did any ACL participant (ACL-D or ACL-R) have any of the following:- If authors do not
423 mention a previously reconstructed ACL assume the answer is 'no'.

424

	Yes	No
Previous Injury to ACL Knee		2
Concurrent damage to ACL knee during ACL injury		2
Injury to the ankle or hip on ACL injury side		2
Injury to contralateral leg		2
Rehabilitation prior to the point of assessment		2

425

426 **C. Representation of Sample**

427

428 Was the recruitment strategy -

429

	Score
Not stated in the text	0
Stated in the text	1

Based on convenience sampling (e.g. physio department, surgical list, sports club)	3
Based on comprehensive sampling (e.g. recruitment of ACL-D and ACL-R across different populations)	5

430

431 **D. Homogeneity of Participants**

432

433 Was a control comparison used?

434

	Score
No	0
Contra-lateral leg	1
Separate control group (true control)	3

435

436

437 Were the following factors *similar or comparable* between the controls and ACL injury
438 group?

439

	True Control	Contra-lateral Knee
Age	2	1
Sex	2	1
Pre-injury levels of activity	2	1

440

441

442

443

444

445 **E. Sample Size**

446

447 Was a justification of sample size given (power calculation or accuracy/minimal detectable
448 difference of the measurement tool)?

449

Yes	No
10	0

450

451 Were the numbers of participants between:-

452

Number of participants in each group	Control Group	ACL injury group 1	ACL injury group 2	Score
0-5				0
6-10				1
11-15				2
16-20				3
21-25				4
>26				5
TOTAL				

453

454 *METHODOLOGICAL QUALITY*

455 **F. Study Design**

456 Was the study design clearly described?

457

Yes	No
1	0

458 Was the data collection -?

459

	Yes
Retrospective	0
Prospective	3

460

461

462 **G. Assessor Blinding / Bias**

463

464 Were the outcome assessors blind to the type of participants?

465

Yes	No
5	0

466

467

468 **H. Statistical Analysis**

469

470 Were the correct statistics used for data analysis in accordance to the type of data collected
471 (i.e. parametric/ non-parametric)? NOTE: if parametric tests were used, was normality of the
472 data assessed?

473

Yes	No / no statistics used
5	0

474

475

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477

478

479 Was the level of significance appropriate and analysis correctly interpreted? -

480

No	0
Level was appropriate only	1
Level was appropriate and correct interpretation was made	3

481

482 Were the OMs tested for inter-tester and test-retest reliability?

483

	Score
No evidence of reliability testing	0
Reliability was reported using results from external studies	1
Yes, reliability tested within the study and ICC / Kappa yielded good results (>.07)	3

484

485

486 Were the OMs tested for sensitivity to change?

487

	Score
No evidence of sensitivity to change testing	0
Sensitivity to change was reported using results from external studies	1
Yes, effect size / MDC yielded good results (>.07)	3

488

489

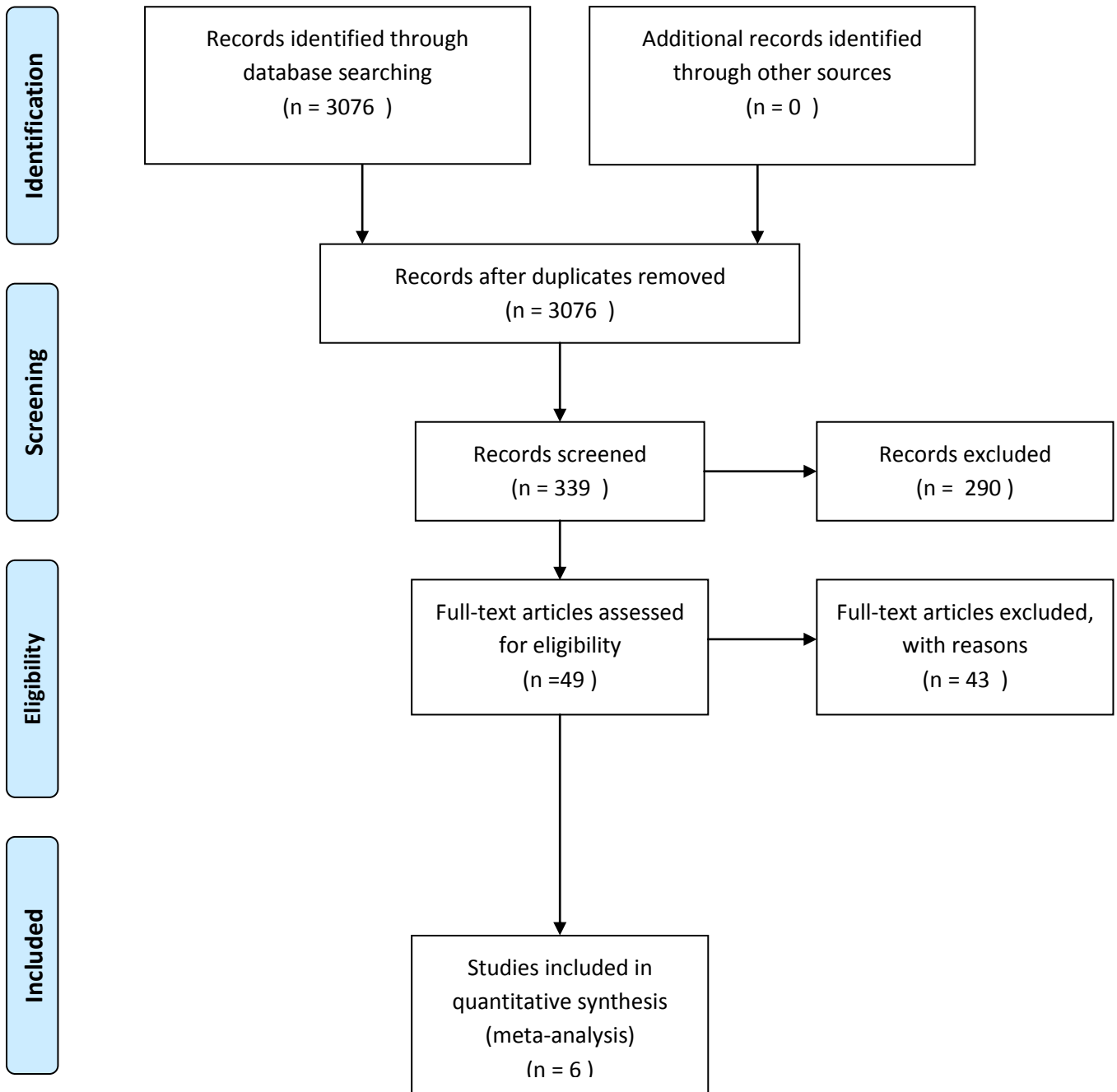
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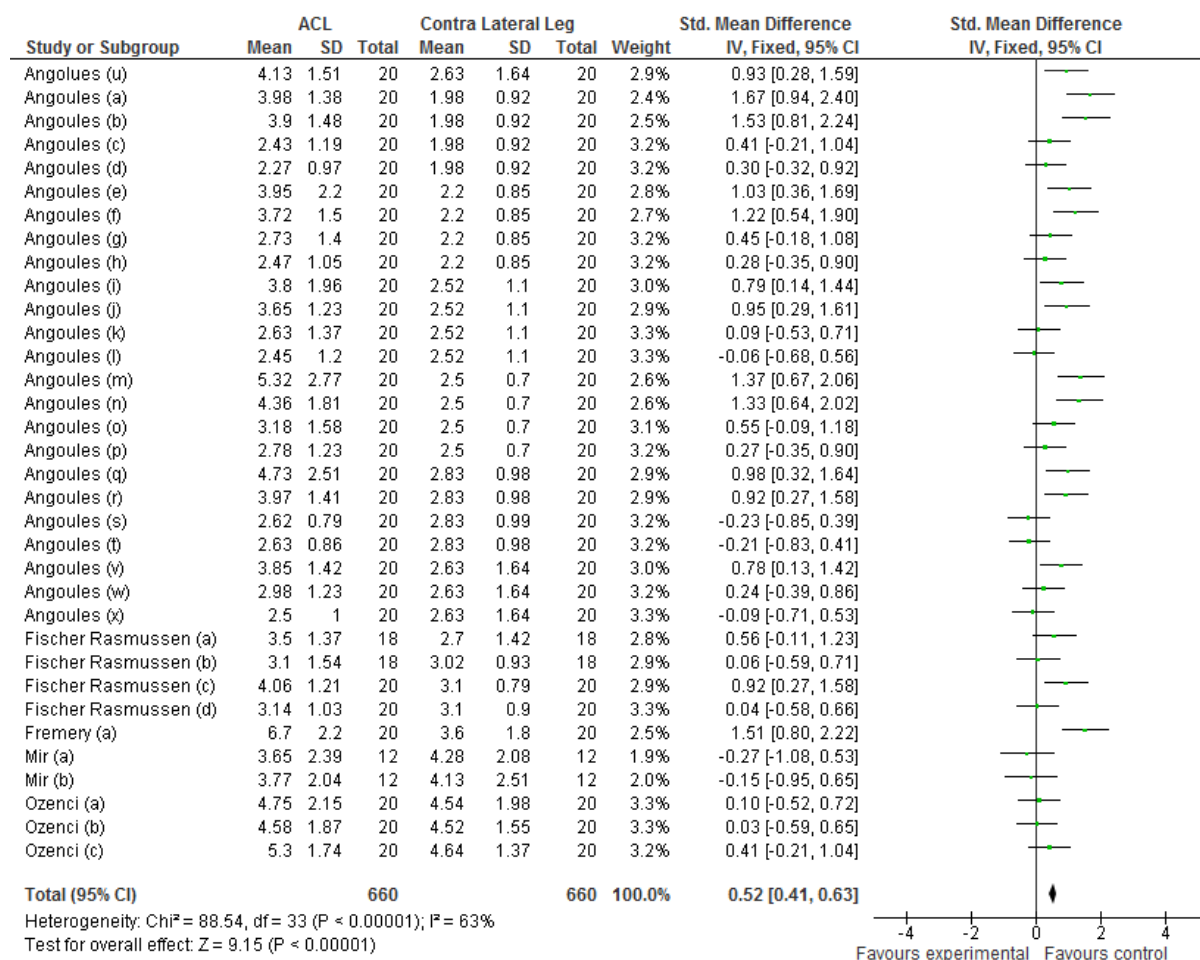
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TOTAL SCORE:

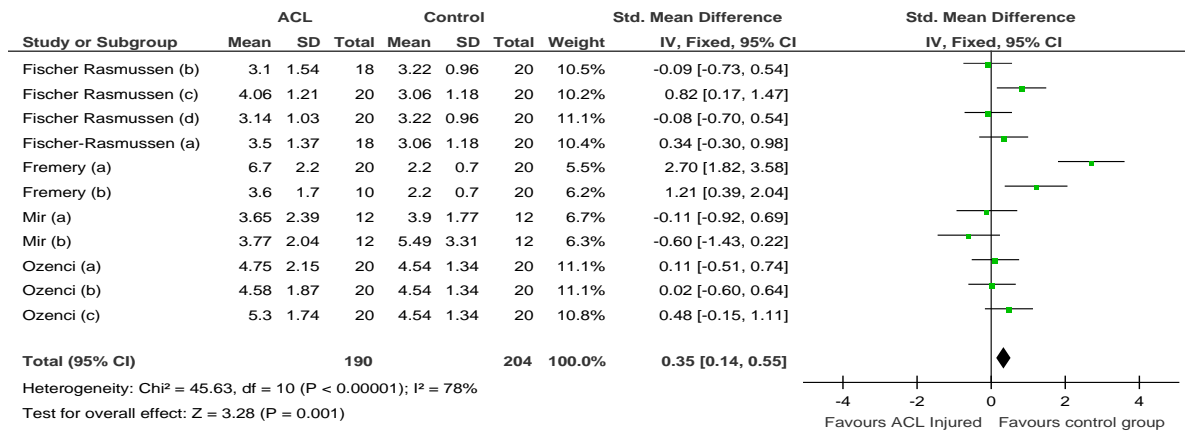
/87

Figure(s)

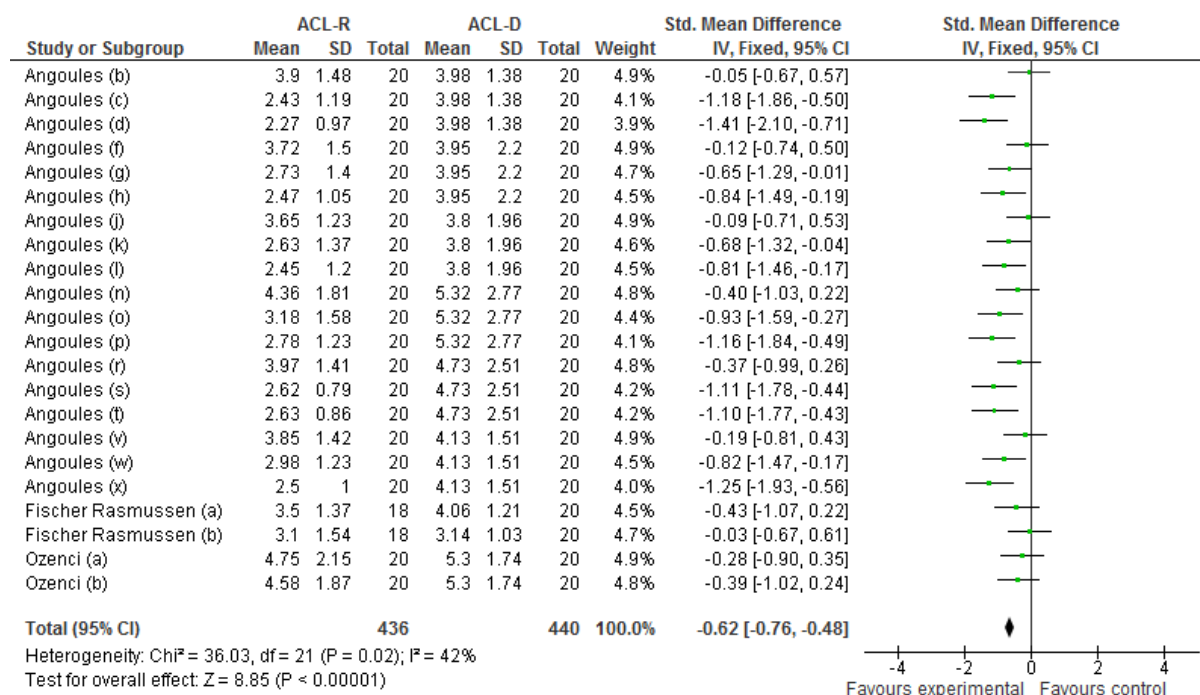




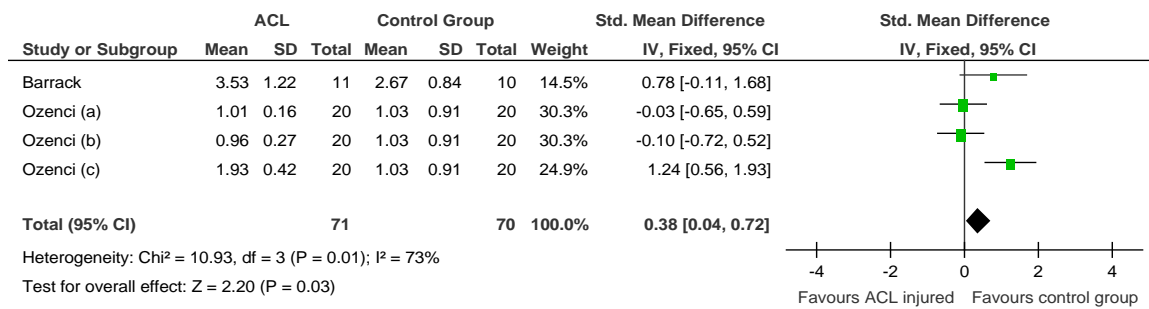
Note: The total number of patients was 170 not 660.



Note: The total number of patients was 140 not 190 and external controls was 104 not 204.



Note: The total number of ACL-R was 116 not 436 and ACL-D was 100 not 440.



Note: The total number of external controls was 30 not 70.

Figures Labels

Figure 1: A PRISMA flow chart of article reduction.

Figure 2-4: Forest plots on the significant joint position sense comparisons. The letters in brackets following the first authors name refer to subgroups and/ or knee motion during proprioception measurement;

Angoules (a) = ACL-D (Pre Hamstring ACL-R) target angle 15°, Angoules (b) = ACL-R (Hamstring- 3months post op) target angle 15°, Angoules (c) = ACL-R (Hamstring- 6months post op) target angle 15°, Angoules (d) = ACL-R (Hamstring- 12 months post op) target angle 15°, Angoules (e) = ACL-D (Pre Hamstring ACL-R) target angle 45°, Angoules (f) = ACL-R (Hamstring- 3months post op) target angle 45°, Angoules (g) = ACL-R (Hamstring- 6months post op) target angle 45°, Angoules (h) = ACL-R (Hamstring- 12 months post op) target angle 45°, Angoules (i) = ACL-D (Pre Hamstring ACL-R) target angle 75°, Angoules (j) = ACL-R (Hamstring- 3months post op) target angle 75°, Angoules (k) = ACL-R (Hamstring- 6months post op) target angle 75°, Angoules (l) = ACL-R (Hamstring- 12months post op) target angle 75°, Angoules (m) = ACL-D (Pre Patella Tendon ACL-R) target angle 15°, Angoules (n) = ACL-R (Patella Tendon- 3months post op) target angle 15°, Angoules (o) = ACL-R (Patella Tendon- 6months post op) target angle 15°, Angoules (p) = ACL-R (Patella Tendon- 12months post op) target angle 15°, Angoules (q) = ACL-D (Pre Patella Tendon ACL-R) target angle 45°, Angoules (r) = ACL-R (Patella Tendon- 3months post op) target angle 45°, Angoules (s) = ACL-R (Patella Tendon- 6months post op) target angle 45°, Angoules (t) = ACL-R (Patella Tendon- 12months post op) target angle 45°, Angoules (u) = ACL-D (Pre Patella Tendon ACL-R) target angle 75°, Angoules (v) = ACL-R (Patella Tendon- 3months post op) target angle 75°, Angoules (w) = ACL-R (Patella Tendon- 6months post op) target angle 75°, Angoules (x) = ACL-R (Patella Tendon- 12months post op) target angle 75°,

Fischer-Rasmussen (a) = ACL-R group with a starting angle of 60°, Fischer-Rasmussen (b) = ACL-R group with a starting angle of 0°, Fischer-Rasmussen (c) = ACL-D group with a starting angle of 60°, Fischer-Rasmussen (d) = ACL-D group with a starting angle of 0°,

Fremerey (a) = ACL-R group, Fremerey (b) = ACL-D Group,

Mir (a) = ACL-R group with starting angle of 60°, Mir (b) = ACL-R group with a starting angle of 0°,

Ozenci (a) = ACL-R (autograft technique) group, Ozenci (b) = ACL-R (allo-graft technique) group and Ozenci (c) = ACL-D group.

Figure 5: Forest plot on the significant threshold to detect passive motion comparison. The letters in brackets following the first authors name refer to subgroups and/ or knee motion during proprioception measurement;

Ozenci (a) = ACL-R (autograft technique) group, Ozenci (b) = ACL-R (allo-graft technique) group and Ozenci (c) = ACL-D group.

1 **Table 1: Characteristics of the articles included in the meta-analysis investigating the effects of ACL injuries on proprioception deficits.**

Study	Participants	Age, mean (SD) and Gender ACL patients	Age, mean (SD) and Gender Controls	Equipment	Knee ROM	Method of measuring proprioception
Barrack <i>et al.</i> , ¹⁷	11 ACL-D 10 Controls.	25 (NP) years 9 men, 2 women	25 (NP)years NP	Purpose built proprioception device.	From a starting angle of 40° at an angular velocity of 0.5°/s.	TTDPM - Mean angle of error in degrees from 10 trials randomly assigned to flexion or extension
Fischer-Rasmussen and Jensen ¹⁸	20 ACL-D 18 ACL-R 20 Controls	ACL-D 27(5) years 11 men, 9 women ACL-R 27(5) years 9 men, 9 women	27(4) years 11 men, 9 women (Plus uninjured knees of patients)	Purpose built proprioception device.	From a starting angle of 25° flexion to 15, 20, 25, 30, 35 or 60° flexion to full extension.	JPS (passive positioning then active repositioning task) – Mean angle of error in degrees from 20 trials randomly assigned to target angles.
Fremerey <i>et al.</i> , ¹⁹	10 ACL-D 20 ACL-R 20 Controls	ACL-D 22.7(3.2) years 7 men, 3 women ACL-R 28.4(4.4) years 13 men, 7 women	26.4(4.8) years 13 men, 7 women (Plus uninjured knees of patients)	Purpose built proprioception device.	From a starting angle of 0° to random target angles in 3 intervals; extension 0-20° , mid range 40-60° and flexion 80-100°. All passive motion was set at 0.5°/s.	JPS (passive positioning then passive repositioning task) – Mean angle of error in degrees from trials randomly assigned from the extension range, mid-range and flexion range.
Ozenci <i>et al.</i> , ²⁰	20 ACL-R (auto-graft) 20 ACL-R (allo-graft) 20 ACL-D 20 Controls	ACL-D 29.0(5.4) years 18 men, 2 women ACL-R Auto – 29.5(6.9) years 20 men Allo – 30.2(4.6) years 16 men, 4 women	27.6(2.6) years 17 men, 3 women (Plus uninjured knees of patients)	Cybox Dynamometer	JPS - From full extension to flexion (no further details given). TTDPM - From 15° flexion to either flexion or extension at an angular velocity of 1°/s.	JPS (passive positioning then active repositioning task) – Mean angle of error in degrees from 10 trials. TTDPM - Mean angle of error in degrees from 10 trials randomly assigned to either flexion or extension.
Anguoles <i>et al.</i> , ²¹	20 ACL-R (hamstring) 20 ACL-R (patella tendon)	16 men, 4 women 18 men, 2 women	N/A	Con-Trex Dynamometer	JPS – From full extension (0°) to flexion angles of 15, 45 & 75°.	JPS (passive positioning then active repositioning task) – Mean angle of error in degrees from three trials.

Mir <i>et al.</i> , ²²	12 ACL-R 12 Controls	23(4.75)years 12 men	22(4.35) years 12 men (Plus uninjured knees of patients)	Digital camera, markers.	From a starting angle of 60° flexion to 30° flexion and from a starting angle of 0° flexion to 30° flexion. All motion was at an angular velocity of 10°/s.	JPS (active positioning then active repositioning task) - Mean error angle in degrees over 3 trials.
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2 ACL-D: Patients with an ACL deficiency, ACL-R: Patients with a reconstructed ACL, TTDPM: Threshold to detect passive motion, JPS: Joint position sense.

3 NP: Not Provided, NA: Not applicable.

Table 2: Methodological quality score for each of the articles included in the meta-analysis

Scoring Section (maximum score)	Barrack <i>et al.</i> , ¹⁷	Fischer-Rasmussen and Jensen ¹⁸	Fremerey <i>et al.</i> , ¹⁹	Ozenci <i>et al.</i> , ²⁰	Angoules <i>et al.</i> , ²¹	Mir <i>et al.</i> , ²²
Confirmation of ACL Deficiency (3)	3	1	3	1	3	0
Representation of Population (19)	9	8	10	14	13	10
Representation of Sample (5)	3	0	3	3	3	0
Homogeneity of Participants (13)	5	11	11	7	4	11
Sample Size (25)	3	9	7	9	6	4
Study Design (4)	1	1	1	1	4	1
Assessor Blinding / Bias (5)	5	0	0	0	5	0
Statistical Analysis (14)	1	1	4	3	14	9
Total (88)	30	31	39	38	52	35
Quality Level	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate

Note: Studies were grouped in to poor (a score of less than 29/88), moderate (a score of 30-58/88) or good (a score of 59+/88) studies based on their final methodological quality score.