

Osteoarthritis and Cartilage



Review

Biomechanical effects of valgus knee bracing: a systematic review and meta-analysis



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SUMMARY

To review and synthesize the biomechanical effects of valgus knee bracing for patients with medial knee osteoarthritis (OA). Electronic databases were searched from their inception to May 2014. Two reviewers independently determined study eligibility, rated study quality and extracted data. Where possible, data were combined into meta-analyses and pooled estimates with 95% confidence intervals (CI) for standardized mean differences (SMD) were calculated. Thirty studies were included with 478 subjects tested while using a valgus knee brace. Various biomechanical methods suggested valgus braces can decrease direct measures of medial knee compressive force, indirect measures representing the mediolateral distribution of load across the knee, quadriceps/hamstring and quadriceps/gastrocnemius co-contraction ratios, and increase medial joint space during gait. Meta-analysis from 17 studies suggested a statistically significant decrease in the external knee adduction moment (KAM) during walking, with a moderate-to-high effect size (SMD = 0.61; 95% CI: 0.39, 0.83; $P < 0.001$). Meta-regression identified a near-significant association for the KAM effect size and duration of brace use only (β , -0.01; 95% CI: -0.03, 0.0001; $P = 0.06$); with longer durations of brace use associated with smaller treatment effects. Minor complications were commonly reported during brace use and included slipping, discomfort and poor fit, blisters and skin irritation. Systematic review and meta-analysis suggests valgus knee braces can alter knee joint loads through a combination of mechanisms, with moderate-to-high effect sizes in biomechanical outcomes.

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Introduction

Knee braces designed to redistribute loads across the knee are available for patients with lower limb malalignment and knee osteoarthritis (OA) primarily affecting one compartment. Valgus braces that are designed to lessen the proportion of load on the knee medial compartment for patients with varus alignment are most common, given the increased load typically borne by that compartment during walking and the higher prevalence of medial knee OA^{1,2}. Systematic review and meta-analysis of existing

randomized trials suggest that valgus bracing can provide small-to-moderate improvements in pain and function³. However, the effect sizes vary largely depending on the study design, with the type of control intervention used as a comparator (e.g., a neutral brace) being particularly important³. Those results provide rationale for systematic review of the evidence supporting or refuting proposed biomechanical effects of valgus braces.

Multiple, and likely overlapping, mechanisms by which valgus braces alter knee joint biomechanics have been proposed^{4–7}. These include both altering the distribution of load and decreasing the magnitude of load on the knee through improvements in malalignment, providing a valgus brace moment to counteract the knee adduction moment (KAM), increasing joint stability, lessening muscle co-contraction and improving proprioception^{4–9}. Although informative, sample sizes for these studies are generally small and results vary considerably. Whether valgus braces can

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indeed provide the proposed beneficial biomechanical effects remain unclear. The uncertainty surrounding the effects of valgus bracing, both in terms of their proposed clinical effects and biomechanical mechanisms, is also reflected by the variable recommendations in clinical practice guidelines^{10–19}. A systematic review with meta-analyses where possible would help clarify the biomechanical mechanisms underlying valgus bracing and may ultimately improve their design and effectiveness. Therefore, the purpose of this study was to review and synthesize the biomechanical effects of valgus knee bracing for patients with medial knee OA.

Methods

Literature sources and study selection

Electronic databases we searched from their inception to May 2014: The Cochrane Central Registry for Controlled Trials, MEDLINE, EMBASE, CINAHL, Scopus, ScienceDirect and Web of Knowledge. Searches used combined and/or truncated key terms including: “knee*”, “osteoarthritis OR arthritis OR arthrosis”, “brace* OR bracing”, and “valgus brace* OR valgus bracing”. A database search strategy is included in the [Online supplement](#). Reference lists of potentially eligible articles were manually searched.

Peer-reviewed studies that examined the biomechanical effects of valgus knee braces in patients with medial compartment knee OA, published as full text, English language journal articles were included. There were no restrictions on study dates or design, the development or severity of knee OA, or on follow-up duration. Editorials, comments, letters, abstracts, review articles, theses and dissertations, and animal or cadaveric studies were excluded. A detailed protocol for this review has not been previously published.

Determining inclusion

Studies that compared a measure indicative of the biomechanical effects of valgus bracing in the same group of patients before and after wearing the brace, with or without comparison to a neutral brace or lateral wedge foot orthotic, were included. Two reviewers (RFM and KML) blinded to journal title and authorship independently assessed eligibility in two stages. Title and abstracts were reviewed. Articles that met the eligibility criteria were then obtained as full manuscripts and reviewed. Disagreements between reviewers regarding article selection were discussed and consensus was achieved. Details of the literature search are reported using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines²⁰.

Outcome measures and data extraction

Using the longest follow-up period, two independent reviewers (RFM and KAM) extracted means and standard deviations before and after wearing a valgus knee brace when available. Outcome measures used to assess changes in biomechanics with brace use included knee joint kinematics, kinetics and electromyography during walking (i.e., gait analysis), the moment provided by the brace, directly measured joint compressive force, static and dynamic radiography, long-term changes in bone mineral density (BMD), joint position sense and standing balance^{4–9}. In addition to measures evaluating biomechanical effects, data on patient-reported compliance and complications with brace use were also extracted. The same reviewers also extracted the following information from each study: study design, number of patients, patient demographics, duration of brace use, all biomechanical outcomes, and funding sources. Disagreements

between reviewers regarding article selection were discussed and consensus was achieved.

Studies were first categorized according to study design. Definitions provided by the Cochrane Collaboration were used to define the studies as observational cohort studies or randomized trials²¹. An observational cohort study followed a defined group of participants over time (prospectively). A randomized clinical trial (RCT) randomly allocated participants to a treatment group and followed them over time (in parallel or crossover). Studies not fitting into these categories, but rather repeated biomechanical evaluations with and without wearing a valgus brace during a single test session, were simply defined as laboratory studies. Authors were contacted when information or data were not reported or were unclear.

Quality assessment of included studies

Two reviewers (RFM and KAM) independently scored the methodological quality of each study using the Downs and Black scale that was modified to include 13 items to assess internal validity²². Each item scored 1-point if the item was satisfied. Disagreements between reviewers were discussed and consensus was achieved.

Data analysis

Agreement between reviewers was evaluated using the kappa (κ) statistic. For the meta-analysis, pooled estimates and 95% confidence intervals (CI) for standardized mean differences (SMD) for change in outcomes were calculated using a random effects model. The SMD was calculated for paired samples using the within-patient change for patients in the valgus knee brace group divided by the pooled standard deviation. Reported sample sizes, pre- and post-intervention means, standard deviations, and/or level of significance were used. The size of the SMD was interpreted using Cohen's d ²³. For studies not reporting sufficient data, and where the authors could not provide data, we estimated values from figures or imputed missing data using the following approach. If a study reported significant findings with a non-exact P value (i.e., $P < 0.05$ or $P < 0.01$), we assigned P values of $P = 0.05$ and $P = 0.01$, respectively^{21,24}. For non-significant findings reported with a non-exact P value, a paired correlation value of $r = 0.5$ was used to calculate the SMD^{25–28}. To evaluate the robustness of this imputation method, three sensitivity analyses were performed while using the highest or lowest reported correlation from included studies, and while excluding studies with imputed data. For studies reporting multiple changes in the external KAM, only the greatest change was included in the meta-analysis. For studies with multiple follow-ups, the last available follow-up was used. Publication bias was assessed using the Egger's regression test²⁹, and if present, adjustment was planned using a trim and fill method³⁰.

Heterogeneity was assessed using the I^2 statistic and Q statistic²⁸. Significant heterogeneity was evaluated by meta-regression using six study characteristics identified a priori including duration of brace use, baseline varus alignment, brace angulation, study quality, year of publication, and funding source.

Complications with brace use were assessed quantitatively from event rates (proportions) using the number of events and total sample size for each study. Each meta-analysis was performed using the Comprehensive Meta-Analysis software program (V2, Biostat, Englewood, NJ, USA). All statistical tests were conducted at a significance level of $P < 0.05$, or the 95% CI failed to cross the line of no significance.

Results

Study selection

After removing duplicates, 519 studies were identified from the literature search, 102 full-text studies were screened and 30 studies evaluating biomechanical effects of valgus knee braces were included (Fig. 1). Inter-rater agreement was excellent for determining eligibility of titles and abstracts ($\kappa = 0.94$) and full-text studies ($\kappa = 0.85$). Of the 72 excluded studies, 11 only evaluated patient-reported outcomes of valgus knee braces (i.e., no biomechanical outcome). After extracting data for 30 full-text studies, disagreement was recorded for 11 (36%) studies and a consensus was met following a joint reassessment. The outcome measures from all 30 studies were examined descriptively. Data from 17 studies were combined in a meta-analysis.

Study characteristics

Characteristics of the included studies are described in Table I^{9,31–59}. Data from 589 subjects were reported and 478

subjects with knee OA were prescribed a valgus knee brace. Age ranged from 21 to 85 years. Of the 22 studies that reported sex, 210 (58%) males and 154 (42%) females were included. Knee OA severity was only reported in 13 studies. Sixteen studies were primarily laboratory studies testing on a single day, ten studies were prospective cohort designs and four studies were randomized controlled trials. No studies evaluated structural measures of disease progression. Authors were contacted for eight articles^{34,39,47,48,50,56,58,59}. Seven authors responded. Five authors were able to provide additional data not reported in the original study.

Sixteen studies investigated the effects of a single brace set at a single valgus angulation^{32–35,37–41,45,47,50,53,57–59}, while five studies compared one valgus brace to another valgus brace, or to the same brace in multiple degrees of valgus angulation^{42–44,51,52}. Seven studies used a control knee brace not intended to apply a valgus moment and alter distribution of joint loads^{31,36,43,46,48,52,54}, and five studies compared valgus bracing to lateral wedge in-soles^{9,49,51,55,56}. Control knee braces included loose or poorly fixated braces, or anterior cruciate ligament (ACL) stabilizing braces.

Nine different brace angulations were used across 23 studies (of 30) and the remaining seven studies did not specify the brace

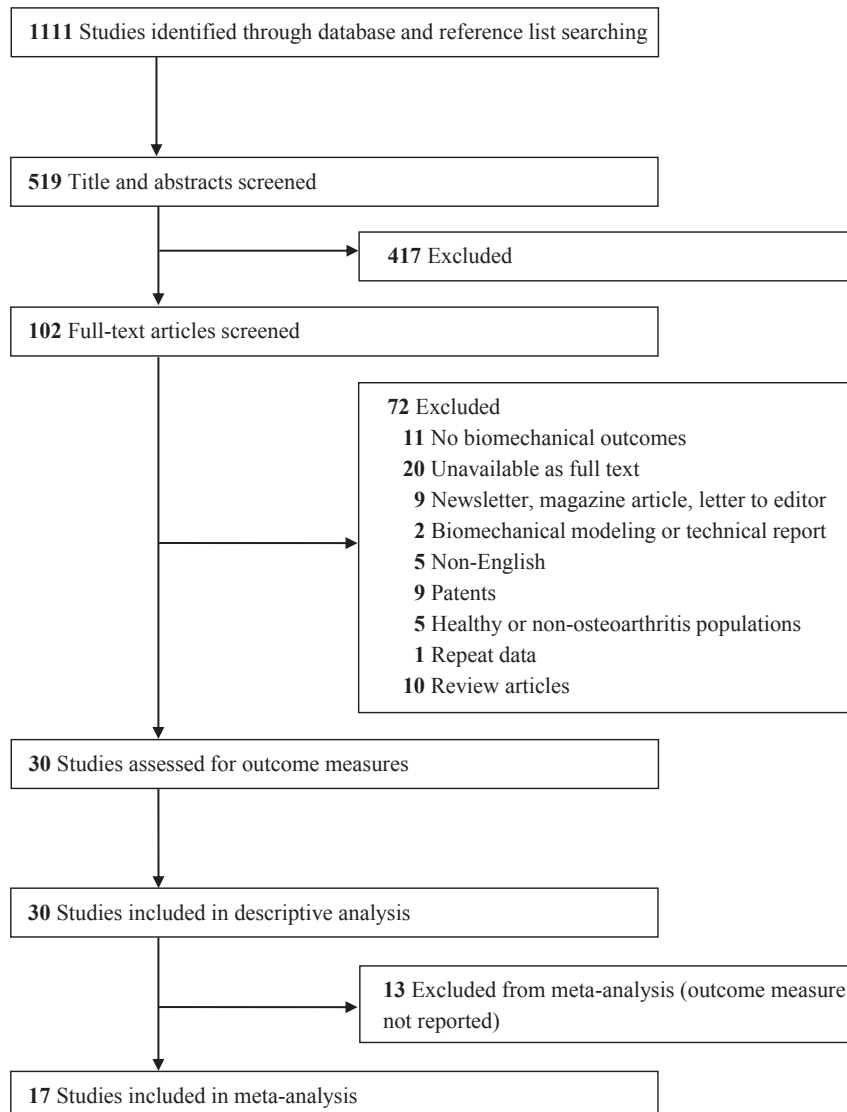


Fig. 1. The 2009 PRISMA Flowchart. Thirty studies were included for descriptive and qualitative analysis.

Table 1
Demographics and study characteristics (n = 30)

Author (year)	n	Age*	Varus alignment (°)*	KL grade of severity	Duration (wks)	Biomechanical outcomes	Funding source
Horlick et al. (1993) ^{31,†}	40	46 (34–69)	–	–	6	Alignment Joint space	Generation II
Lindenfeld et al. (1997) ^{32,‡}	11	47.5 ± 14	–	–	4–6	KAM	Cincinnati Sport Medicine Research and Education Foundation
Matsuno et al. (1997) ^{33,‡}	20	76.6 (58–84)	185.1¶	3, n = 13 4, n = 4 5, n = 3	52	KFM/KEM Alignment	Generation II
Hewett et al. (1998) ^{34,‡}	20	41 (21–78)	–	–	52	KAM KFM/KEM	Bledsoe Brace Systems, Cincinnati Sport Medicine Research and Education Foundation
Katsuragawa et al. (1999) ^{35,‡}	14	69 (57–80)	–	–	12	BMD	Unclear
Komistek et al. (1999) ^{36,§}	15	–	–	–	–	Joint space Alignment	Bledsoe Brace Systems
Self et al. (2000) ^{37,§}	5	49 (40–55)	–	–	–	KAM Brace force	–
Birmingham et al. (2001) ^{38,§}	20	59 ± 9	Males: 8.4 ± 4.3# Females: 8.0 ± 4.3#	–	–	Proprioception Balance	Medical Research Council, Physiotherapy Foundation of Canada
Pollo et al. (2002) ^{39,§}	11	53.2 ± 9.8	–	–	2	KAM Brace moment	Generation II
Barnes et al. (2002) ^{40,‡}	30	61.66 49.33	–	2.66 3.11	8	Joint space Alignment	–
Anderson et al. (2003) ^{41,§}	11	–	–	–	–	Joint force	New Zealand War Pensions Medical Research Trust Fund
Nadaud et al. (2005) ^{42,§}	5	–	–	–	–	Joint space	–
Dennis et al. (2006) ^{43,§}	40	–	–	4, n = 40	–	Joint space	Bledsoe Brace Systems
Draganich et al. (2006) ^{44,‡}	10	50.8 ± 5.4	6.4 ± 3.0#	–	4–5	KAM Alignment	DonJoy Orthopedics
Gaasbeek et al. (2007) ^{45,§}	15	52 ± 11	5.1 (2–11)#	–	6	KAM	POM, Nijmegen, The Netherlands and Bauerfeind GmbH
Ramsey et al. (2007) ^{46,‡}	16	54.9 ± 8.8	7.5 ± 3.3**	–	2	Muscle activation Alignment	National Center for Research Resources, National Institutes of Health
Schmalz et al. (2010) ^{47,§}	16	56 ± 9	–	1, n = 1 2, n = 5 3, n = 7 4, n = 3	4	KAM Brace moment KFM/KEM	–
Fantini Pagani et al. (2010) ^{48,‡}	11	55.5 ± 5.5	–	2, n = 6 3, n = 5	2	KAM Angular Impulse Brace moment	Institute of Biomechanics of German Sport
van Raaij et al. (2010) ^{49,†}	91	54.9 ± 7.4	6.9 ± 3.6#	1, n = 22 2, n = 7 3, n = 17	6	Alignment	–
Toriyama et al. (2011) ^{50,§}	19	68.4 ± 7.8	184.8 ± 3.33¶	2, n = 5 3, n = 13 4, n = 1	–	KAM KFM/KEM	–
Fantini Pagani et al. (2011) ^{51,§}	10	57.5 ± 7.1	2.1 ± 1.2**	2, n = 6 3, n = 4	–	KAM Angular impulse Alignment Brace moment	Institute of Biomechanics of German Sport
Kutzner et al. (2011) ^{52,§}	3	65 ± 5.6	2.67 ± 1.53#	–	–	Joint force	Deutsche Arthrose-Hilfe, Zimmer GmbH, Deutsche Forschungsge-meinschaft
Esrafilian et al. (2012) ^{53,§}	2	53	–	–	–	KAM Alignment	–
Fantini Pagani et al. (2012) ^{54,§}	12	56 ± 4.6	–	–	–	Muscle activation	Institute of Biomechanics of German Sport
Moyer et al. (2013) ^{9,§}	16	55 ± 7	6.6 ± 3.3#	1, n = 2 2, n = 5 3, n = 6 4, n = 3	24	KAM Angular impulse	–
Arazpour et al. (2013) ^{55,†}	24	58.8 ± 2.2	–	1, n = 5 2, n = 7	6	KAM	–
Jones et al. (2013) ^{56,†}	28	66.3 ± 8.2	6.6 ± 4.1**	2, n = 10 3, n = 18	2	Alignment KAM Angular impulse	–
Della Croce et al. (2013) ^{57,§}	18	68 ± 9	–	–	–	KAM	–
Johnson et al. (2013) ^{58,‡}	10	60 (44–85)	–	2 or 3	12	KAM	–
Larsen et al. (2013) ^{59,†}	46	63.7 ± 10.6	3.28 ± 4.48**	1 or 2, n = 11 3 or 4, n = 12	8	KAM Alignment	VQ Orthocare

KL = Kellgren and Lawrence.

* Age and alignment are reported as mean ± standard deviation or mean (range).

† Randomized controlled trial: randomly allocates participants to a group and follows them over time.

‡ Observational cohorts: follows a single, defined group of participants over time.

§ Experimental study design with cross-sectional analysis: ideal testing conditions at a single point in time while controlling for other variables.

|| Grade of severity reported only for patients wearing a valgus knee brace.

¶ Static measures of alignment using X-ray anatomic angle.

Mechanical axis angle.

** Motion capture system knee adduction angle.

angulation. Braces were described as off-the-shelf (i.e., pre-made and available in a number of predetermined sizes)^{36,42–44,49,57}, or custom (i.e., customized to the individual patient based on limb size and morphology)^{9,32,33,37,44,47,55,58,59}. Angulations were described as neutral^{31,36,46,48,52,54}; 10°³¹; 8°^{39,51,52}; 6°⁵⁶; and 4°^{38,39,46,48,52,54}.

Quality assessment of included studies

Inter-rater agreement for each item of the methodological quality assessment was moderate to high ($\kappa = 0.72–0.91$). The mean quality appraisal score was 6.8 ± 1.4 (range: 4–9). Most studies received a score of zero for blinding and concealing randomization until recruitment was completed. As expected, blinding subjects and assessors was a substantial challenge to bracing intervention studies, but is of questionable significance given the biomechanical measurements investigated. No studies were excluded on the basis of quality appraisal. Results from the assessment tool can be located in the [Online supplement](#).

Outcomes measures

Frontal plane kinetics

Seventeen studies (of 30) reported the effect of the brace on the external KAM during walking. Twelve studies (of 17) reported the overall peak KAM^{32–34,37,39,44,45,53,55,57–59} while five studies reported the first and second peak KAMs separately^{9,48,50,51,56}. Extracted data were analyzed and combined in a meta-analysis ($n = 218$). Individual and pooled SMDs for changes in the external KAM are illustrated in [Fig. 2](#). Adjusting the pre-post correlation, or excluding studies with imputed data, had minimal effect on outcomes. Overall, there was a moderate-to-large, statistically significant difference favoring the valgus brace group for improvement in the KAM (SMD, 0.61; 95% CI, 0.39 to 0.83, $P < 0.001$; $I^2 = 51.2\%$; $P = 0.008$) ([Fig. 2](#)). Asymmetry in the funnel plot was observed and the Egger's regression test was positive for significant evidence of publication bias (intercept = 2.82, 95% CI: 1.11, 4.52; $P = 0.002$)

([Fig. 3](#)). Using the trim and fill method, the adjusted SMD was 0.41 (95% CI: 0.17, 0.66).

A meta-regression analysis examined six study characteristics to potentially explain the significant heterogeneity among biomechanical studies evaluating the external KAM ([Table II](#)). There were no significant associations of treatment effect size with baseline varus alignment, brace angulation, study quality, year of publication, or funding sources. The duration of brace use approached a statistically significant association with treatment effect size ($\beta, -0.01$; 95% CI: $-0.03, 0.0007$; $P = 0.06$), with longer durations of brace use associated with smaller treatment effects.

Five studies (of 30) described the valgus moment provided by the brace to directly oppose the external KAM^{37,39,47,48,51}. One study (of five) reported a maximum valgus brace force of 60 N, which remained fairly constant throughout stance³⁷. Four studies (of five) described the valgus moment created by the brace, and each suggested that greater valgus moments were associated with greater valgus angulations or strap tensions at both the first and second peaks of the KAM^{39,47,48,51}. One study also reported the valgus brace moment relative to the magnitude of the KAM, suggesting that the mean maximum valgus moment generated by the brace accounted for approximately 10% of the external KAM during non-brace walking⁴⁷.

Sagittal plane kinetics

Four studies (of 17 studies that reported results for the external KAM) also described the effects of valgus knee bracing on the sagittal plane moment^{32,34,47,50}. Two studies^{32,34} reported no significant difference with and without wearing the brace, while the other two studies reported variable results. Toriyama *et al.*⁵⁰ reported significant changes for both peak flexion and extension moments during stance, however; the increase in knee flexion moment (KFM) observed by Schmalz *et al.*⁴⁷ was not significantly different with and without wearing a valgus knee brace. Although sagittal plane kinetics were not evaluated, Pollo *et al.*³⁹ emphasized

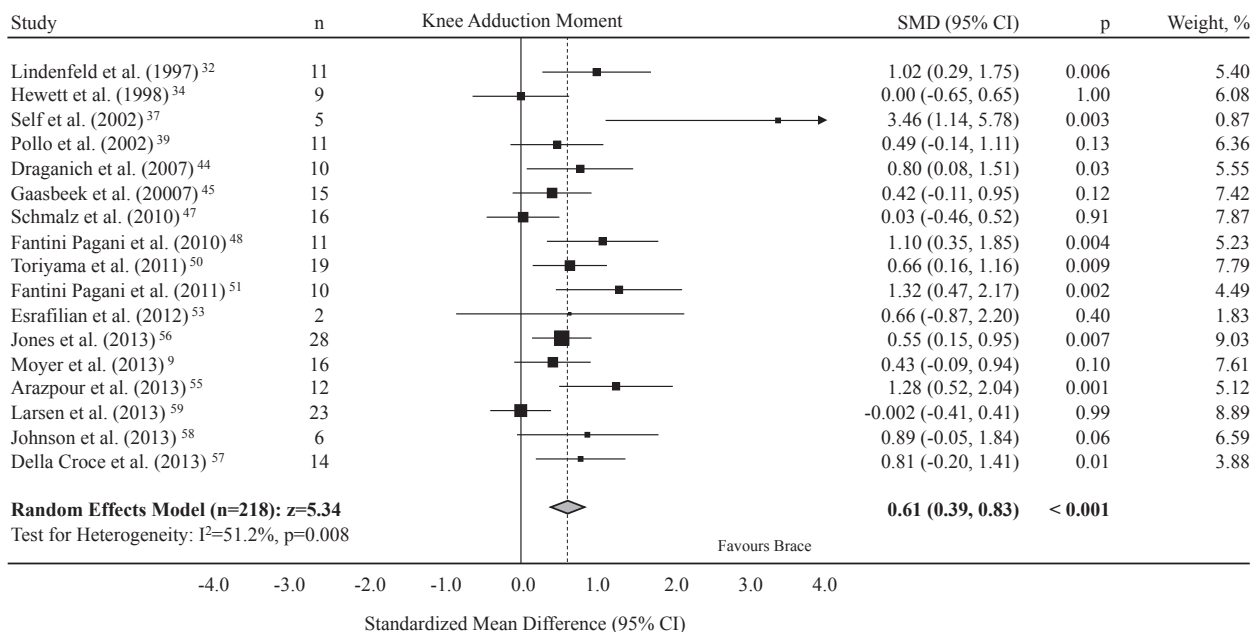


Fig. 2. SMD and 95% CI for the external KAM during walking with and without a valgus knee brace. The diamond represents the pooled effect size using a random effects model. The vertical line at 0 represents no difference. Data to the right of 0 represent a decrease in the peak external KAM. According to the I^2 and Q statistic (P value), heterogeneity was moderate and significant.

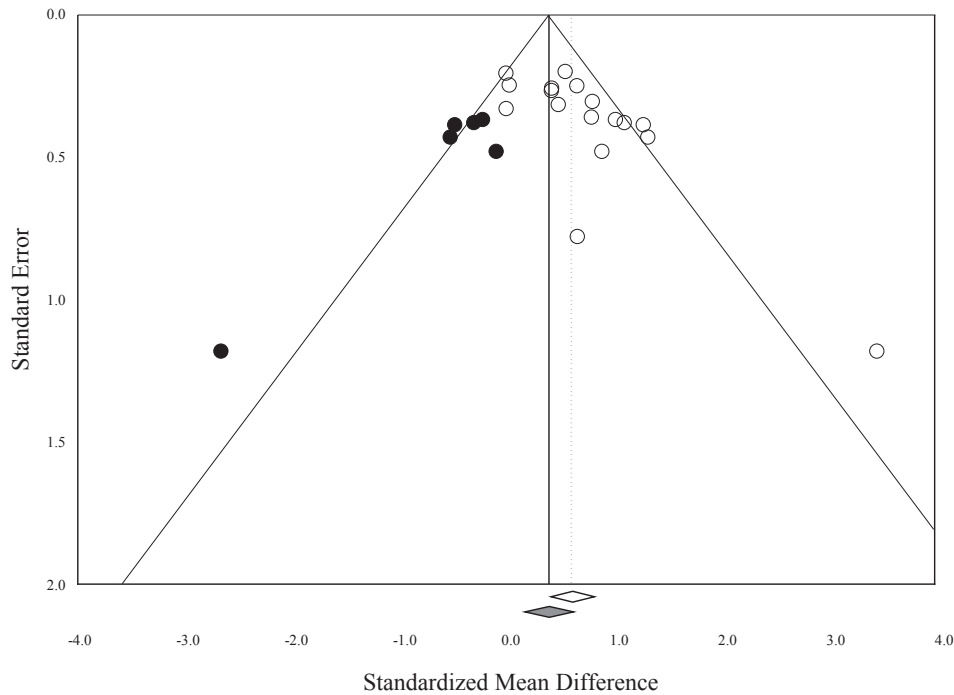


Fig. 3. Funnel plot representing publication bias across seventeen studies. The white and gray diamonds represent the observed and adjusted effect sizes for the KAM, respectively.

that consideration of knee flexion and extension moments (KFM/KEM) is important to better understand the effects of valgus braces.

Medial compartment joint space

Five studies (of 30) reported the effect of valgus knee bracing on medial compartment joint space^{31,36,40,42,43}. Two studies used standing, hip-to-ankle anteroposterior (AP) radiographs and reported no significant difference in medial joint space between braced and non-braced conditions^{31,40}. Means or measures of variability were not reported. Three studies (of five) used fluoroscopic gait analysis to measure knee joint space during walking^{36,42,43}. Two studies (of three) reported statistically significant increases in condylar separation while wearing the brace^{36,43}. The average increase in medial compartment separation (mean \pm SD) for both studies ($n = 15$, $n = 40$)^{36,43} was $1.3 \text{ mm} \pm 1.8 \text{ mm}$, respectively. In only those patients that had reported improvements in pain (12/15)³⁶ or an increase in joint space (31/40)⁴³, the respective average increase in medial compartment separation approached 2.0 mm and 1.7 mm. One study (of three) did not report whether the change in condylar separation was statistically significant (range: 0.2–0.8 mm)⁴².

Table II

Meta-regression analysis of study characteristics potentially related to heterogeneity*

	β (95% CI)	<i>P</i>
Duration of intervention use (weeks)	-0.01 (-0.03, 0.0007)	0.06
Varus alignment†	-0.01 (-0.12, 0.10)	0.82
Angulation of the brace	0.06 (-0.14, 0.26)	0.55
Funding source	-0.01 (-0.26, 0.29)	0.94
Quality of the study	-0.05 (-0.20, 0.10)	0.53
Year of publication	-0.001 (-0.04, 0.04)	0.96

* Each study characteristics was evaluated individually against effect size.

† Only seven studies that reported the knee adduction moment before and after brace use reported lower limb alignment at baseline.

Lower limb malalignment

Eleven studies (of 30) reported effects on lower limb varus alignment^{31,33,36,40,44,46,49,51,53,56,59}. Five studies used the knee adduction angle calculated from three-dimensional gait analysis^{46,51,53,56,59}. Non-significant decreases^{46,59} and significant improvements in lower limb alignment (2.6°)⁵⁶ were reported. One study (of five) reported significant and non-significant improvements in lower limb alignment when patients wore an 8° and 4° valgus brace, respectively⁵¹. One study was excluded from further analysis because the values reported occurred during the swing phase of gait⁵³. One study used fluoroscopic gait analysis and reported a decrease in varus alignment (2.2°) in 80% of patients ($n = 12/15$)³⁶. Five studies used the hip-knee-ankle or femoro-tibial angle (FTA) measured on standing AP radiographs^{31,33,40,44,49}. Non-significant decreases^{31,40,49} and significant improvements in lower limb alignment (1.4°)³³ were reported. One study (of five) reported significant and non-significant changes in lower limb alignment when patients wore a custom fit and off-the-shelf brace, respectively⁴⁴. Across nine (of 11) studies, the change in varus alignment ranged from 0° to 2.6° .

Muscle co-contraction

Two studies (of 30) examined the effects of a valgus brace on muscle co-contraction during walking^{46,54}. Ramsey *et al.* (2007)⁴⁶ and Fantini Pagani *et al.* (2012)⁵⁴ reported decreases in co-contraction ratios for the following muscle pairs: vastus medialis-medial hamstrings (VM-MH), vastus lateralis-lateral hamstrings (VL-LH), vastus medialis-medial gastrocnemius (VM-MG) and vastus lateralis-lateral gastrocnemius (VL-LG). Ramsey *et al.* (2007)⁴⁶ observed a reduction in VM-MH with a 4° brace and VL-LH with both a neutral and 4° valgus setting (100 ms prior to initial contact through to the first peak KAM). No changes were observed for either VM-MG or VL-LG co-contractions. Reductions in VM-MH and VL-LH were also reported by Fantini Pagani *et al.* (2012)⁵⁴ for both neutral and 4° brace settings; however, these findings were only noted during the pre-activation phase of the gait cycle (150 ms

before heel contact). During the loading phase (0–15% stance), reductions in VL-LG were also observed with the 4° brace. No changes were observed for VM-MG co-contractions.

Proprioception

One study (of 30) evaluated the effects of valgus bracing on measures of proprioception³⁸. Birmingham *et al.* tested patients' abilities to actively replicate target knee joint angles, while blind-folded and in a seated position, and tested single-limb standing balance while standing directly on a force platform and while standing on a foam mat placed over the platform. Statistically significant improvements were observed for the joint repositioning test only. Although improvements in the one measure of proprioception were noted, the authors also questioned its relevance and carry-over to weight-bearing, functional activities.

Direct measures of tibiofemoral contact force

Two studies (of 30) examined the effects of a brace on direct measures of joint loading *in vivo*^{41,52}. Anderson *et al.* (2003)⁴¹ reported no significant difference on medial compartment load during standing with and without a brace when tested using Tekscan pressure sensors inserted arthroscopically. Authors suggested that their results might be attributable to sensors shifting. Kutzner *et al.* (2011)⁵² reported decreased medial compartment force during walking with a brace when tested using telemetric implants in three patients after total knee arthroplasty. In neutral, 4° and 8° valgus brace settings, contact force was reduced by 10%, 18% and 23% respectively at the first peak KAM, and was reduced by 9%, 24%, and 30% respectively at the second peak KAM.

BMD

One study (of 30) reported changes in BMD after 3 months of brace use³⁵. BMD increased 3% and 7% in the medial and lateral tibial condyles, respectively.

Dosage and frequency of brace use

Thirteen studies reported details regarding instructions for brace use. Instructions included wearing the brace all day^{44,45,59}, during activity^{9,31,56,39}, as needed^{34,40,49} or at least 30 min per

day⁵⁸. Two articles indicated that a clinician fit the brace and provided instructions, but did not specify type or frequency of use^{46,47}. Twelve studies reported patient compliance with brace use at the longest follow-up period (2–52 weeks), ranging from 29 to 100% of patients^{31,33,34,40,44–47,49,55,56,58}. Definitions for patient compliance varied widely.

Patient-reported complications

Six studies (of 30) reported difficulties experienced by patients using a brace. Event rates with 95% CI are summarized in Fig. 4. Statistically significant heterogeneity prevented data pooling. The reported difficulties included slipping⁴⁷, instability or discomfort^{40,46,52,57}, and constraining or poor fit^{40,49}. Additional complications resulting from brace use included skin irritation⁴⁹, and blisters⁴⁹.

Discussion

The present systematic review with meta-analysis suggests that valgus knee braces can significantly alter knee joint biomechanics during walking, through multiple mechanisms. Studies suggest that valgus knee braces can significantly decrease direct measures of medial compartment load⁵², indirect measures representing the distribution of loads across the knee^{9,32,37,39,44,45,48,50,51,55–58}, muscle co-contraction^{46,54}, and increase medial joint space during gait^{36,42,43}. The changes in BMD observed over time are also consistent with these alterations in joint load³⁵. Potential mechanisms by which valgus braces alter loads include the application of a valgus moment at the knee to directly oppose the external KAM, with or without an alteration in frontal plane alignment of the lower limb, and/or the provision of increased knee joint stability that enables less muscle co-contraction. The most commonly supported mechanism is that a valgus brace opposes the external KAM that exists during walking^{37,39,47,48,51}. Observations of greater reductions in the KAM with larger valgus brace angulations are consistent with this mechanism^{51,52}. Importantly, the inconsistent changes in a patient's lower limb frontal plane alignment with a valgus brace do not coincide with consistent decreases in medial compartment loads. This finding suggests a change in alignment is

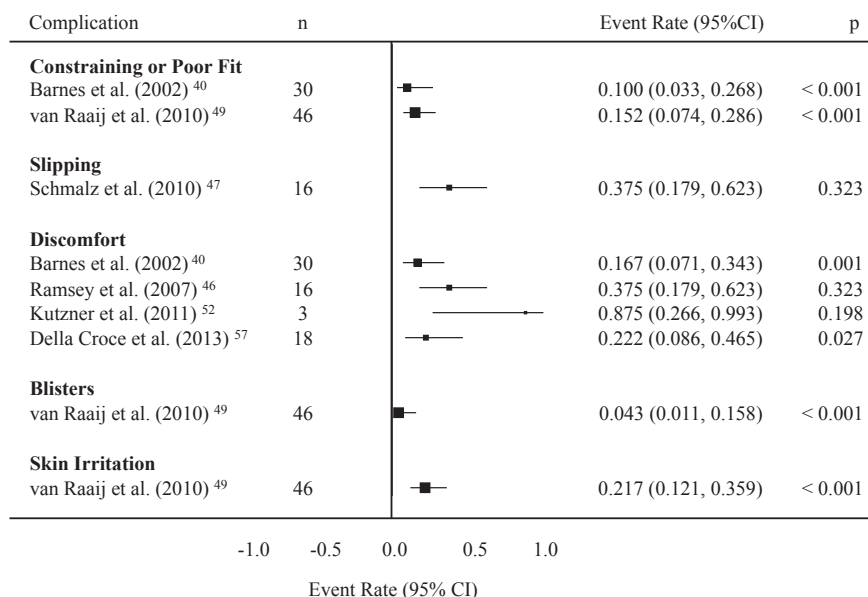


Fig. 4. Event rates and 95% CI for difficulties and complications during brace use. Significant heterogeneity prevented data pooling.

not necessarily required to shift load away from the medial compartment^{31,36,40,44,46,49}. Alternatively, loads may be transferred from the medial compartment to the brace. Without a consistent change in lower limb alignment, transferring load to the brace may not necessarily lead to observable decreases in the KAM³⁹. A less commonly suggested mechanism is that the brace stabilizes the knee and thereby enables decreased muscle co-contraction^{46,54}. Observations of decreased co-contraction^{46,54} with braces in neutral angulation are consistent with this mechanism. Few studies consider the biomechanical effect of bracing in the sagittal plane and report inconsistent findings for the flexion and extension moments. The inconsistent findings and suggestions that both the knee adduction and flexion moment contribute to future disease progression highlight a need for future investigations of valgus bracing beyond the frontal plane^{39,60,61}. Based on the studies reviewed, valgus braces likely provide a combination of biomechanical mechanisms, acting in concert.

The importance of the observed biomechanical effects remains controversial. When described as a pooled effect size (Fig. 2: SMD, 0.61; 95% CI, 0.39 to 0.83, $P < 0.001$), the decrease in the external KAM can be considered moderate-to-high. After adjusting for publication bias, the pooled effect size was reduced somewhat, but can still be considered moderate (SMD, 0.41; 95% CI, 0.17, 0.66). Importantly, the external KAM represents the medial-to-lateral distribution of knee joint load rather than the actual force on the medial compartment^{52,62}, and proposed beneficial decreases in the KAM must be interpreted cautiously in situations where the total joint contact force may increase^{52,62,63}. When considering the other biomechanical measures investigated, the fact that four studies reported small to no change in the external KFM^{32,34,47,50}, two studies suggested a decrease in knee extensor and flexor muscle co-contraction^{46,54}, and two studies reported an increase in medial joint space^{36,43}, these overall findings are consistent with directly measured decreases in medial contact force with valgus brace use. The magnitude of these effects remains unclear, however, with some authors suggesting the size of the decrease in load on the medial compartment observed with bracing is too small to be of much benefit, while other authors suggesting even small changes in knee joint loading may be important given the thousands of steps taken per day^{9,32,45,48,51,55,56}.

Although these biomechanical results are generally encouraging, they are tempered substantially by the available data on patient compliance. Reasons for poor compliance are numerous and may relate to the reported difficulties experienced with brace use (Fig. 4). Consistent reports of decreased brace use over time^{40,51,64,65} may explain the significant association observed between the duration of brace use and treatment effects. As the duration of brace use increases, patient compliance decreases, limiting overall treatment effects. Patient characteristics, fading motivation for treatment adherence, and brace effectiveness combated by disease progression, are speculated as sources for diminishing treatment effects with prolonged use. Similarly, biomechanical studies have previously indicated that greater valgus angulations in the brace create greater reductions in the external KAM^{51,52}. Unfortunately, greater valgus angulations are also associated with less comfort and may not be tolerated by the patient for prolonged durations^{39,52,54}. The current regression analysis did not show a significant association between brace angulation and treatment effect, possibly due to poorer patient compliance associated with discomfort. If bracing is to play a larger role in the treatment of patients with knee OA, further research is required to determine optimal dosage. Additionally, exploring the effects of different brace angulations, durations of use, and the combined use of different types of orthoses to achieve larger

biomechanical effects while maintaining patient comfort is warranted^{9,66}.

Limitations of this review

Only studies that evaluated the effects of valgus knee bracing during level walking were included in this review. Data during stair use, from two studies that also evaluated the biomechanical effects of valgus bracing during gait, were excluded^{44,52}. Both studies showed significant reductions of the KAM during stair use with a custom vs off-the-shelf brace⁴⁴ or brace with large vs small angulations⁵². Studies varied in design, disease severity of patients, brace type and data collection and analysis procedures. Although moderate heterogeneity was observed, the meta-regression only identified potential effects of different study methods (e.g., duration of brace use) on the present findings and should be acknowledged. Additionally, adjusting for publication bias using the trim and fill method assumes funnel plot symmetry and that an asymmetrical plot is the result of absent negative or undesirable findings. Considerable variation in patient response was consistently observed across studies highlighting the heterogenous nature of knee OA and the need for appropriateness criteria for non-surgical treatments. Furthermore, some patients may respond better to valgus braces than others. Current reports of subgroup data lack consistency; therefore identifying those patients likely to respond best is limited^{36,49,65,67,68}.

Conclusions

This systematic review with meta-analysis suggests valgus braces can alter knee joint biomechanics through a combination of mechanisms, with the preponderance of previous studies reporting moderate-to-high effect sizes in the measures evaluated. Findings are tempered substantially by uncertainty in the clinical benefit of the effect sizes reported, and the consistent reports of poor compliance with long-term brace use. Identified gaps in the literature requiring further research include optimal dosage (i.e., the angular correction, valgus moment provided by the brace, and the duration of use) while balancing patient comfort, patient characteristics of those who are likely to respond best, effects on disease progression and economic evaluations.

Contributors

Drs Moyer and Birmingham take responsibility for the integrity of the work as a whole. All authors had full access to all of the data in the study and take responsibility for the integrity of the data and the accuracy of the data analysis.

Conception and design: Moyer, Birmingham, Bryant, Giffin.

Collection and assembly of data: Moyer, Marriott, Leitch.

Analysis and interpretation of the data: Moyer, Birmingham, Bryant.

Drafting and final approval of the article: Moyer, Birmingham, Bryant, Giffin, Marriott, Leitch.

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Role of the sponsor

Funders had no involvement with design and conduct of the study; collection, management, analysis, and interpretation of the data; and preparation, review, or approval of the manuscript.

Disclaimers

None.

Competing interest statement

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Supplementary data

Supplementary data related to this article can be found at <http://dx.doi.org/10.1016/j.joca.2014.11.018>.

References

- Andriacchi TP. Dynamics of knee malalignment. *Orthop Clin North Am* 1994;25:395–403.
- Gross KD, Hillstrom HJ. Noninvasive devices targeting the mechanics of osteoarthritis. *Rheum Dis Clin North Am* 2008;34(3):755–76.
- Moyer RF, Birmingham TB, Bryant DM, Giffin JR, Marriott KA, Leitch KM. Valgus bracing for knee osteoarthritis: a meta-analysis of randomized trials. *Arthritis Care Res* 2014, <http://dx.doi.org/10.1002/acr.22472>. in press.
- Briem K, Ramsey DK. The role of bracing. *Sports Med Arthrosc Rev* 2013;21(1):11–7.
- Ramsey DK, Russell ME. Unloader braces for medial compartment knee osteoarthritis: implications on mediating progression. *Sports Health* 2009;1(5):416–26.
- Pollo FE, Jackson RW. Knee bracing for unicompartmental osteoarthritis. *J Am Acad Orthop Surg* 2006;14(1):5–11.
- Segal NA. Bracing and orthoses: a review of efficacy and mechanical effects for tibiofemoral osteoarthritis. *PM R* 2012;4 (5 Suppl 1):S89–96.
- Reeves ND, Bowling FL. Conservative biomechanical strategies for knee osteoarthritis. *Nat Rev Rheumatol* 2011;7(2):113–22.
- Moyer RF, Birmingham TB, Dombroski CE, Walsh RF, Leitch KM, Jenkyn TR, et al. Combined effects of a valgus knee brace and lateral wedge foot orthotic on the external knee adduction moment in patients with varus gonarthrosis. *Arch Phys Med Rehabil* 2013;94(1):103–12.
- McAlindon TE, Bannuru RR, Sullivan MC, Arden NK, Berenbaum F, Bierma-Zeinstra SM, et al. OARSI guidelines for the non-surgical management of knee osteoarthritis. *Osteoarthritis Cartilage* 2014;22(3):363–88.
- Nelson AE, Allen KD, Golightly YM, Goode AP, Jordan JM. A systematic review of recommendations and guidelines for the management of osteoarthritis: the chronic osteoarthritis management initiative of the US bone and joint initiative. *Semin Arthritis Rheum* 2014;43(6):701–12.
- Zhang W, Moskowitz RW, Nuki G, Abramson S, Altman RD, Arden N, et al. OARSI recommendations for the management of hip and knee osteoarthritis, part II: OARSI evidence-based expert consensus guidelines. *Osteoarthritis Cartilage* 2008; 16(2):137–62.
- Jordan KM, Arden NK, Doherty M, Bannwarth B, Bijlsma JW, Dieppe P, et al. EULAR recommendations 2003: an evidence based approach to the management of knee osteoarthritis: report of a task force of the standing committee for international clinical studies including therapeutic trials (ESCSIT). *Ann Rheum Dis* 2003;62(12):1145–55.
- National Collaborating Centre for Chronic Conditions. Osteoarthritis: National Clinical Guideline for Care and Management in Adults. London: Royal College of Physicians; 2008.
- Hochberg MC, Altman RD, April KT, Benkhalti M, Guyatt G, McGowan J, et al. American College of Rheumatology 2012 recommendations for the use of non-pharmacologic and pharmacologic therapies in osteoarthritis of the hand, hip, and knee. *Arthritis Care Res (Hoboken)* 2012;64(4): 465–74.
- The American Academy of Orthopaedic Surgeons. Treatment of Osteoarthritis of the Knee. Evidence Based Guideline, 2nd edn. <http://www.aaos.org/research/guidelines/TreatmentofOsteoarthritisoftheKneeGuideline.pdf>. Accessed February 19, 2014.
- Beaudreuil J, Bendaya S, Faucher M, Coudeyre E, Ribink P, Revel M, et al. Clinical practice guidelines for rest orthosis, knee sleeves and unloading knee braces in knee osteoarthritis. *Joint Bone Spine* 2009;76(6):629–36.
- Li LC, Maetzel A, Pencharz JN, Maguire L, Bombardier C. Use of mainstream non-pharmacologic treatment by patients with arthritis. *Arthritis Care Res* 2004;51(2):203–9.
- Dhawan A, Mather III RC, Karas V, Ellman MB, Young BB, Bach Jr BR, et al. An epidemiologic analysis of clinical practice guidelines for non-arthroplasty treatment of osteoarthritis of the knee. *Arthroscopy* 2014;30(1):65–71.
- Liberati A, Altman DG, Tetzlaff J, Mulrow C, Gøtzsche PC, Ioannidis JPA, et al. The PRISMA statement for reporting systematic reviews and meta-analyses of studies that evaluate health care interventions: explanation and elaboration. *Ann Intern Med* 2009;151(4):65–94.
- Higgins JPT, Green S. *Cochrane Handbook for Systematic Reviews of Interventions*. West Sussex, England: John Wiley and Sons; 2008:672.
- Downs SH, Black N. The feasibility of creating a checklist for the assessment of the methodological quality of both of randomized and non-randomized studies of health care interventions. *J Epidemiol Community Health* 1998;52(6):377–84.
- Cohen J. *Statistical Power Analysis in the Behavioural Sciences*. Hillsdale, NJ: Lawrence Erlbaum Associates; 1988:567.
- Rosenthal R. *Meta-analytic Procedures for Social Research: Combining Probabilities*. Beverly Hills, CA: Sage Publications; 1984:89–109.
- Norman GR, Streiner DL. *Biostatistics: The Bare Essentials*. Shelton, CT: PMPH-USA Ltd; 2008:393. Series.
- Borenstein M. Effect sizes for continuous data. In: Cooper HM, Hedges LV, Valentine JC, Eds. *Handbook of Research Synthesis and Meta-analysis*. New York, NY: Russell Sage Foundation; 2009:221–36.
- Follman D, Elliott P, Cutler J. Variance imputation for overviews of clinical trials with continuous response. *J Clin Epidemiol* 1992;45(7):769–73.
- Higgins JPT, Thompson SJ, Deeks JJ, Altman DG. Measuring inconsistency in meta-analysis. *BMJ* 2003;327(7414):557–60.

29. Rothstein HR, Sutton AJ, Borenstein M, Eds. *Publication Bias in Meta-analysis: Prevention, Assessment and Adjustments*. West Sussex, England: John Wiley and Sons; 2006:374.
30. Duval S, Tweedie R. Trim and fill: a simple funnel-plot-based method of testing and adjusting for publication bias in meta-analysis. *Biometrics* 2000;56(2):455–63.
31. Horlick SG, Loomer RL. Valgus knee bracing for medial gonarthrosis. *Clin J Sports Med* 1993;3(4):251–5.
32. Lindenfeld TN, Hewett TE, Andriacchi TP. Joint loading with valgus bracing in patients with varus gonarthrosis. *Clin Orthop Relat Res* 1997;344:290–7.
33. Matsuno H, Kadowaki KM, Tsuji H. Generation II knee bracing for severe medial compartment osteoarthritis of the knee. *Arch Phys Med Rehabil* 1997;78:745–9.
34. Hewett TE, Noyes FR, Barber-Westin SD, Heckman TP. Decrease in knee joint pain and increase in function in patients with medial compartment arthrosis: a prospective analysis of valgus bracing. *Orthopedics* 1998;21:131–8.
35. Katsuragawa Y, Fukui N, Nakamura K. Change in bone mineral density with valgus knee bracing. *Int Orthop* 1999;23:164–7.
36. Komistek RD, Dennis DA, Northcutt EJ, Wood A, Parker AW, Traina SM. An in vivo analysis of the effectiveness of the osteoarthritic knee brace during heel strike of gait. *J Arthroplasty* 1999;14(6):738–42.
37. Self BP, Greenwald RM, Pflaster DS. A biomechanical analysis of medial unloading brace for osteoarthritis in the knee. *Arthritis Care Res* 2000;13(4):191–7.
38. Birmingham TB, Kramer JF, Kirkley A, Inglis JT, Spaulding SJ, Vandervoort AA. Knee bracing for medial compartment osteoarthritis: effects on proprioception and postural control. *Rheumatol (Oxford)* 2001;40(3):285–9.
39. Pollo FE, Otis JC, Backus SI, Warren RF, Wickiewicz TL. Reduction of medial compartment loads with valgus bracing of the osteoarthritic knee. *Am J Sports Med* 2002;30(3):414–21.
40. Barnes CL, Cawley PW, Hederman B. Effect of CounterForce brace on symptomatic relief in a group of patients with symptomatic unicompartamental osteoarthritis: a prospective 2-year investigation. *Am J Orthop* 2002;31:396–401.
41. Anderson IA, MacDiarmid AA, Harris ML, Gillies M, Phelps R, Walsh WR. A novel method for measuring medial compartment pressures within the knee joint in-vivo. *J Biomech* 2003;36:1391–5.
42. Nadaud MC, Komistek RD, Mahfouz MR, Dennis DA, Anderle MR. In vivo three-dimensional determination of the effectiveness of the osteoarthritic knee brace: a multiple brace analysis. *J Bone Joint Surg* 2005;87-A(S2):114–9.
43. Dennis DA, Komistek RD, Nadaud MC, Mahfouz M. Evaluation of off-loading braces for treatment of unicompartamental knee arthrosis. *J Arthroplasty* 2006;21(4):2–8.
44. Draganich L, Reider B, Rimington T, Piotrowski G, Mallik K, Nason S. The effectiveness of self-adjustable custom and off-the-shelf bracing in the treatment of varus gonarthrosis. *J Bone Joint Surg* 2006;88-A(12):2645–52.
45. Gaasbeek RDA, Groen BE, Hampsink B, van Heerwaarden RJ, Duysens J. Valgus bracing in patients with medial compartment osteoarthritis of the knee: a gait analysis study of a new brace. *Gait Posture* 2007;26:3–10.
46. Ramsey DK, Briem K, Axe MJ, Snyder-Mackler L. A mechanical theory for the effectiveness of bracing for medial compartment osteoarthritis of the knee. *J Bone Joint Surg* 2007;89:2398–407.
47. Schmalz T, Knopf E, Drewitz H, Blumentritt S. Analysis of biomechanical effectiveness of valgus-inducing knee brace for osteoarthritis of knee. *J Rehabil Res Dev* 2010;47(5):419–30.
48. Fantini Pagani CH, Bohle C, Potthast W, Bruggemann GP. Short-term effects of a dedicated knee orthosis on knee adduction moment, pain and function in patients with osteoarthritis. *Arch Phys Med Rehabil* 2010;91:1936–41.
49. van Raaij TM, Reijman M, Brouwer RW, Bierma-Zeinstra A, Verhaar JAN. Medial knee osteoarthritis treated by insoles or braces: a randomized trial. *Clin Orthop Relat Res* 2010;468(7):1926–32.
50. Toriyama M, Deie M, Shimada N, Otani T, Shidahara H, Maejima H, et al. Effects of unloading bracing on knee and hip joints for patients with medial compartment knee osteoarthritis. *Clin Biomech* 2011;26:497–503.
51. Fantini Pagani CH, Hinrichs M, Bruggemann GP. Kinetic and kinematic changes with the use of valgus knee brace and lateral wedge insoles in patients with medial knee osteoarthritis. *J Orthop Res* 2011;7:1125–32.
52. Kutzner I, Kuher S, Heinlein B, Dymke J, Bender A, Halder AM, et al. The effect of valgus braces on medial compartment load of the knee joint – in vivo load measurements in three subjects. *J Biomech* 2011;44:1354–60.
53. Esrafilian A, Karimi MT, Eshraghi A. Design and evaluation of a new type of knee orthosis to align the mediolateral angle of the knee joint with osteoarthritis. *Adv Orthop* 2012:104927.
54. Fantini Pagani CH, Willwacher S, Kleis B, Bruggemann GP. Influence of a valgus knee brace on muscle activation and co-contraction in patients with medial knee osteoarthritis. *J Electromyogr Kinesiol* 2012;23:490–500.
55. Arazpour M, Bani MA, Maleki M, Ghomshe FT, Kashani RV, Hutchins SW. Comparison of the efficacy of laterally wedged insoles and bespoke unloader knee orthoses in treating medial compartment knee osteoarthritis. *Prosthet Orthot Int* 2013;37:50–7.
56. Jones RK, Nester CJ, Richards JD, Kim WY, Johnson DS, Jari S, et al. A comparison of the biomechanical effects of valgus knee braces and lateral wedge insoles in patients with knee osteoarthritis. *Gait Posture* 2013;37(3):368–72.
57. Della Croce U, Crapanzano F, Li L, Kasi PK, Patritti BL, Mancinelli C, et al. A preliminary assessment of a novel pneumatic unloading knee brace on the gait mechanics of patients with knee osteoarthritis. *PM R* 2013;5(10):816–24.
58. Johnson AJ, Starr R, Kapadia BH, Bhave A, Mont MA. Gait and clinical improvements with a novel knee brace for knee OA. *J Knee Surg* 2013;26:173–8.
59. Larsen BL, Jacofsky MC, Brown JA, Jacofsky DJ. Valgus bracing affords short-term treatment solution across walking and sit-to-stand activities. *J Arthroplasty* 2013;28(5):792–7.
60. Schipplien OP, Andriacchi TP. Interaction between active and passive knee stabilizers during level walking. *J Orthop Res* 1991;9(1):113–9.
61. Chehab EF, Favre J, Erhart-Hledik JC, Andriacchi TP. Baseline knee adduction and flexion moments during walking are both associated with 5-year cartilage changes in patients with medial knee osteoarthritis. *Osteoarthritis Cartilage* 2014;22(11):1833–9.
62. Trepczynski A, Kutzner I, Bergmann G, Taylor WR, Heller MO. Modulation of the relationship between external knee adduction moments and medial joint contact forces across subjects and activities. *Arthritis Rheumatol* 2014;66:1218–27.
63. Meyer AJ, D'Lima DD, Besier TF, Lloyd DG, Colwell Jr CW, Fregly BJ. Are external knee load and EMG measures accurate indicators of internal knee contact forces during gait? *J Orthop Res* 2013;31(6):921–9.
64. Giori NJ. Load-shifting brace treatment for osteoarthritis of the knee: a minimum 2 ½-year follow-up study. *J Rehabil Res Dev* 2004;41(2):187–94.

65. Squyer E, Stamper DL, Hamilton DT, Sabin JA, Leopold SS. Unloader knee braces for osteoarthritis: do patients actually wear them? *Clin Orthop Relat Res* 2013;47:1982–91.
66. Hunter D, Gross KD, McCree P, Li L, Hirko K, Harvey WF. Realignment treatment for medial tibiofemoral osteoarthritis: randomised trial. *Ann Rheum Dis* 2012;71(10):1658–65.
67. Brouwer RW, van Raaij TM, Verhaar JAN, Coene LNJEM, Bierma-Zienstra MA. Brace treatment for osteoarthritis of the knee: a prospective randomized multi-centre trial. *Osteoarthritis Cartilage* 2006;14(8):777–83.
68. Finger S, Paulos LE. Clinical and biomechanical evaluation of the unloading brace. *J Knee Surg* 2002;15:155–9.