

# Footwear and offloading interventions to prevent and heal foot ulcers and reduce plantar pressure in patients with diabetes: a systematic review

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## Abstract

**Background** Footwear and offloading techniques are commonly used in clinical practice for preventing and healing of foot ulcers in persons with diabetes. The goal of this systematic review is to assess the medical scientific literature on this topic to better inform clinical practice about effective treatment.

**Methods** We searched the medical scientific literature indexed in PubMed, EMBASE, CINAHL, and the Cochrane database for original research studies published since 1 May 2006 related to four groups of interventions: (1) casting; (2) footwear; (3) surgical offloading; and (4) other offloading interventions. Primary outcomes were ulcer prevention, ulcer healing, and pressure reduction. We reviewed both controlled and non-controlled studies. Controlled studies were assessed for methodological quality, and extracted key data was presented in evidence and risk of bias tables. Uncontrolled studies were assessed and summarized on a narrative basis. Outcomes are presented and discussed in conjunction with data from our previous systematic review covering the literature from before 1 May 2006.

**Results** We included two systematic reviews and meta-analyses, 32 randomized controlled trials, 15 other controlled studies, and another 127 non-controlled studies. Several randomized controlled trials with low risk of bias show the efficacy of therapeutic footwear that demonstrates to relieve plantar pressure and is worn by the patient, in the prevention of plantar foot ulcer recurrence. Two meta-analyses show non-removable offloading to be more effective than removable offloading for healing plantar neuropathic forefoot ulcers. Due to the limited number of controlled studies, clear evidence on the efficacy of surgical offloading and felted foam is not yet available. Interestingly, surgical offloading seems more effective in preventing than in healing ulcers. A number of controlled and uncontrolled studies show that plantar pressure can be reduced by several conservative and surgical approaches.

**Conclusions** Sufficient evidence of good quality supports the use of non-removable offloading to heal plantar neuropathic forefoot ulcers and therapeutic footwear with demonstrated pressure relief that is worn by the patient to prevent plantar foot ulcer recurrence. The evidence base to support the use of other offloading interventions is still limited and of variable quality. The evidence for the use of interventions to prevent a first foot ulcer or heal ischemic, infected, non-plantar, or proximal foot ulcers is practically non-existent. High-quality controlled studies are needed in these areas. Copyright © 2015 John Wiley & Sons, Ltd.

**Keywords** diabetes mellitus; diabetic foot; foot ulcer; prevention; healing; offloading; footwear; shoes; plantar pressure; surgery; systematic review

**Abbreviations** ATL, Achilles tendon lengthening; CI, confidence interval; NRCT, non-randomized controlled trials; RCT, randomized controlled trial; RR, relative risk ratio

## Introduction

There is a long clinical tradition in the use of casting, footwear, surgical interventions and other offloading techniques to prevent and heal foot ulcers in patients with diabetes. In 2008, we published a systematic review of the available literature on the effectiveness of footwear and offloading interventions [1]. We concluded that sufficient evidence was available to support the use of non-removable offloading techniques to heal plantar forefoot ulcers. We also concluded that more high-quality studies were needed to confirm promising effects of other offloading interventions, so to better inform clinicians and practitioners about effective treatment. We considered the quality of the research performed as of 1 May 2006 used in that review to be of low to moderate quality. The present systematic review assesses the medical scientific literature published since that date on the effectiveness of footwear and offloading interventions to prevent or heal foot ulcers or reduce mechanical pressure in patients with diabetes. The results are used to update the evidence and form the basis for the guidance on footwear and offloading produced by the International Working Group on the Diabetic Foot [2].

## Methods

The systematic review was performed according to the Preferred Reporting Item for Systematic reviews and Meta-Analyses guidelines [3] and was prospectively registered in the PROSPERO database for systematic reviews (CRD42014013647).

The population of interest for this systematic review was patients with diabetes mellitus type 1 or 2, and the clinical problem addressed was a foot ulcer. Primary outcome categories were as follows: ulcer prevention, ulcer healing, and the reduction of mechanical pressure, i.e. offloading. The interventions considered were four groups of techniques used throughout the world in clinical practice:

1. Casting: total contact cast (TCC); cast shoes.
2. Footwear: shoes; insoles; in-shoe orthoses; socks; insole plugs.

3. Surgical offloading: Achilles tendon lengthening (ATL); silicone injections/tissue augmentation; metatarsal head resection; osteotomy/arthroplasty/ostectomy/exostectomy; external fixation; flexor tendon transfer or tenotomy.
4. Other offloading techniques: bed rest; crutches/canes/wheelchairs; bracing (patella tendon bearing, ankle-foot orthoses); (non-)removable walkers; offloading dressings; felted foam/padding; callus debridement; walking exercise; and gait modification.

Each intervention group was defined *a priori*, and the literature was systematically searched for each group separately. Studies on healthy subjects or patients with other diseases than diabetes were not considered. Study designs that were included were systematic reviews and meta-analyses and original research conducted as randomized controlled trials (RCTs), non-randomized controlled trials (NRCTs), case-control studies, cohort studies, controlled before-and-after studies, interrupted time series, prospective and retrospective uncontrolled studies, cross-sectional studies, and case series. Case studies were excluded. Tracking of references in included articles was not performed.

Validation sets of approximately 20 publications were created for each intervention group, including key publications either known to the authors or from references in or to these known key publications. Using these sets, the systematic search was validated; that is, each publication in the set had to be identified in the literature search.

The search was performed on 29 July 2014 and covered references in all languages that were published since 1 May 2006. The following databases were searched: PubMed, EMBASE via Ovid SP, CINAHL, Cochrane Database of Systematic Reviews, Database of Abstracts of Reviews of Effect, Central Register of Controlled Trials, National Health Service Economic Evaluation Database, and Health Technology Assessment Database. The search strings for each database and are shown in Appendices S1–S4. In contrast to our previous systematic review [1], search terms for the search string included three rather than four categories: population, outcome, and intervention; study design was left out of the search string to increase sensitivity in the literature search.

For each intervention group, two members of the working group (i.e. observers) independently assessed records by title and abstract for eligibility for inclusion, based on four criteria: population, intervention, and outcome and now including study design as well. Cohen's kappa was calculated for agreement between observers. Any disagreement on inclusion of publications was discussed between observers until consensus was reached. Publications included in more than one intervention group were discussed among all group members and further analysed

where most appropriate. Subsequently, full-article copies of included publications were obtained and assessed independently on the same four criteria for final eligibility for inclusion.

The same two observers per intervention group independently assessed each controlled study for methodological quality (i.e. risk of bias) using scoring sheets developed by the Dutch Cochrane Centre ([www.cochrane.nl](http://www.cochrane.nl)). Equal weighting was applied to each validity item in the scoring sheet, and only those items rated as '+' contributed to the risk of bias score. The level of evidence of each article was based on study design and total risk of bias score using the Scottish Intercollegiate Grouping Network instrument: level 1 for RCTs and level 2 for NRCTs, case-control, cohort, controlled before-and-after, or interrupted time series studies. Risk of bias was scored for each study as ++ (very low risk of bias), + (low risk of bias), or - (high risk of bias). Any disagreement between observers regarding risk of bias was resolved by discussion until a consensus was reached. Observers did not participate in the assessment and discussion of publications for which they were a co-author to prevent any conflict of interest. In these cases, another observer in the working group assessed the article.

Key data from each controlled study were extracted, summarized in an evidence table, and additionally described on a study-by-study narrative basis. One observer extracted the data; another checked the data. Separate risk-of-bias tables were developed. The evidence and risk-of-bias tables were discussed among all members of the working group. Included level 3 studies, i.e. prospective and retrospective uncontrolled studies, cross-sectional studies, and case series, were also assessed and summarized on a narrative basis.

The evidence table and narrative descriptions were combined with the existing evidence tables and descriptions from our previous systematic review covering the literature from before 1 May 2006 [1]. Controlled studies from before 1 May 2006 were reassessed for risk of bias if deemed necessary. Finally, the two observers per intervention group drew conclusions for each intervention based on the strength of the available evidence. These conclusions were discussed among all members of the working group, and final conclusions based on the available evidence were reached.

## Results

Our literature database search of records since 1 May 2006 identified a total of 666 records for casting, 1171 for footwear, 3300 for surgical offloading, and 3339 for other offloading interventions (see the Preferred Reporting Item for Systematic reviews and Meta-Analyses

flow diagram in Figure 1). Agreement between observers for selecting records based on title and abstract assessment was fair to moderate (Cohen's kappa: 0.24 to 0.66 across intervention groups, Figure 1). We identified two systematic reviews/meta-analyses, 20 RCTs, four other controlled studies, and 54 non-controlled studies for review. This is in addition to the 12 RCTs, eight other controlled studies assessed in our previous systematic review, and three additional controlled studies from before 1 May 2006 that were newly identified [4–6]. Risk of bias scores can be found in Table 1. Key data extracted from the meta-analyses and controlled studies are presented in the evidence table in Table S2. Twelve non-controlled studies from our previous systematic review [7–18] were excluded because they were case studies or otherwise did not fit the scope. Results are presented separately for each outcome and intervention group.

## Ulcer prevention

### Casting

Three non-controlled studies concluded that a non-removable TCC or walker boot can be effective and safe for weight-bearing treatment to prevent ulcers in acute Charcot's neuro-osteoarthropathy [19–21].

### Footwear

We found seven RCTs, four cohort studies, and nine non-controlled studies for analysis on this topic. Because of the large number of relatively recently published controlled studies, we do not report the results of the non-controlled studies [22–30].

Only one controlled study reported exclusively on prevention of a first ulcer. An RCT with low risk of bias including 167 patients showed significantly fewer ulcers and hyperkeratotic lesions at 3 months after the use of one of three types of custom-made digital silicon orthoses in addition to standard care (i.e. sharp debridement, a 'soft' accommodating insole, and extra-depth footwear) compared with standard care alone: 1.1% versus 15.4% for ulcers,  $p < 0.001$ , and 41% versus 84% for hyperkeratotic lesions,  $p = 0.002$  [31].

Two RCTs included patients with and without ulcer history [32,33], but the results were not reported specifically for these groups. An RCT with high risk of bias found in 299 patients, of whom 26% had prior ulcers, that insoles designed to reduce shear stress and worn inside extra-depth therapeutic shoes did not significantly reduce ulcer incidence after 18 months compared with standard insoles that were worn in the same type extra-depth shoes: 2.0% versus 6.7% ( $p = 0.08$ ) [32].

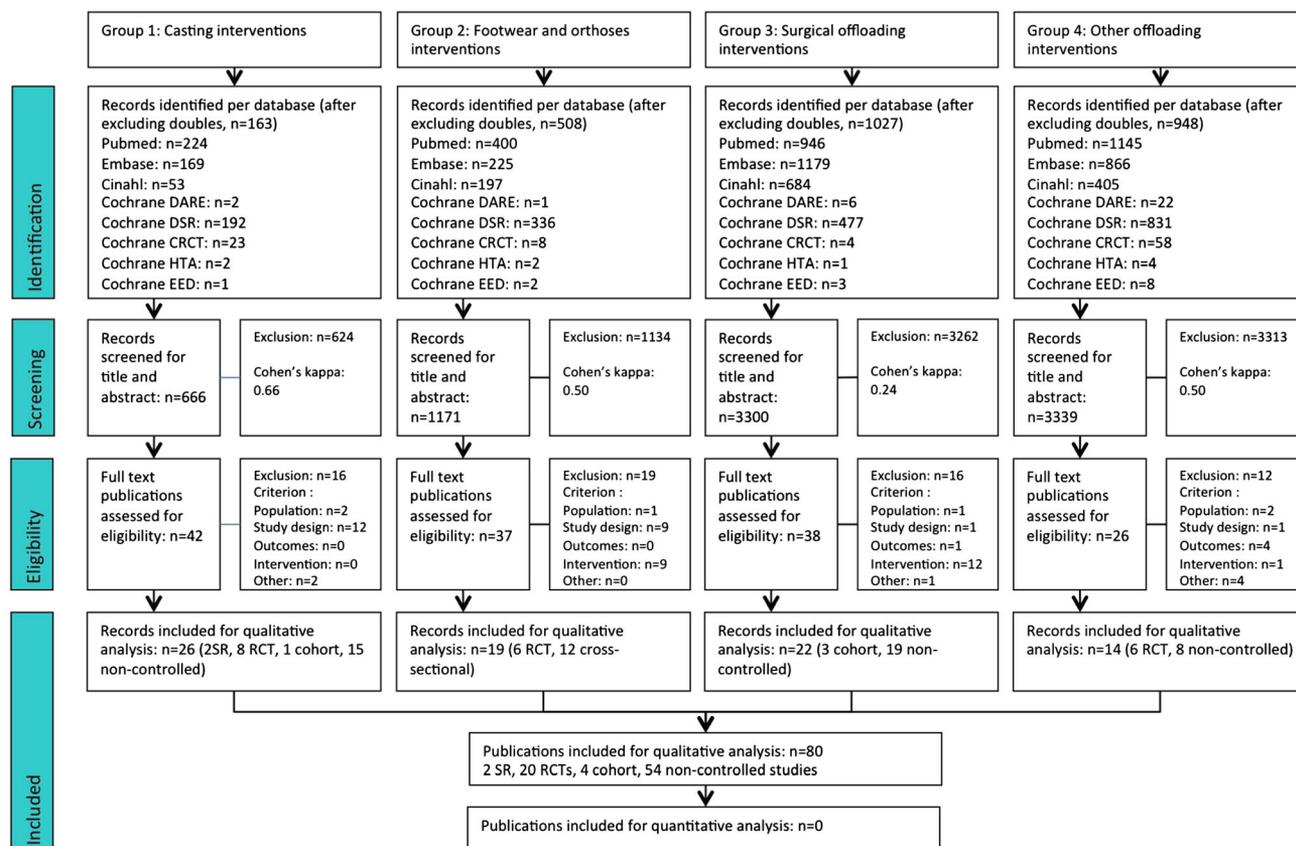


Figure 1. Flow diagram of articles identified in the literature search, screened, found eligible and assessed, for the four different intervention categories

Another RCT with high risk of bias randomized 298 patients (with 46% having neuropathy and deformity, 20% previous ulceration, and 25% previous minor amputation) to intensive footwear therapy based on a prescription algorithm [34] or no footwear prescription [33]. Ulcer incidences at 1, 3, and 5 years were significantly lower in the prescription group (11.5%, 17.6%, and 23.5%, respectively) compared with the non-prescription group (38.6%, 61%, and 72%, respectively,  $p < 0.0001$ ). However, there was a large attrition after 1 year, and several other methodological aspects are not clearly defined (Table S2).

The four other RCTs and four cohort studies assessed patients with ulcer history.

An RCT with very low risk of bias randomized 130 neuropathic patients to two designs of custom insoles. The intervention set was designed on the basis of foot shape and barefoot plantar pressure data in a process of computer-aided design and manufacture, while the other set was designed on the basis of foot shape and standard clinical reasoning [35]. Both sets were worn in extra-depth shoes. The intervention group showed significantly fewer recurrent metatarsal head foot ulcers at 15 months: 9.1% versus 25.0%,  $p = 0.007$ .

An RCT with very low risk of bias in 171 neuropathic patients compared an intervention group who received custom-made footwear that had been iteratively modified to reduce in-shoe plantar pressure at specific at-risk locations to a group who received the same type custom-made footwear that did not undergo such modifications [36]. There was no significant difference in recurrent plantar foot ulcers at 18 months between the intervention and control group: 38.8% vs 44.2%,  $p = 0.48$ . However, in about half of the patients who wore their custom-made shoes for at least 80% of their measured activity, ulcer incidence was significantly lower in the intervention group than control group: 25.7% versus 47.8% ( $p = 0.045$ ).

An RCT with high risk of bias randomized 400 patients (neuropathy present in 58% of them) to therapeutic shoes with customized medium-density cork inserts, to therapeutic shoes with prefabricated polyurethane inserts, or to their own worn footwear [37]. The authors found no significant difference in ulcer recurrence incidence over a 2-year period between therapeutic shoes and control shoes (15% vs 14% and 17%). The methodological quality of this study has been debated [38,39].

An RCT with high risk of bias randomized 69 patients to two different types of footwear. The authors found a significantly lower proportion of subjects with a first or

Table 1. Risk of bias of controlled studies, organized by study design and intervention category

Reference	Clearly defined research question	>1 person select studies + extract data	Comprehensive literature search	States if and how limit by publication type	Review lists included + excluded articles	Characteristic included studies provided	Scientific quality assessed + documented	Scientific quality assessed appropriately	Appropriate methods to combine study results	Likelihood publication bias assessed	Conflicts of interest declared	Score
<b>Systematic reviews</b>												
<i>Casting and (non-)removable offloading</i>												
Lewis and Lipp, 2013	+	+	+	+	+	+	+	+	+	-	-	9/11
Morona et al., 2013	?	?	+	+	-	+	+	+	+	-	+	8/11
<b>Randomized controlled trials</b>												
Reference	Randomization	Independent assignment	Similarity groups	Patient blinded	Care provider blinded	Outcome assessor blinded	Withdrawal/dropout acceptable (<20%)	Intention-to-treat	Patients treated equally except for intervention	Score		
<i>Casting and (non-)removable offloading</i>												
Lavery et al., 2014	+	?	+	-	?	-	-	+	+	4/9		
Miyan et al., 2013	+	?	+	-	-	-	?	-	+	3/9		
Ganguly et al., 2008	+	?	?	-	?	-	+	?	-	2/9		
van de Weg et al., 2008	+	+	-	-	-	+	+	?	+	5/9		
Plaggiati et al., 2007	+	?	+	-	?	-	+	+	+	5/9		
Faglia et al., 2010	+	?	+	-	?	-	+	+	+	5/9		
Caravaggi et al., 2007	+	?	?	-	?	-	+	+	+	4/9		
Gutekunst et al., 2011	+	+	+	-	-	-	+	+	+	6/9		
Armstrong et al., 2001	+	?	+	-	-	-	+	-	+	4/9		
Armstrong et al., 2005	+	+	+	-	-	-	+	+	+	6/9		
Caravaggi et al., 2000	+	?	+	-	-	-	+	?	+	4/9		
Katz et al., 2005	+	?	+	-	-	-	+	+	+	5/9		
Mueller et al., 1989	+	?	+	-	-	-	-	+	+	4/9		
<i>Footwear and orthoses</i>												
Lavery et al., 2012	?	?	+	-	+	-	?	+	+	4/9		
Rizzo et al., 2012	+	?	+	-	-	-	-	-	+	3/9		
Scire et al., 2009	+	?	+	-	-	+	+	+	+	6/9		
Paton et al., 2012	+	+	+	+	-	-	+	+	?	6/9		
Uccioli et al., 1995	+	?	+	-	-	-	?	?	+	3/9		
Ulbrecht et al., 2014	+	+	+	+	-	+	-	+	+	7/9		
Bus et al., 2013	+	+	+	-	-	+	+	+	+	7/9		
Reiber et al., 2002	+	?	+	-	-	+	+	?	+	5/9		
<i>Surgical interventions</i>												
Mueller et al., 2003	+	+	+	-	-	?	+	-	+	5/9		
Plaggiati et al., 1998	+	?	+	-	-	-	+	+	+	5/9		
Maluf et al., 2004	+	?	+	-	-	-	+	-	+	4/9		
Van Schie et al., 2000	+	-	+	+	-	+	+	+	+	7/9		
<i>Other offloading interventions</i>												
Zimny et al., 2003	+	-	+	-	-	-	-	?	+	3/9		
Hastings et al., 2012	+	+	+	+	+	+	+	+	+	9/9		

(Continues)

Table 1. (Continued)

Reference	Study groups clearly defined	Selection bias avoided/excluded	Intervention clearly defined	Outcome clearly defined	Outcome assessed blind for exposure	Withdrawal/dropout acceptable (<20%)	Selective loss to follow-up excluded	Major confounders/prognostic factors identified/controlled	Score
Non-randomized controlled trials									
<i>Casting and (non-)removable offloading</i>									
Black, 1990	-	?	-	-	?	+	?	+	2/9
Cohort studies									
<i>Casting and (non-)removable offloading</i>									
Udovichenko et al., 2006	+	-	+	+	-	+	-	-	4/8
Agas et al., 2006	+	?	+	+	-	?	?	?	3/8
Ha Van et al., 2003	+	-	+	+	-	+	+	-	5/8
<i>Footwear and orthoses</i>									
Reike et al., 1997	+	-	+	+	-	-	?	-	3/8
Busch and Chantelau, 2003	+	-	+	-	?	+	+	?	4/8
Viswanathan et al., 2004	?	-	+	-	-	?	?	-	1/8
Dargis et al., 1999	+	+	?	+	-	+	?	-	4/8
Birke et al., 2002	+	-	+	?	-	+	?	+	4/8
<i>Surgical offloading</i>									
Armstrong et al., 2005	+	-	+	+	?	?	?	-	3/8
Armstrong et al., 2003	+	-	+	+	?	-	?	-	2/8
Armstrong et al., 2012	+	?	+	+	-	+	+	+	6/8
Vanlerberghe et al., 2014	-	?	+	-	-	+	+	?	3/8
Faglia et al., 2012	+	-	+	+	-	-	?	-	3/8
Case-control studies									
<i>Surgical offloading</i>									
Lin et al., 2000	+	+	-	+	+	-	-	-	4/7

recurrent ulcer over a 1-year period in those who had worn therapeutic shoes compared with those who continued to use their own shoes: 27.7% versus 58.3%,  $p = 0.009$  [40].

One cohort study with high risk of bias including 241 patients found that the use of therapeutic sandals resulted in significantly fewer recurrent ulcers at 9 months compared with wearing sandals with a hard leather board insole [41]. Another cohort study with high risk of bias found 15% recurrence in 62 patients who were beneficiaries of prescribed diabetic footwear compared with 60% recurrence in 30 patients who were not reimbursed and therefore wore their own footwear ( $p < 0.001$ ) [4]. A cohort study with high risk of bias including 46 patients found no significant difference in ulcer recurrence at 2 years between patients accepting a prescription of orthopaedic footwear and patients not accepting the prescription but continuing to wear their own shoes [5]. A cohort study that compared education and treatment including therapeutic footwear, with treatment at a different clinic that did not include therapeutic footwear found a significantly lower incidence of foot ulcers at 2 years in favour of the therapeutic footwear intervention [42]. In each of these cohort studies, selection bias may have influenced the outcome.

## Surgical offloading

We identified two RCTs, six other controlled studies, and 27 non-controlled studies for analysis on this topic, all examining the effect on ulcer recurrence after using the procedure for primary healing. Four studies on flexor tenotomy, in addition, examined the prophylactic effect on ulcer occurrence in patients without an active foot ulcer.

### *Achilles tendon lengthening*

An RCT with low risk of bias randomized 63 patients with limited ankle dorsiflexion to ATL in addition to TCC or to TCC alone and found after 7 months follow-up significantly fewer recurrent ulcers in the ATL group than in the TCC-alone group (15% vs 59%,  $p = 0.001$ ), an effect that persisted at 2 years: 38% versus 81%,  $p = 0.002$  [43].

One non-controlled retrospective study found 2% recurrence at a mean 3 years follow-up in 138 patients treated with ATL compared with 25% in a historic cohort of 149 patients treated with wound closure surgery ( $p < 0.001$ ) but found significantly more transfer lesions (12% vs 4%,  $p = 0.001$ ) [44]. Several other non-controlled studies show recurrence rates between 0 and 20% over 17 to 48 months follow-up after ATL treatment [45–49].

### *Single or pan-metatarsal head resection*

An RCT with low risk of bias randomized 41 patients to either surgical excision of the ulcer, eventual debridement

and removal of bone segments underlying the lesion, and surgical wound closure, or to conservative treatment (i.e. relief of weight-bearing and regular dressing) and found a significant reduction in ulcer recurrence at 6 months follow-up in the surgical group: 14% vs 41%,  $p < 0.01$  [50].

A retrospective cohort study with high risk of bias including 207 patients compared surgical bone removal of the toe or metatarsal head with minor amputation of the toe and found no significant difference between groups for ulcer recurrence after a mean of 40.6 months follow-up [51]. Another retrospective cohort study with high risk of bias including 50 patients demonstrated a lower recurrence rate at 6 months follow-up of single metatarsal head resection compared with conservative treatment ('aggressive off-loading'): 5% versus 28%,  $p = 0.04$  [52]. Another retrospective cohort study with low risk of bias including 92 patients also demonstrated lower recurrence rates at 1 year follow-up of pan-metatarsal head resection compared with conservative treatment: 15.2% versus 39.1%,  $p = 0.02$  [53].

One prospective and four retrospective non-controlled studies on the effect of pan-metatarsal head resection, including between 10 and 119 patients, reported between 0% and 41% recurrent ulcers after a mean of 13 to 74 months follow-up [54–58].

### *Joint arthroplasty*

One retrospective cohort study with high risk of bias including 41 patients found a 5% recurrence at 6 months follow-up in patients treated with metatarsophalangeal joint arthroplasty of the great toe compared with 35% in patients treated with (non-)removable offloading for their active ulcer ( $p = 0.02$ ) [59]. A case-control study reported no ulcer recurrence at the site of interest after 1-year follow-up with either metatarsal-phalangeal joint arthroplasty or TCC [60].

Three small non-controlled studies found 0–17% recurrent ulcers at 1 to 5 years follow-up in patients who underwent either interphalangeal joint arthroplasty or resection of the proximal phalanx of the great toe [61–63].

### *Osteotomy*

A retrospective cohort study with high risk of bias showed that subtraction osteotomy distal to metatarsal head ulcers to redress the bone alignment, plus arthrodesis, resulted in a significantly lower rate of combined recurrence and amputation when compared with conservative treatment (7.5% vs 35.5%,  $p = 0.0013$ ), although data on recurrent ulcers alone was not significantly different between groups (7.5% vs 18%,  $p = 0.14$ ) [64]. Conservative treatment was not clearly defined. One non-controlled study found no recurrent ulcers during 13 months of follow-up in 21 patients who underwent osteotomy [65].

### Digital flexor tenotomy

Seven retrospective case series showed ulcer recurrence rates between 0% and 20% in 11 to 36 months follow-up in a cumulative total of 231 patients treated with percutaneous digital flexor tendon tenotomy [66–72]. Four of these studies showed no ulcer occurrence during a mean of 11–31 months follow-up in a cumulative total of 58 patients with an impending ulcer (i.e. abundant callus on tip of the toe) that were treated prophylactically with this procedure [68–70,72].

### Other procedures

Several non-controlled studies showed relatively low ulcer recurrence rates in selected patients following any of several surgical procedures: flexor hallucis longus tendon transfer, plantar fascia release, or Achilles tenotomy [73–76]. Exostectomy appears to result in a large percentage of recurrent or transfer ulcers [77].

## Ulcer healing

### Casting/(non-)removable offloading devices

Two systematic reviews and meta-analyses, 13 RCTs, four other controlled studies, and 33 non-controlled studies were identified for this topic. Because of the presence of two meta-analyses, we will not separately report the results of the RCTs, other controlled studies [78–81], or non-controlled studies [6,22,82–112].

Two high-quality meta-analyses show that non-removable offloading (either TCC or walkers rendered irremovable) more effectively heals neuropathic plantar forefoot ulcers than removable offloading (either walkers or footwear) [113,114]. One meta-analysis included five RCTs [115–119] with a cumulative total of 230 patients and found a relative risk ratio to achieve healing of 1.17 [95% confidence interval (CI) 1.01–1.36,  $p = 0.04$ ] for non-removable offloading [114]. The other meta-analysis, which included ten RCTs and non-randomized clinical studies with a cumulative total of 524 patients [79,80,115–117,119–123] showed a relative risk ratio to achieve healing of 1.43 (95% CI 1.11–1.84,  $p = 0.001$ ) for non-removable offloading [113]. Stratified by type of removable device, five RCTs [115–117,119,123] showed a trend but not a statistically significant difference between non-removable and removable knee-high devices (RR = 1.23, 95% CI 0.96–1.58,  $p = 0.085$ ) [113]. Two RCTs suggest that the TCC is more effective in healing than providing no pressure relief at all [120,124]. Six studies [79,80,116,120–122] show that non-removable offloading promotes healing significantly better than therapeutic or half shoes (RR 1.68;

95% CI 1.09–2.58;  $p = 0.004$ ) [113]. Two relatively small RCTs [118,125] show that a removable walker rendered irremovable is as effective as a TCC in healing neuropathic plantar forefoot ulcers (RR = 1.06; 95% CI 0.88–1.27;  $p = 0.31$ ) [113]. There is no evidence of a difference in side effects or foot infections with using non-removable or removable devices [113,114].

Two recent RCTs, both with high risk of bias, were not included in the two meta-analyses. One RCT, including 73 patients, showed that a TCC healed a significantly higher proportion of neuropathic plantar forefoot ulcers than a removable walker with shear-reducing footbed, and it healed ulcers significantly faster than a healing shoe with 8-mm Plastazote® inlay [126]. The other RCT, including 70 patients, showed no significant difference in healing neuropathic plantar forefoot ulcers between a modified TCC with plywood platform, a Scotchcast® boot, and a modified footwear sandal [127].

## Footwear

One RCT, one cohort study, and three non-controlled studies were identified that had shoes as primary treatment modality to heal plantar foot ulcers.

One RCT with low risk of bias randomized 43 patients, many of whom had moderate peripheral artery disease, to either custom-made temporary shoes or TCC for healing relatively large and deep ulcers, some with mild infection. The study found healing proportions of 30% and 26% at 16 weeks, respectively, and non-significant differences in reduction in ulcer area between groups [121].

One retrospective cohort study with high risk of bias including 120 patients showed no significant difference in the proportion of forefoot ulcers healed at 12 weeks, or time to healing, between a post-operative shoe with quarter-inch foam inlay, a relief cut under the ulcer area, and a wedged outsole, or a TCC (81% in 32.7 days *versus* 92% in 31.7 days, respectively) [6].

A non-controlled study including patients with mostly Wagner grade 2 or 3 forefoot ulcers showed that in those treated with half shoes and use of crutches, 96% healed in a median of 70 days, compared with a historic cohort of patients instructed to completely offload the foot at home with crutches or wheelchair, in which 59% healed in a median 118 days [128].

Another non-controlled retrospective study of patients with Charcot's neuro-osteoarthropathy showed that ulcers present under a rocker-bottom midfoot deformity took a median 7 months to heal using crutches and therapeutic sandals with rigid rocker-bar outsoles, compared with 4 months for ulcers located elsewhere; 37% of patients required surgical intervention to heal [129]. Another non-controlled study showed that by the use of

properly fitted interchangeable insoles, 97% of neuropathic ulcers present in 21 patients healed in a mean of 3.6 months [130].

## Surgical offloading

We identified two RCTs, five other controlled studies, and 40 non-controlled studies on this topic.

### *Achilles tendon lengthening*

One RCT with low risk of bias including 63 patients with plantar forefoot ulceration and limited ankle dorsiflexion (i.e.  $\leq 5^\circ$ ) found no significant difference in healing between those patients treated with ATL in addition to TCC *versus* those who received TCC alone: 100% healing in 41 days *versus* 88% healing in 58 days, respectively [43].

Two non-controlled retrospective studies showed that in patients with reduced ankle dorsiflexion range of motion after non-successful healing with a standard offloading regime (TCC or removable walker), 91–93% of plantar forefoot ulcers healed with ATL in a mean of 6 to 12 weeks [46,48]. Other non-controlled studies confirm these findings for selected patients with limited ankle dorsiflexion and metatarsal head or midfoot plantar ulcers [47,49].

### *Single or pan-metatarsal head resection*

An RCT with low risk of bias including 41 patients showed higher healing rates and shorter time to healing of forefoot plantar ulcers for a combination of surgical excision, debridement, removal of bone segments underlying the lesion, and surgical closure when compared with conservative offloading treatment, 95% in 47 days *versus* 79% in 129 days ( $p < 0.05$ ), although conservative offloading did not involve the current standard of care (TCC) [50].

A retrospective cohort study with high risk of bias including 50 patients with recalcitrant plantar ulcers showed that fifth metatarsal head resection was as effective as offloading treatment, both 100% healing rate, but resulted in shorter time to healing (maximum 5.8 *vs* 8.7 weeks) [52]. A retrospective cohort study with low risk of bias evaluated 92 patients with multiple plantar forefoot ulcers and showed that those treated with pan-metatarsal head resection healed significantly faster (mean 60.1 *vs* 84.2 days,  $p = 0.02$ ) than those treated with 'aggressive offloading' (which was not defined) [53]. Results of six non-controlled studies of patients treated with single or pan-metatarsal head resection after failed conservative treatment showed between 88% and 100% healing [54,55,57,58,131,132].

### *Joint arthroplasty*

Two small retrospective cohort studies with high risk of bias studied the efficacy of first metatarsal-phalangeal joint arthroplasty in comparison to knee-high (non-) removable offloading to heal plantar hallux ulcers and showed no difference between treatments in the proportion of ulcers healed but a significantly shorter time to healing with arthroplasty: mean 24.2 *versus* 67.1 days in one study [59], and maximum 23 *versus* 47 days in the other [60]. Three non-controlled studies showed between 91% and 100% healing of plantar, lateral, or dorsal toe ulcers using interphalangeal or metatarsal-phalangeal joint arthroplasty [62,63,133].

### *Exostectomy*

Four non-controlled studies found relatively high percentages of healing in patients with rigid, prominent deformities secondary to Charcot's neuro-osteoarthropathy after exostectomy [77,134–136].

### *Osteotomy*

In a retrospective cohort study with high risk of bias, 22 patients treated with osteotomy of the bone plus arthrodesis just distal to the metatarsal head ulcer healed in 51 days, with a 2.5% amputation rate, compared with 54 patients treated conservatively (not defined) who healed in 159 days, with 15% amputation rate [64]. Three non-controlled studies reported healing percentages between 94% and 100% for metatarsal osteotomies performed in patients with recalcitrant or frequently recurring neuropathic foot ulcers [65,137,138].

### *Digital flexor tenotomy*

In seven retrospective case-series studies, a 92–100% healing rate in a mean time to healing of 21 to 40 days, and a low rate of complications, was found in a cumulative total of 231 patients treated with percutaneous digital flexor tenotomy to heal apex toe ulcers [66–72].

### *Other procedures*

Non-controlled case series of other selected surgical procedures such as Achilles tenotomy [76], flexor hallucis tendon transfer [74,75], plantar fascia release [73], calcanectomy [139–141], silicone injections [142], and surgical reconstruction [143,144] or external fixation [145,146] of Charcot deformity, or a combination of gastrocnemius recession, peroneus longus tendon transfer, and metatarsal head resection [56] suggest that these techniques may have value in promoting wound healing in selected cases.

## Other offloading interventions

Studies on the efficacy of bed rest and the use of crutches, canes, or wheelchairs to heal foot ulcers were not identified. The effects of bracing and felted foam were studied in two RCTs, two cohort studies, and two non-controlled studies.

### *Felted foam*

An RCT with high risk of bias randomized 54 patients to either felted foam worn in a post-operative shoe or to a pressure relief half shoe and found a significantly shorter time to healing of 10 days in the felted foam group [147]. Another RCT with high risk of bias in 32 patients considered felt fitted directly to the foot compared with felt fitted to the insole of a therapeutic shoe. No difference between the groups in the number of ulcers healed in 14 weeks or time to healing was found [148]. In a retrospective cohort analysis, a quarter-inch-thick adhesive felt pad worn in a wedged-soled post-operative shoe was reported to be as effective as a TCC in both proportion healed ulcers and time to healing [6].

### *Ankle-foot orthoses*

In a small NRCT with high risk of bias, the use of a foot and ankle walking brace did not lead to higher healing proportions than topical ulcer care, but the study may have been underpowered [78]. Additionally, two case series of patients with recalcitrant plantar ulceration showed that treatment with an ankle-foot orthosis or a modified Charcot Restraint Orthotic Walker can result in healing within 12 weeks [149,150].

## Plantar pressure reduction

### Casting and (non-)removable walkers

One RCT and eight cross-sectional studies were identified for this topic. One RCT compared in-cast pressure measurements of the TCC with a removable walker in 23 patients with active neuropathic plantar foot ulcers [123]. The walker yielded a significantly greater peak pressure reduction at the midfoot (77% vs 63% for the TCC in pressure relief compared with barefoot walking) and forefoot (92% vs 84%). The TCC healed 82% of ulcers compared with only 42% in the removable cast walker, which may be explained by a difference in adherence.

Different cross-sectional studies showed removable walkers to be as effective as TCCs and more effective than forefoot offloading or extra-depth shoes in offloading the forefoot [151,152]. The heel region seems best offloaded with a TCC, then a removable walker, and then depth-inlay shoes [153]. In another study, a TCC can reduce

peak pressure at the ulcer site (of which half were at the midfoot or heel) with 55% when compared with the patient's own, non-orthopaedic, shoes [85]. Modifying a TCC by adding a 12 mm Poron® layer under the foot further improved offloading (70% peak pressure relief compared with canvas shoe *versus* 44% relief for a conventional TCC) [154]. In one study, applying a window in a cast shoe for local wound treatment of the ulcer did not seem to increase pressure at the edges of the window [155].

In one comparative study, a post-operative shoe showed lower peak plantar pressures for the midfoot and forefoot regions than high-cut and low-cut vacuum walkers [156]. A similar study comparing the same low-cut vacuum walker with a forefoot offloading shoe showed both offloading modalities to significantly reduce forefoot peak pressures compared with standard footwear (41–56% reduction) [157]. Another study examined three different heights of removable walkers for their offloading capabilities and found that all walkers performed significantly better than a training shoe and peak pressures were progressively lower with higher-cut devices, although this latter effect was not large and the effects on pressure-time integral were similar between low-cut and high-cut walkers [158].

## Footwear

One RCT and 27 predominantly cross-sectional studies investigating a variety of interventions were identified for this topic. The RCT, with low risk of bias, randomized 109 patients to either over-the-counter insoles or custom-made insoles that were designed by a single individual according to a defined protocol [159]. There were no significant differences between groups in regional peak pressure either at baseline or at 6 months follow-up.

Shoes with a rocker-bottom outsole are reported to be effective in reducing forefoot peak pressures [160–162]. Also, forefoot offloading shoes effectively offload the forefoot [163] and more effectively than accommodative felt and foam dressings worn in a post-operative sandal or post-operative shoes alone [152]. A shoe with removable insole plugs can provide significantly more offloading than a control shoe or the patients' own shoes [164]. Using an insole with removable plugs and an arch support can provide even further pressure relief when compared with just using insoles with removable plugs or basic flat insoles [165].

A series of studies show that custom-moulded insoles or orthoses more effectively offload the foot than non-custom-made insoles [151,166–176]. Shoes with flat insoles showed to be less effective than shoes with custom-made

insoles [173,177], even though the use of polyurethane foam sheets inside the patients' own shoes can improve offloading compared with wearing standard shoes [178]. Custom-made insoles designed on the basis of foot shape and plantar pressure profile of the patient provide significantly more offloading than custom insoles that are designed on the basis of foot shape alone [179]. With the use of in-shoe plantar pressure measurement as a tool to guide modifications to custom-made insoles and shoes, significantly more offloading can be achieved [180]. Metatarsal pads, used either alone or in combination with a medial longitudinal arch support, provide a significant pressure relief compared with not using these elements, but this is critically dependent upon placement; pads may actually increase plantar pressure if placed incorrectly [176,181,182]. Two studies have examined long-term pressure relief provided by insoles [183,184]. Peak pressures with these insoles were found to be higher after the subject took 50 000 steps. Most insole compression occurred during the initial 6 months of wear, and compression did not appear to change between 6 and 12 months.

The results for studies of offloading provided by padded hosiery are not conclusive.

## Surgical offloading

Two RCTs and another two non-controlled studies were identified for this topic. One RCT with low risk of bias compared the pressure-reducing effect of regular liquid silicone injections with saline injections under callused metatarsal heads and found significantly reduced peak plantar pressures in the silicone group at 12 months, but not at 24 months follow-up [185]. In a subset analysis of a larger RCT [43], peak plantar forefoot pressures were evaluated in patients subjected to ATL + TCC treatment or to TCC alone [186]. The study showed significant pressure reductions post-ATL, but these reductions were not sustained at 8 months follow-up.

Uncontrolled studies suggest that ATL and metatarsal head resections effectively reduce pressure in the forefoot [131,187].

## Other offloading interventions

Five RCTs related to alteration of plantar pressure by influencing leg muscle strength and/or the patient's gait were identified. An RCT with low risk of bias explored a 24-week exercise program aiming to increase leg strength and reduce plantar pressure, but the authors did not observe a significant difference compared with a control group [188]. Another RCT with low risk of bias conducted a similar program for 12 weeks, which also found no

significant changes to forefoot plantar pressure [189]. One RCT with high risk of bias that investigated the effect of a 12-week program of backward walking exercises on plantar pressure provided no conclusive evidence [190]. None of the previous studies reported the type of footwear used. In a pilot RCT with very low risk of bias, botulinum toxin injection showed no effect on plantar pressure during walking [191].

An RCT with high risk of bias used plantar pressure feedback in a single session to train patients to adapt their walking to achieve pressure reduction [192]. The limited changes measured on the training days were not sustained during measurements 1 week later. Two non-controlled studies showed a significant pressure reduction of 27–32% on the day of training, which was maintained after 10 days through plantar pressure feedback [193,194].

In two cross-sectional studies, callus removal has been reported to have a beneficial effect on the reduction of plantar pressure [195,196].

## Discussion

For this systematic review on footwear and offloading, two systematic reviews and meta-analyses, 32 RCTs, 15 other controlled studies, and 127 non-controlled studies were included and described. The risk of bias table (Table 1) shows that the methodological quality of the studies varied, with 17 RCTs having low risk of bias and 15 having high risk of bias. Most of the published RCTs have investigated the healing of plantar foot ulcers, reflecting the central role that offloading plays in this context. Regarding prevention, most RCTs were on the use of therapeutic footwear to prevent ulcer recurrence, reflecting its important role in this context. We found several high-quality studies in both these areas allowing us to draw relevant conclusions about effect. Studies on other interventions were limited in number, and the quality varied greatly. Clinicians should therefore be cautious in interpreting the results from these studies. In several important areas, such as prevention of a first or a non-plantar foot ulcer and healing of more ischemic or infected foot ulcers, hardly any evidence is available.

## Ulcer prevention

Recurrence of a foot ulcer remains a major problem in people with diabetes [36,197]. The results of several recent RCTs on the efficacy of therapeutic footwear suggest some underlying principles to guide footwear prescription in patients with prior ulcers. One study has shown that prescription of custom-made footwear results in fewer ulcers than no footwear prescription [33]. While this is

something that most clinicians will find obvious, there is at least evidence that now supports this basic tenet of foot care. Another RCT has shown that one clinician's design for a custom insole was not superior in reducing plantar pressure compared with an off-the-shelf product [159]. While limited in its generalizability, this study is important because it demonstrates that simply providing the patient with 'a custom-made insole' does not guarantee improving the mechanical environment for the foot. Two studies have demonstrated that directly measuring the plantar pressure under the foot, in contrast to just using foot shape and clinical opinion, can improve the efficacy of the resulting footwear [35,36]. In one case, an algorithm based on foot shape and barefoot plantar pressure was used in orthotic design [35], while the second study used in-shoe plantar pressure to guide the adjustment of the foot–shoe interface to lower pressure in key 'at-risk' regions of the foot [36]. The final piece of new information that has emerged contains important, if perhaps obvious, lessons for research and clinical practice: good footwear is only effective if it is worn by the patient for most of their steps in a day [36]. Some of the contrasting results seen between the more recent and the older studies of footwear effectiveness are likely to be the result of the wide diversity of interventions and control conditions investigated in these studies, as well as the lack of knowledge of unloading efficacy in some older studies [4,5,37,40], which is not always measured in advance of prescription. This lack of standardization complicates the comparison of studies. However, the development and documentation of more standard procedures in recent years have greatly improved our understanding on the efficacy of therapeutic footwear to prevent ulcer recurrence in diabetes.

Several surgical offloading techniques, such as ATL, joint arthroplasty, single or pan-metatarsal head resection, and other bone resections, appear to reduce the risk of ulcer recurrence in selected patients with forefoot neuropathic plantar ulcers when compared with conservative offloading treatment. Several other surgical offloading procedures, in particular digital flexor tendon tenotomy, may be promising to prevent recurrence, or even a first ulcer. However, with most of these procedures, often only one RCT or controlled study has been performed. Furthermore, nearly all studies focus primarily on ulcer healing, not on the prevention of recurrence. Additionally, the disadvantages and potential complications of surgical interventions should always be taken into consideration. Some studies report problems with gait and other functional tasks and the risk of heel ulceration with ATL [46,198,199]. Others report risk of transfer ulcers, soft tissue infections, and acute Charcot's neuro-osteoarthropathy [46,57,65,132,137]. Clearly, more high-quality controlled studies are needed before more definitive statements

can be made about the efficacy and safety of preventative surgery.

## Ulcer treatment

Evidence from two recent, high-quality systematic reviews and meta-analyses shows that non-removable offloading heals a higher proportion of neuropathic plantar forefoot ulcers, at a faster rate, than removable offloading, without leading to a higher incidence of complications or side effects [113,114]. Non-removable offloading may consist of either a TCC or a removable walker rendered irremovable, because both approaches show equally effective outcomes. This implies that centres no longer have to rely only on what has long been considered the gold standard treatment, the TCC, but that they now have the option to use prefabricated modalities with an appropriate foot–device interface. This helps in settings where casting is not available or not of sufficient quality. Interestingly, one RCT also showed that patients wearing a TCC reduce ambulatory activity, which may contribute to effective healing in TCC [116]. This suggests that activity measurements should ideally be part of healing studies on offloading devices. While the evidence base to support the TCC for ulcer healing is quite strong, studies have shown that clinical practice does not follow these evidence-based guidelines [200,201].

On the basis of one RCT and mostly non-controlled studies, cast shoes, forefoot offloading shoes, and custom-made temporary shoes show to promote healing of neuropathic plantar ulcers. However, confirmation of their effect in prospective controlled studies is needed, before they can be recommended for more widespread use. While commonly used in clinical practice [202], the evidence base for the use of felted foam for healing neuropathic plantar forefoot ulcers remains weak, mostly because studies fail to apply the correct study design to assess the effect of felted foam under controlled offloading conditions (footwear or cast).

In healing plantar forefoot ulcers, ATL seems to have limited value in addition to the TCC alone. The evidence also indicates that most other surgical options do not improve the proportion of healed ulcers; they only improve time to healing. In fact, based on the available evidence, it seems that compared with conservative treatment, many surgical offloading procedures are more effective in preventing ulcer recurrence than they are in healing foot ulcers, even though they primarily target ulcer healing. Therefore, these procedures may have more value in prevention than in healing. Another consideration is the potentially higher risk for complications with surgery, even though some procedures, like digital flexor tenotomy, show very little risk of side effects in multiple

case series. High-quality controlled studies, preferably a multi-centred RCT, are needed to further define the role of surgical approaches compared with conservative treatment.

## Plantar pressure reduction

An exploration of plantar pressures in offloading treatment is useful because it provides a perspective on the level of pressure reduction that is required for healing and prevention of foot ulcers. TCCs and removable walkers are very effective in offloading ulcer sites and other high pressures regions in midfoot and forefoot. This effective offloading is likely important for plantar foot ulcer healing using these devices, together with the non-removable nature of the intervention [203]. However, studies that consider the healing of foot ulcers in direct association with measured offloading are needed to further improve our confidence in the role of offloading in ulcer healing. Within this context, it is noted that the threshold for offloading required to adequately heal neuropathic plantar foot ulcers is currently unknown.

The mechanical effect of therapeutic footwear relies on plantar pressure reduction at at-risk areas by a transfer of load to other regions. Mechanical pressure from footwear is also likely to play a role both in causing and preventing *non-plantar* ulcers. Significant pressure reduction can be achieved with footwear with a rocker-bottom outsole, a custom-moulded insole, and the addition of metatarsal pads or bars and arch support to the insole, but also from the systematic use of plantar pressure measurements in design and evaluation of footwear. These effects should be considered when designing therapeutic footwear for ulcer prevention, with the aim to reach more standardized prescription routines for better offloading footwear.

The findings on surgical approaches such as silicone injections or ATL suggest that these interventions may only have a temporary effect. Efficacy of the long-term use of these approaches is still in question. The adverse biomechanical effects of other surgical procedures are unintended increases in pressure in non-target areas of the foot and therefore should be carefully considered. There is no evidence to support the use of botulinum toxin injections to reduce calf muscle strength and forefoot plantar pressure. Additionally, there is currently no evidence for offloading effects of various exercise approaches and muscle strength training. Questions around adherence to exercise, or a lack of effect in terms of strength, may relate to these findings, and progress in the area may require advances in home-based monitoring and coaching.

## Other considerations

Several issues related to the findings and conclusions in this systematic review should be considered.

1. Effectiveness in ulcer prevention and healing is always likely to be confounded by the level of patient adherence to treatment. Even the best offloading device will not be effective if not worn. Studies in diabetic patients have reported that patients wear their prescribed footwear or offloading device only a limited percentage of the total ambulatory time or steps made [204–207]. However, there are now clear and objective indications that those who do not adhere to wearing their offloading device or therapeutic footwear will present with significantly worse outcomes [36,113,114]. While non-removable devices can overcome this problem for ulcer healing, these devices also have disadvantages. Furthermore, there is still much to learn regarding ways to encourage patients to adhere to their prescribed treatment. Offering more attractive or specific offloading footwear for indoor use and improving the perception of footwear benefits or acceptance of wearing therapeutic shoes may help in this regard [206,208–210]. Ways to improve adherence and to encourage patients to adhere should receive immediate attention from clinicians and researchers.
2. We acknowledge the difficulties inherent in the design of trials involving surgical procedures. Regional variations in equipment, technique, and surgical practice, and the fact that surgical intervention is often a last resort intervention after failed healing with conservative methods, make RCTs more challenging in surgery than in other interventions in this area. For this reason, we accept that foot ulcer healing and prevention of recurrence may be suitable endpoints for other study designs, although multicentre RCTs or robust case-control or cohort designs provide the best evidence.
3. The available evidence almost exclusively focuses on non-complicated neuropathic plantar forefoot ulcers. Little information exists on the efficacy to heal non-plantar ulcers, even though such ulcers are common [211]. Additionally, few studies include ulcers proximal to the forefoot, even though these ulcers also require adequate offloading and are often difficult to heal. In addition, we identified only one research study on offloading ulcers that are complicated by infection or ischemia [100]. While such complicated ulcers often require adjunctive treatment to reduce infection or ischemia, they still require offloading to promote healing. High-quality studies on ulcers other than the neuropathic plantar forefoot ulcer are urgently needed to better inform clinicians about effectively offloading such ulcers.
4. Even though the costs of footwear and offloading may be substantial, studies on cost-effectiveness are not present in the literature. Especially with surgical offloading or when coupled with the use of plantar pressure measuring devices [35,36], it is important

that such costs are viewed with respect to treatment effect and total costs of ulcer care, including potential risk of infection and amputation. The direct costs of caring for a patient with a foot ulcer are substantial [212,213]. Therefore, there is much to be gained from prevention and non-complicated healing. We suggest that the issue of costs should always be considered in RCTs on footwear and offloading.

5. A major obstacle in comparing studies is the persistent lack of standardization in terminology, prescription, manufacture, and material properties of footwear and offloading devices. While initiatives to achieve more standardization should be employed, as a minimum, we urge authors to provide detailed descriptions of the devices tested in their studies.
6. Our choice to include only studies that included people with diabetes in this systematic review has prevented drawing any conclusions on interventions that were effective in other patient groups or in healthy people and that may potentially be effective in the diabetic population. We support the testing of interventions in the intended target population and thus urge clinical researchers to study such promising interventions in the diabetic population.
7. The majority of published studies in this systematic review are from economically more developed countries, most of which have relatively mild temperate climates. There is a need for studies and build-up of evidence on optimal approaches to ulcer prevention and healing in less economically developed countries, and those where climate may be a factor in adherence to, or efficacy of, treatment.

## Conclusions

This systematic review shows that the evidence base to support the use of footwear and offloading interventions has improved substantially in several areas over the last years but is still small or non-existent in other areas. The best available evidence is for the use of non-removable devices, either TCC or walkers renders irremovable, for the healing of neuropathic plantar forefoot ulcers. Additionally, high-quality recent evidence supports the use of therapeutic footwear that has a demonstrated reduction in plantar pressure and that is consistently worn by the patient to prevent plantar foot ulcer recurrence.

The evidence base to support the use of interventions that prevent a first foot ulcer and prevent or heal non-plantar foot ulcers or ischemic or infected ulcers is practically non-existent. Furthermore, no definitive statements can yet be made regarding the efficacy and safety of surgical interventions to heal foot ulcers or to prevent recurrence, because of the limited number of RCTs and

other controlled studies that overcome the possible selection bias in the current literature. Similarly, the evidence for the use of felted foam in healing plantar ulcers is still weak. Appropriately controlled high-quality studies that include measures of offloading efficacy and treatment adherence (where appropriate) are urgently needed to better inform clinicians and practitioners about effective offloading treatment in these areas.

## Conflicts of interest

PRC owns stock in DIAPedia and is an inventor on US patents 6 610 897, 6 720 470, and 7 206 718 that describe a load-relieving dressing and a method of insole manufacture for offloading diabetic feet.

SB, RvD, DGA, JL, CC: None declared.

## Author contributions

SB designed the search strings, performed the literature search, assessed the literature, extracted data and drew conclusions within 'casting and surgical offloading interventions', checked and completed the evidence and risk of bias tables, and wrote the manuscript. RvD assessed the literature, extracted data and drew conclusions within 'footwear and other offloading interventions', and critically reviewed the manuscript. DGA assessed the literature, extracted data and drew conclusions within 'surgical offloading interventions', and critically reviewed and edited the manuscript. JL assessed the literature, extracted data and drew conclusions within 'casting and other offloading interventions', and critically reviewed the manuscript. CC assessed the literature, extracted data and drew conclusions within 'surgical offloading interventions', and critically reviewed the manuscript. PRC assessed the literature, extracted data and drew conclusions within 'footwear interventions', and critically reviewed and edited the manuscript. SB acted as the secretary of the working group, PRC as the chair of the working group.

## Literature databases

PubMed is PubMed Central®, a free full-text archive of biomedical and life sciences journal literature at the U.S. National Institutes of Health's National Library of Medicine (NIH/NLM – <http://www.ncbi.nlm.nih.gov/pmc/>).

EMBASE is the Excerpta Medica database (<http://www.elsevier.com/online-tools/embase>).

CINAHL is the Cumulative Index to Nursing and Allied Health Literature (<http://www.ebscohost.com/nursing/products/cinahl-databases/cinahl-complete>).

Cochrane; the Cochrane Reviews are systematic reviews of primary research in human health care and health policy (<http://community.cochrane.org/cochrane-reviews>).

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## Supporting information

Table 2 (evidence table) and the search strategy can be downloaded as supplements from the publisher's website.