A systematic review of multidisciplinary teams to reduce major amputations for patients with diabetic foot ulcers

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ABSTRACT

Objective: Multiple single-center studies have reported significant reductions in major amputations among patients with diabetic foot ulcers after initiation of multidisciplinary teams. The purpose of this study was to assess the association between multidisciplinary teams (ie, two or more types of clinicians working together) and the risk of major amputation and to compile descriptions of these diverse teams.

Methods: We searched PubMed, Scopus, Cumulative Index to Nursing and Allied Health, and Cochrane Central Register of Controlled Trials from inception through May 24, 2019 for studies reporting the association between multidisciplinary teams and major amputation rates for patients with diabetic foot ulcers. We included original studies if ≥50% of the patients seen by the multidisciplinary team had diabetes, they included a control group, and they reported the effect of a multidisciplinary team on major amputation rates. Studies were excluded if they were non-English language, abstracts only, or unpublished. We used the five-domain Systems Engineering Initiative for Patient Safety Model to describe team composition and function and summarized changes in major amputation rates associated with multidisciplinary team care. A meta-analysis was not performed because of heterogeneity across studies, their observational designs, and the potential for uncontrolled confounding (PROSPERO No. 2017: CRD42017067915).

Results: We included 33 studies, none of which were randomized trials. Multidisciplinary team composition and functions were highly diverse. However, four elements were common across teams: teams were composed of medical and surgical disciplines; larger teams benefitted from having a "captain" and a nuclear and ancillary team member structure; clear referral pathways and care algorithms supported timely, comprehensive care; and multidisciplinary teams addressed four key tasks: glycemic control, local wound management, vascular disease, and infection. Ninety-four percent (31/33) of studies reported a reduction in major amputations after institution of a multidisciplinary team.

Conclusions: Multidisciplinary team composition was variable but reduced major amputations in 94% of studies. Teams consistently addressed glycemic control, local wound management, vascular disease, and infection in a timely and coordinated manner to reduce major amputation for patients with diabetic foot ulcerations. Care algorithms and referral pathways were key tools to their success. (J Vasc Surg 2020;71:1433-46.)

Keywords: Interdisciplinary; Patient care team; Health care team; Limb salvage; Limb preservation

Nearly 2 million Americans develop a diabetic foot ulcer each year; within 5 years of ulceration, 5% will undergo major amputation and 50% to 70% will die.[1-4] Caring for patients with diabetic foot ulcer is complicated by a nexus of comorbidities including diabetes, vascular disease, neuroarthropathy, and peripheral neuropathy that cross the boundaries of usual medical or surgical care. These comorbidities, coupled with secondary infection, stymie ulcer healing, and care gaps further amplify the risk of major amputation.[3,5] Experts have recommended a multidisciplinary team approach to optimally address these comorbidities in a coordinated manner and to reduce major amputations.[6-8]

Two systematic reviews assessed the impact of multidisciplinary teams on diabetic foot ulcer outcomes.[9,10] In one, three of three studies reported a decrease in major amputations.[9] In the other, eight of nine reported reductions in major amputations associated with multidisciplinary team care.[10] Neither of these reviews included systematic descriptions of the multidisciplinary teams.

Given the recent global surge in multidisciplinary teams to care for patients with diabetic foot ulcers and the lack of understanding of how they form and function, we conducted a systematic review using descriptive analysis

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of teams. In this study, we define a multidisciplinary team as two or more clinicians from different disciplines working together to care for patients with foot ulcers, where the majority of patients have diabetes. We describe consistent elements of multidisciplinary teams that may be instrumental in achieving reductions in major amputations. Descriptions may benefit clinicians who are contemplating starting a multidisciplinary clinic at their institutions and researchers interested in interventional or comparative effectiveness studies.

The purpose of this study was twofold: to describe multidisciplinary team composition and function using a systems engineering conceptual model and to summarize the impact of multidisciplinary teams on major amputations. We hypothesize that multidisciplinary teams are associated with a reduced risk of major amputation.

METHODS

We conducted this systematic review in conformity with Preferred Reporting Items for Systematic Reviews and Meta-Analyses[11] and Meta-analysis Of Observational Studies in Epidemiology[12] guidelines. We followed a protocol that was registered a priori with an international prospective register of systematic reviews (PROSPERO No. 2017: CRD42017067915). Because this systematic review used only results from previously published studies, it was not considered human subjects research and as such did not qualify for Institutional Review Board review.

Search strategy. Investigators collaborated with a medical reference librarian to develop a comprehensive search strategy using controlled vocabulary and keywords. These included diabetic foot, foot ulcer, multidisciplinary, interdisciplinary, multispecialty, patient care team, amputation, limb salvage, and limb preservation (The full search strategy is available in Supplementary Table I, online only.). The librarian searched the following databases from their inceptions through May 24, 2019: PubMed, Scopus, Cumulative Index to Nursing and Allied Health, and Cochrane Central Register of Controlled Trials. We augmented our database search by manually screening references of all selected articles. We contacted corresponding authors to obtain articles that were unavailable through national and international interlibrary loans. Beyond this, we had no contact with authors of identified, screened, or selected studies.

Study selection process. We included all original studies that met the following inclusion criteria: ≥50% of the patients seen by the multidisciplinary team had diabetes; the study included a control group; and the study reported the effect of a multidisciplinary team, defined as two or more types of clinicians working together, on major (above-ankle) amputation rates for patients with foot ulcers. Studies were excluded if they were written in a language other than English, published as abstracts only, or unpublished. We purposely kept our inclusion and exclusion criteria broad to encompass the experiences of as many different teams as possible and to increase the generalizability of our findings. Specifically, if a group of clinicians described themselves as a team, we accepted their self-designation to capture the widest range of teams possible. We included observational studies because these designs are more frequently used to test interventions at the system level rather than at the individual level. Two independent reviewers screened all titles and abstracts of the studies identified for inclusion. Discrepancies were resolved by a third independent reviewer. We repeated this process using full-text articles during the second phase of screening. Three articles reported the initial effect of a single multidisciplinary team soon after team formation with more longitudinal data captured in a subsequent publication.[13-18] When this occurred, we included only the article with the most longitudinal outcome data and excluded the initial article. This allowed us to give equal weights to each unique multidisciplinary team.

Theoretical model. Previous systematic reviews did not provide descriptions of the heterogeneous teams or their functions, which we thought would be useful in understanding *how* multidisciplinary teams might reduce major amputation rates for patients with diabetic foot ulcers.[9,10] We used the Systems Engineering Initiative for Patient Safety (SEIPS) model to systematically compile team descriptions. The SEIPS model (Fig 1) focuses on five work system domains—people, tasks, tools and technologies, physical environment, and organizational conditions. The model describes how elements of multidisciplinary teams interact to influence processes (managing diabetic foot ulcers) and outcomes (major amputation).[19]

Data abstraction. The primary outcome of this review was the change in major amputation rates. We abstracted the following study attributes: publication year, design, location, sample size, length of enrollment, and whether team composition and function were reported. We abstracted the following patient attributes affecting the risk of major amputation and potentially confounding results: age, sex, race, whether a majority or all of the patients managed by the multidisciplinary team had diabetes, mean hemoglobin A_{1c} levels, proportion with peripheral vascular disease, proportion with peripheral neuropathy, and whether the ulcer required hospitalization. We abstracted the following multidisciplinary team attributes, corresponding to the work system components of the SEIPS model (Fig 1): team composition by discipline (people); practice setting of inpatient or outpatient and whether teams functioned in a universal health care system (environment); aspects of clinical care addressed (tasks); what tools and technology were used (tools and technology); and organizational changes to implement

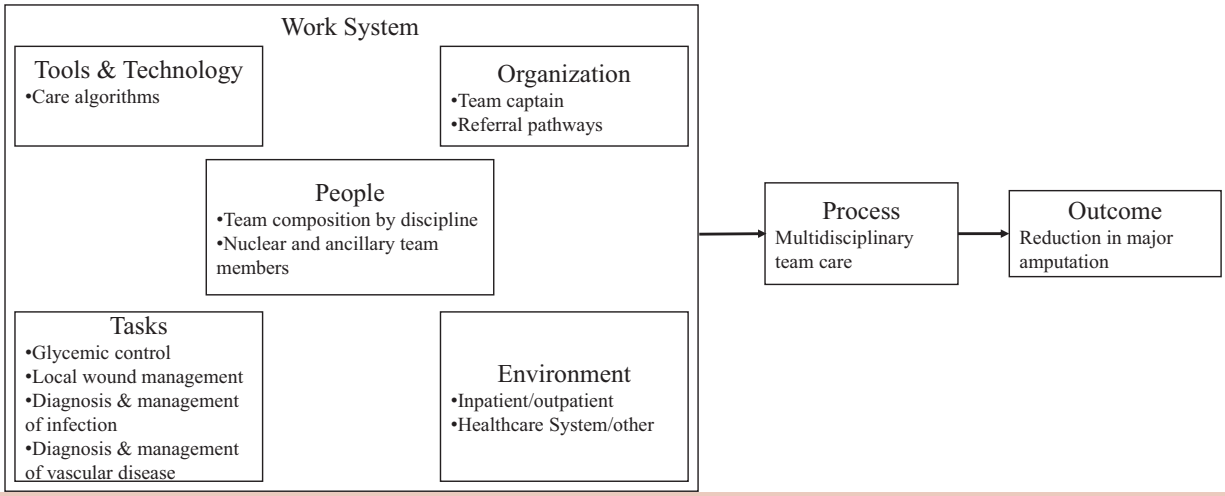

Fig 1. Systems Engineering Initiative for Patient Safety (SEIPS) model, adapted to the context of multidisciplinary care teams for diabetic foot ulcers.[19]

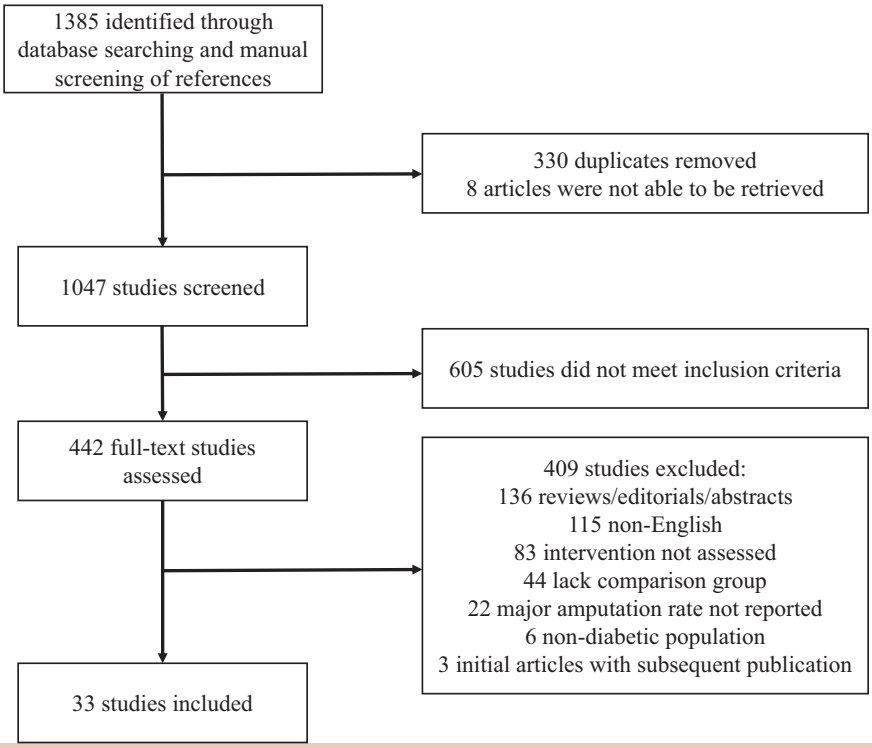

Fig 2. Preferred Reporting Items for Systematic Reviews and Meta-Analyses diagram for inclusion and exclusion of studies.

the multidisciplinary care teams (organization). Two reviewers independently abstracted all data using standardized, web-based forms. Reviewers met to resolve differences and to clean data.

Risk of bias assessment. Two independent reviewers assessed the methodologic quality and risk of bias for each included study using a modified Downs and Black[20] checklist for randomized and nonrandomized studies of health care interventions. Higher scores indicated higher quality studies, with a maximum modified score of 25. Scores within 3 points of each other were averaged. Otherwise, reviewers discussed discrepancies and agreed on a final score. Studies were also assigned descriptors of study quality (excellent, good, fair, or poor) based on the final score and previously reported ranges.[21]

Analysis. We created descriptions of the multidisciplinary teams using the SEIPS model; we focused on commonalities that might be necessary core components to reduce major amputations. We constructed a summarizing forest plot of all studies reporting odds

ratios or raw data from which odds ratios could be calculated. We also tabulated studies reporting population-based incidence rates and reported results from papers reporting high to low amputation ratios. A meta-analysis was not performed because of heterogeneity across studies, their observational designs, and the potential for uncontrolled confounding that might significantly bias the resulting summary statistic.

RESULTS

Our search identified 1047 distinct articles, of which 605 were excluded during title and abstract screening. The remaining 442 full-text articles were reviewed, and 33 met inclusion criteria (Fig 2).

Study characteristics

All 33 studies were observational, with global center representation (Table I). No randomized trials met our inclusion criteria. Twenty-six (79%) included at least 50 patients treated by their respective multidisciplinary teams.[14,22-44] Length of enrollment varied greatly among the 21 studies (64%) that reported it in terms of calendar time or time to clinical end points.[14,17,22-30,32,34-36,38,41,42,45-47] Some studies, often those using a historically controlled (pre-post) design, had unclear follow-up (Table II; brief descriptions of case and control patients are available in Supplementary Table II, online only). The mean bias score was 15.3 (standard deviation, 1.9), and most studies (82%) ranked fair. Lack of randomization and blinding—at the level of patients, providers, and researchers—commonly detracted from study quality.

Patient characteristics

All but two multidisciplinary teams exclusively treated those with diabetes.[16,45] Most studies (22/33 [67%]) limited their recruitment to patients with ulcers severe enough to warrant hospitalization.[14,22-26,28,30-32,34,36-39,41-43,45,47-49] Six studies further restricted recruitment to those requiring revascularization, major or minor amputation, or plastic surgery reconstruction.[24,30,34,36,45,48]

When patients' characteristics were reported, they were generally well balanced between those who received multidisciplinary care and those who did not. The mean age of the patients ranged from 56 to 76 years.[14,17,22-32,36,37,39,41-45,47-49] Men composed 34% to 100% of patients.[14,17,22-25,27-32,36-39,41-45,47,48] Five studies reported the patients' race; four included predominantly (>80%) white patients, and one included 100% Asian patients.[14,16,27,29,49] The proportion of patients with peripheral vascular disease ranged from 42% to 100%.[14,25,26,29-31,36,41,43-45,47,48] Three studies were entirely composed of patients with peripheral vascular disease.[25,36,45] The proportion of patients with peripheral neuropathy ranged from 64% to 100%.[14,26,28,36,41,43,44,47,48] In the 11 studies reporting mean hemoglobin A_{1c} values, two were <8%.[23,26,30,31,41,43-45,47-49]

Table I. Characteristics of the 33 included studies

Study characteristic	No. (%)
Publication date	
Before 1990	0
1990-1999	3 (9)
2000-2009	8 (24)
2010-February 2019	22 (67)
Design[a]	
Historically controlled (pre-post)	26 (76)
Retrospective cohort	4 (12)
Prospective cohort	2 (6)
Case controlled	2 (6)
Randomized controlled	0
Location	
Europe	18 (55)
South America, Asia, or Africa	8 (24)
North America	5 (15)
Australia	2 (6)
No. of patients (multidisciplinary care)	
0-24	0 (0)
25-49	2 (6)
50-74	6 (18)
75-100	2 (6)
>100	18 (55)
Unknown	5 (15)
Length of enrollment	
Unknown	12 (36)
Until hospital discharge	7 (21)
Until ulcer healed or major amputation	5 (15)
Other	9 (27)
Bias score	
22-25 (excellent)	0 (0)
17-21 (good)	4 (12)
12-16 (fair)	27 (82)
<12 (poor)	2 (6)

[a]The number for study design totals 34 rather than 33 because one study used both retrospecitve cohort and historically controlled (pre-post) designs. We counted it in both categories.[22]

Multidisciplinary team characteristics

People. Team composition was highly heterogeneous, with 36 different disciplines represented on the 27 teams reporting their members.[14,16,17,26-46,48-50] The average team included physicians from five distinct disciplines (range of three to nine physician disciplines per team). Typically, larger teams were divided into a nuclear team led by two or three physicians and ancillary team members called on as needed. Some studies stressed that it was important to identify a team "captain" to coordinate efforts.[16,30,34] Another large team reported a "learning curve," as teamwork improved and major amputation rates fell over time.[36]

Table II. Study descriptions

Study	Bias score	Study design				Follow-up
		Prospective cohort	Retrospective cohort	Case-control	Historically controlled (pre-post)	
Chung,[45] 2015	20		X			Median 539 days (interquartile range, 314 ± 679 days)
Weck,[26] 2013	18.5	X				730 days
Laakso,[39] 2017	17.5				X	Unclear
Chiu,[30] 2011	17			X		Until wound healing or amputation
Riaz,[44] 2019	16.5				X	Unclear
Kim,[43] 2018	16.5				X	Unclear
Crihana,[28] 2014	16.5				X	Duration of admission
Setacci,[25] 2013	16.5				X	182 days
Alexandrescu,[36] 2009	16.5				X	Mean 700 days (range, 30-2040 days)
Williams,[16] 2018	16				X	Until wound healing or amputation
Martínez-Gómez,[32] 2014	16				X	Inpatient observed until discharge; outpatient and inpatient observed for 730 days after admission
Yesil,[41] 2009	16				X	300 days after discharge
Hedetoft,[48] 2009	16			X		Unclear
Rerkasem,[37] 2008	16				X	Unclear
Dargis,[27] 1999	16	X				730 days
Jiménez,[17] 2017	15.5				X	Until ulcer healing, sometimes longer on case-by-case basis
Wang,[49] 2016	15.5				X	Duration of hospitalization
Plusch,[47] 2015	15.5		X			Duration of hospitalization
Cahn,[31] 2014	15.5				X	Duration of hospitalization
Denjalić,[23] 2014	15				X	Observed until ulcer healing (did not follow up for recurrence)
Nather,[42] 2010	15				X	Duration of admission and follow-up care for surgical intervention (length of stay range, 10.81-20.36 days)
Crane,[22] 1999[a]	15		X		X	Duration of admission
Hsu,[46] 2015	14.5				X	Until wound healed
Armstrong,[34] 2012	14.5				X	Through wound healing, surgical postoperative care, metabolic control, and others; timing was not reported
Witsø,[50] 2010	14.5				X	Unclear
Aydin,[14] 2010	14.5				X	Duration of hospitalization (mean length of stay, 26.9 days)
Meltzer,[29] 2002	14.5				X	Between 1 day and 1095 days but poorly defined
Anichini,[33] 2007	14				X	Unclear
Nason,[38] 2013	13.5				X	Unclear; length of stay reported for those who were hospitalized
Holstein,[35] 2000	2000				X	Until 1996
Gibbons,[24] 1993					X	365 days
Troisi,[51] 2016	11.5				X	Unclear
McGill,[40] 2003			X			Unclear

[a]Crane et al 1999 used both retrospective cohort and historically controlled (pre-post) designs.

Table III. Multidisciplinary team compositions

Study	Bias score[a]	OR for change in major amputation rate after multidisciplinary care
Chung,[45] 2015	20	0.45 (0.16-1.24)
Weck,[26] 2013	18.5	0.28 (0.20-0.40)
Laakso,[39] 2017	17.5	0.47 (0.27-0.82)
Chiu,[30] 2011	17	0.09 (0.03-0.29)
Alexandrescu,[36] 2009	16.5	0.47 (0.20-1.08)
Crihana,[28] 2014	16.5	0.25 (0.07-0.90)
Kim,[43] 2018	16.5	1.14 (0.59-2.20)
Riaz,[44] 2019	16.5	0.29 (0.20-0.42)
Dargis,[27] 1999	16	0.39 (0.04-3.55)
Hedetoft,[48] 2009	16	[e]
Martínez-Gómez,[32] 2014	16	0.47 (0.33-0.68)
Rerkasem,[37] 2008	16	0.27 (0.08-0.97)
Williams,[16] 2018	16	−368/100,000
Yesil,[41] 2009	16	0.56 (0.34-0.93)
Cahn,[31] 2014	15.5	0.49 (0.25-0.94)
Wang,[49] 2016	15.5	0.27 (0.13-0.57)
Jiménez,[17] 2017	15.5	−1.6/100,000/year
Nather,[42] 2010	15	0.37 (0.21-0.66)
Armstrong,[34] 2012	14.5	[f]
Aydin,[14] 2010	14.5	0.53 (0.25-1.15)
Hsu,[46] 2015	14.5	0.28 (0.13-0.60)
Meltzer,[29] 2002	14.5	0.16 (0.07-0.37)
Witsø,[50] 2010	14.5	−160/100,000/y
Anichini,[33] 2007	14	−3.2/100,000
Holstein,[35] 2000	13.5	−20.3/100,000
Nason,[38] 2013	13.5	0.61 (0.23-1.62)
McGill,[40] 2003	9.5	0.19 (0.13-0.27)
Total (%)		

OR, Odds ratio; *PM&R*, physical medicine and rehabilitation.
[a]Studies are ordered on the basis of bias scores, with higher quality studies listed first.
[b]Other physician-based disciplines included anesthesiology and pain services, cardiology, cardiovascular surgery, dermatology, emergency medicine, interventional angiography, microbiology, neurology, psychology, and radiology.
[c]Nursing disciplines spanned general nursing, nurse case management, diabetic foot nursing, vascular nursing, and wound care nursing.
[d]Other allied health professions included diabetes educators, medical quality, nutrition, occupational therapy, pharmacy, physical therapy, plaster technicians, prosthetics, and social work.
[e]Hedetoft et al reported an increase in the high-low (major-minor) amputation ratio from 0.46 to 0.55 after introduction of a multidisciplinary team.
[f]Armstrong et al reported a reduction in the high-low (major-minor) amputation ratio from 0.35 to 0.27 after introduction of a multidisciplinary team.

All but one team included physicians from medical and surgical disciplines (Table III). Endocrinology was the most common medical specialty (82%). To a lesser extent, infectious disease (37%), general medicine (30%), and physical medicine and rehabilitation (22%) specialists were involved. Most teams (85%) included two or more surgical specialties.[14,16,17,27-31,33-42,45,46,48-50] Peripheral vascular surgery was the most common surgical specialty (74%), although orthopedic surgery (67%), podiatry (52%), and plastic surgery (44%) were involved frequently.

In general, the roles of nurses and allied health professionals were less well documented. Team tasks, such as use of negative pressure wound therapy and casting, suggest that these disciplines were under-reported. The involvement of nurses was explicitly stated in 15 studies (56%), including general nursing, wound care nursing, and nurse case management.[14,16,29,33,35-37,40-42,44,46,48-50] The contributions of allied health professionals were cited in 14 studies (52%), with even broader discipline involvement: casting, diabetes education, medical quality, nutrition, occupational therapy, orthotics, pharmacy,

Table III. Continued.

Physician disciplines										Nursing[c] and allied health professionals		
Medical				Surgical					Other[b]			
Endocrinology	General medicine	Infectious disease	PM&R	General surgery	Orthopedics	Vascular surgery	Plastic surgery	Podiatry		Nursing	Orthotics	Other[d]
	X	X				X	X	X	X			X
X						X			X			
	X	X			X	X	X		X			
X						X	X					
X	X	X			X	X	X	X	X	X	X	
X				X			X		X		X	
X					X	X						
X					X	X			X	X		
X			X		X			X			X	
X					X			X		X		
X	X	X	X	X					X			X
X	X		X			X	X			X		
					X	X		X	X	X		
X		X	X		X	X	X		X	X	X	X
X		X			X		X		X			
X					X	X	X			X		X
X	X	X	X	X	X	X		X	X			
X		X			X	X		X		X	X	X
	X	X				X		X				X
X		X			X		X		X	X		
X			X	X	X	X	X		X	X		X
						X	X	X		X		X
X					X	X		X	X	X	X	X
X				X	X	X		X		X		
X					X	X		X		X	X	
X					X	X		X			X	
X	X			X				X		X		
22 (82)	8 (30)	10 (37)	6 (22)	6 (22)	18 (67)	20 (74)	12 (44)	14 (52)	14 (52)	15 (56)	8 (30)	8 (30)

physical therapy, prosthetics, and social work.[27-29,32,34-36,38,41,42,45,46,49,50] Of these, orthotics was the allied health professional discipline most commonly included on teams (8/28 [30%]).

Tasks. Despite varied compositions, teams consistently addressed four key clinical tasks: glycemic control, local wound management, vascular disease, and infection (Table IV). Twenty-six teams (79%) addressed three or more of these key factors. Regarding local wound management, most (29/32 [91%]) were able to surgically débride and to perform minor amputations in addition to nonsurgical interventions, such as bedside débridement and offloading.[14,16,17,23,25-46,48-50] In addressing vascular disease, most teams (24/32 [75%]) were able to revascularize patients as needed in addition to performing diagnostic testing and medical management.[14,16,17,24-26,29,30,33-39,41-46,49-51] Tasks associated with medical management of vascular disease, such as diagnosis and treatment of dyslipidemias, antiplatelet therapy, and smoking cessation, were not well described in the majority of the articles. Only one mentioned smoking cessation as an explicit

Table IV. Four key clinical tasks addressed by multidisciplinary teams

			Key clinical task						
			Glycemic control	Wound care		Infection	Vascular disease		
Study	Bias score[a]	OR for major amputation		Surgical	Nonsurgical		Revascularization	Diagnostic/ medically managed	No. of tasks addressed
Chung,[45] 2015	20	0.45 (0.16-1.24)	X	X	X	X	X	X	4
Weck,[26] 2013	18.5	0.28 (0.20-0.40)	X		X	X	X	X	4
Laakso,[39] 2017	17.5	0.47 (0.27-0.82)	X	X	X	X	X	X	4
Chiu,[30] 2011	17	0.09 (0.03-0.29)	X	X	X		X	X	3
Alexandrescu,[36] 2009	16.5	0.47 (0.20-1.08)	X	X	X	X	X	X	4
Crihana,[28] 2014	16.5	0.25 (0.07-0.90)	X	X	X	X		X	4
Setacci,[25] 2013	16.5	0.70 (0.50-0.96)		X	X	X	X	X	3
Kim,[43] 2018	16.5	1.14 (0.59-2.20)	X	X	X		X	X	3
Riaz,[44] 2019	16.5	0.29 (0.20-0.42)	X	X	X		X	X	3
Dargis,[27] 1999	16	0.39 (0.04-3.55)	X	X	X			X	3
Hedetoft,[48] 2009	16	[b]	X	X	X				2
Martínez-Gómez,[32] 2014	16	0.47 (0.33-0.68)	X	X	X	X		X	4
Rerkasem,[37] 2008	16	0.27 (0.08-0.97)	X	X	X		X	X	3
Williams,[16] 2018	16	−368/100,000		X	X		X	X	2
Yesil,[41] 2009	16	0.56 (0.34-0.93)	X	X	X	X	X	X	4
Cahn,[31] 2014	15.5	0.49 (0.25-0.94)	X	X	X	X			3
Wang,[49] 2016	15.5	0.27 (0.13-0.57)	X	X	X		X	X	3
Jiménez,[17] 2017	15.5	−1.6/100,000/y	X	X	X	X	X	X	4
Crane,[22] 1999[a]	15	0.30 (0.10-0.92)	X			X			2
Denjalić,[23] 2014	15	0.49 (0.30-0.78)	X	X	X	X			3
Nather,[42] 2010	15	0.37 (0.21-0.66)	X	X	X	X	X	X	4
Armstrong,[34] 2012	14.5	[c]		X	X	X	X	X	3
Aydin,[14] 2010	14.5	0.53 (0.25-1.15)	X	X	X	X	X	X	4
Hsu,[46] 2015	14.5	0.28 (0.13-0.60)	X	X	X		X	X	3
Meltzer,[29] 2002	14.5	0.16 (0.07-0.37)	X	X	X	X	X	X	4
Witsø,[50] 2010	14.5	−160/100,000/y	X	X	X	X	X	X	4
Anichini,[33] 2007	14	−3.2/100,000	X	X	X		X	X	3
Gibbons,[24] 1993	13.5	0.22 (0.10-0.47)				X	X	X	2
Holstein,[35] 2000	13.5	−20.3/100,000	X	X	X	X	X	X	4
Nason,[38] 2013	13.5	0.61 (0.23-1.62)	X	X	X	X	X	X	4
Troisi,[51] 2016	11.5	−8.8/100,000					X	X	1
McGill,[40] 2003	9.5	0.19 (0.13-0.27)	X	X	X				2
Total (%)			27 (84)	28 (88)	29 (91)	20 (63)	24 (75)	27 (84)	Mean, 3.22

OR, Odds ratio.
[a]Studies are ordered on the basis of bias scores, with higher quality studies listed first.
[b]Hedetoft et al reported an increase in the high-low (major-minor) amputation ratio from 0.46 to 0.55 after introduction of a multidisciplinary team.
[c]Armstrong et al reported a reduction in the high-low (major-minor) amputation ratio from 0.35 to 0.27 after introduction of a multidisciplinary team.

task.[38] Eleven teams directly addressed patient education.[22,27,33-35,37,38,42,46,49,50] One study commented that team members would reinforce each other's recommendations, sending a consistent message and increasing patients' adherence.[48]

Studies stressed that individual tasks performed by multidisciplinary teams could and often did happen in standard practice. However, performing all tasks for all patients, especially in a coordinated and expedited manner, was not facilitated by use of the standard

practice model. Multidisciplinary teams credited their improved outcomes to the combination of consistently and synchronously addressing all contributing factors and providing timely care.[16,25,30,33,37,39,46,48]

Teams held standing meetings or rounded together to coordinate and to expedite care. Typically, meetings were held weekly.[25,31,39,41,45] Some larger teams met weekly with the nuclear team and convened the whole team less frequently.[31,39] One team stressed "continuous multidisciplinary activity" or daily interactions between team members to improve multidisciplinary work beyond meetings.[16] In addition to focusing on individual patient care, meetings were used to address access and resource allocation.[37] One team dedicated a portion of these meetings to review the care plans of high-utilization patients.[16]

Tools and technology. Teams used basic tools to assist with communication and coordination, not advanced technology. The most common tool was a care algorithm.[22-26,28-30,32,37,41,43,44,46] This tool helped ensure that teams were providing comprehensive care in an agreed on order by designated disciplines. Usually, care algorithms were constructed with input from team members before initiation of multidisciplinary team care.[29,32,37,44,46] Algorithms varied greatly in the amount of detail and complexity they contained, with more detailed and complex algorithms tending to be more prescriptive.[22-26,28-30,32,37,41,43,44,46] One team used existing guidelines as a general framework, tailoring details to their specific team and system.[17] Another stressed innovation in designing their algorithm, an approach that resulted in a combined group- and home-based patient educational program they thought was much more effective than their previous standard lectures and pamphlets.[37] Another used the algorithm not only to address physiologic factors but to facilitate inpatient to outpatient transitions.[26] One team designated a nurse to implement the algorithm and to track patients' care through them.[37] Another used patient-tailored care algorithms as a metric of accountability among team members.[31] Non-algorithm tools were used less frequently and included standardized documentation templates and order sets, antibiotic algorithms, and patient pamphlets.[37,41,42,50]

Within individual disciplines, advanced technologies were employed. These included endovascular revascularization protocols, advanced plastic surgery closures, and wound vacuums.[24,28,30,36]

Environment. Teams functioned in inpatient settings (9 [27%]),[14,22-24,31,35,39,42,43] outpatient settings (6 [18%]),[27,29,33,44,47,50] or both settings (18 [55%]).[16,17,25,26,28,30,32,34,36-38,40,41,45,46,48,49,51] Some described starting in either the inpatient or outpatient setting and then expanding to encompass both as their teams became more established. This facilitated continuity of care, which the multidisciplinary teams highly valued.[41] In caring for inpatients, co-locating patients on the same ward facilitated team rounding.[31,41] Most studies (28/33 [85%]) took place within universal health care systems.[14,16,17,23,25-28,30,32,33,35-42,46-51]

Organization. Teams worked with existing resources and focused on changing system organization to improve patient outcomes.[37,39,44] Before initiation of multidisciplinary team care, organizational changes focused on two areas: within-team organization and the interface between the team and other health care providers. Within-team organizational change included developing care algorithms and rules of conduct between team members, including who would captain the team, which discipline would serve as the primary admitting service, and how consultations would be called.[16,30,32,34,37,42,46] Two outpatient teams grouped patients who required surgical consultation on the same day, increasing the efficient consultation of ancillary surgical team members.[38,40] Two teams incorporated a priori systems for improvement through either annual audit and feedback or a patient registry.[32,46]

Before initiation of care, multidisciplinary teams met with specialists and primary care providers within their health care systems to establish clear referral pathways.[16,17,25,26,33,40,48,50,51] Consensus among specialists was needed so that patients referred to specialists who were not part of the multidisciplinary team would be redirected to the team.[40,50] Meetings with primary care providers focused on advertising the multidisciplinary teams and introducing referral pathways.[16,26,33,40,50] Rapid triage was emphasized. One team guaranteed new patient evaluation within 24 hours.[33] Others developed telephone triage lines for referring providers so that new patients could be seen in an appropriate time frame and setting (eg, outpatient clinic or hospital admission).[16,25] Recognizing that the specialists involved in these multidisciplinary teams were a limited resource, some teams focused on educating primary care providers in how to care for less complicated diabetic foot ulcers so that the multidisciplinary teams could focus on patients with severe ulcerations.[33,51] These efforts included clear parameters to refer to specialty care and pre-referral workups.[33] Two teams noted a steady increase in referrals over time, which expanded outside initial catchment areas.[16,50]

Major amputation rates

All but two studies (31/33 [94%]) reported a decrease in major amputations associated with multidisciplinary teams. Twenty-five studies reported odds ratios or raw data from which odds ratios could be calculated.[14,22-32,36-47,49] Of these, the absolute percentage change in major amputations associated with multidisciplinary teams ranged from a 2% increase[43] (odds ratio, 1.14; 95% confidence interval, 0.59-2.20) to a 51% absolute or 89% relative reduction (odds ratio, 0.11; 95% confidence interval, 0.05-0.25; Fig 3).[23] Six studies

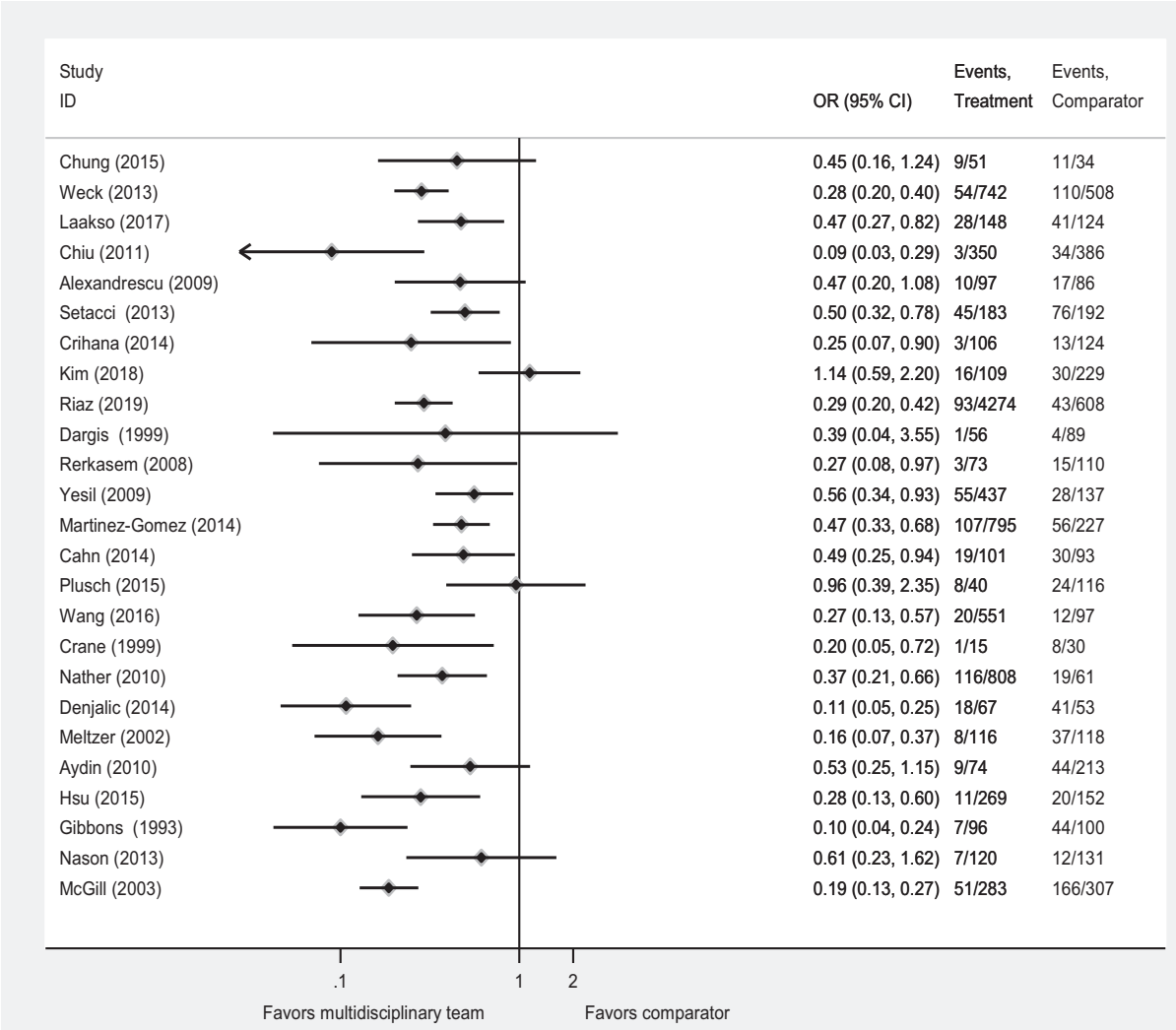

Fig 3. Forest plot of the estimated odds ratios (*ORs*) for the change in major amputation rates after initiation of multidisciplinary care compared with standard care for 25 of the 33 included studies for which odds ratios could be calculated. *CI,* Confidence interval; *ID,* identifier.

reported changes in incidence rates[16,17,33,35,50,51]; all of these took place within national health care systems, involved stable populations, and reported decreases in major amputation rates associated with multidisciplinary teams (Table V). Two studies used the high-low (major-minor) amputation ratio.[34,48] One of these reported a decrease from 0.35 to 0.27 after introduction of a multidisciplinary care team.[34] The other reported an increase from 0.46 to 0.55.[48]

DISCUSSION

Despite heterogeneous team composition and function, multidisciplinary teams are associated with significant reductions in major amputations for patients with diabetic foot ulcers. Although we were unable to perform a meta-analysis, the direction of the association between multidisciplinary teams and major amputation is clear. Of 33 studies, 31 found that multidisciplinary teams were associated with fewer major amputations for patients with diabetic foot ulcers. Consistent reductions in major amputations across studies and diverse teams also contribute to the robustness of the finding. Multidisciplinary teams embedded in a variety of health care systems and composed of different provider combinations were able to reduce major amputations by collaboratively and efficiently addressing underlying factors.

Multidisciplinary team care is an effective strategy for the highest risk patients, especially those with ulcers severe enough to warrant hospitalization and underlying peripheral vascular disease (ie, the majority of patients served by multidisciplinary teams included in this review). It is consistent with expert opinion guidelines suggesting a tiered approach to care based on ulcer severity.[7,52,53] In

Table V. Decrease in incidence rates of major amputations associated with multidisciplinary teams for patients with diabetic foot ulcers

Study, country	Bias score[a]	Incidence of major amputation/ 100,000 inhabitants with diabetes		Decrease in incidence with multidisciplinary teams
		Controls	Multidisciplinary teams	
Williams,[16] 2018, United Kingdom	16	412[b]	44[b]	368[b]
Jiménez,[17] 2017, Spain	15.5	6.1[c]	4.5[c]	1.6[c]
Witsø,[50] 2010, Norway	14.5	400[d]	240[d]	160[d]
Anichini,[33] 2007, Italy	14	6.3	3.1	3.2
Holstein,[35] 2000, Denmark	13.5	27.2	6.9	20.3
Troisi,[51] 2016, Italy	11.5	37.5	28.7	8.8

[a]Studies are ordered on the basis of bias scores, with higher quality studies listed first.
[b]Williams et al expressed the incidence of major amputation based on 100,000 inhabitants with diabetes, adjusted for age and sex.
[c]Jiménez et al expressed the incidence of major amputation based on 100,000 general inhabitants per year.
[d]Witsø et al expressed the incidence of major amputation based on 100,000 inhabitants with diabetes per year.

this model, primary care is responsible for preventing foot ulcers. Relatively straightforward ulcers can be managed locally with collaboration between primary care and populous specialties with wide geographic distributions, such as podiatry. Large multidisciplinary teams, like those included in this review, are in tertiary care centers and reserved for patients with severe ulcers. This model depends on effective triage so that patients receive the appropriate level of care.[54]

Our review includes descriptions of how multidisciplinary teams integrate into their broader health care organizations and provides evidence to support aspects of this tiered model. Teams educated primary care providers and other local health care professionals to screen and to care for patients with minimally complex ulcers. They also focused on streamlined triage into their highly specialized multidisciplinary teams for patients with severe ulcers. These results support health services research within the United States and England, demonstrating decreased major amputation rates in systems with effective referral pathways.[55,56] What is lacking is an understanding of how best to leverage these resource-intense multidisciplinary teams. Subsequent investigations should focus on identifying the severity threshold for initiating multidisciplinary team care, which is likely to fluctuate on the basis of available resources.

We were able to identify common elements of successful multidisciplinary teams using a health systems engineering conceptual model. It is important to identify commonalities between these successful teams because they may represent core elements or facets of multidisciplinary team care that are necessary to reduce major amputations.[57] Clinicians starting a multidisciplinary team may want to incorporate these elements, and researchers may opt to investigate which common elements are necessary core elements for success. With this in mind, we noted the following.

1. Teams were composed of medical and surgical disciplines.
2. Larger teams benefitted from having a captain and a nuclear and ancillary team member structure.
3. Clear referral pathways and care algorithms supported timely, comprehensive care.

Each of the preceding elements addressed work system conditions that enabled the multidisciplinary teams to perform their tasks consistently, collaboratively, and rapidly.

4. Multidisciplinary teams addressed four key tasks: glycemic control; local wound management, including surgical débridement and minor amputation; diagnosis and management of vascular disease, including revascularization; and diagnosis and management of infection.

Previous studies also suggested that coordination facilitated by referral pathways and care algorithms (consistent element 3) as well as comprehensively addressing all comorbidities contributing to ulceration (consistent element 4) are tactics used by teams to reduce major amputation rates.[55,58]

The most notable limitation of our study is the quality of included studies, with the majority being ranked fair. This precluded our ability to perform a meta-analysis. It also introduced potential bias favoring multidisciplinary teams. Most studies used a historically controlled (pre-post) design, with control patients receiving care before case patients. In some studies, this difference was substantial and may have biased results; the formation of a multidisciplinary team may have occurred soon after increased utilization of endoscopic revascularizations or other advanced technologies. These technologies may have partially accounted for reductions in major amputations that were attributed solely to the multidisciplinary team. However, we do not think that this could entirely account for our findings as some studies used more robust designs, and some historically controlled (pre-post) studies took place during relatively brief periods when secular trends would be less influential. Another concern is that as teams' reputations and

capacities increased, they cared for patients with less severe ulcers than in control patients. This may bias results toward multidisciplinary care, depending on how control patients were selected. However, this potential bias should not exist in the six population-based studies, all of which reported a decreased incidence of major amputation after institution of multidisciplinary teams (Table V). We understand that studies of major shifts in care delivery, such as new multidisciplinary teams, are difficult to design. Treatment diffusion and lack of blinding make controlled study designs difficult. A stepwise wedge approach may offer a viable and ethically appropriate option.[59] Pre-post study design using historical controls can improve rigor using interrupted time series analysis.[60] We would welcome future studies incorporating these methods. In addition to improving study design, adjusting for confounders with multivariate statistical modeling would have improved study quality. All reported odds ratios were unadjusted, raising the potential that differences in comorbidities between treatment and control groups could confound results. This concern is somewhat assuaged by generally well balanced treatment and control groups among those studies reporting comorbidities. Another limitation was the exclusion of non-English language articles, although our intent was to perform a systematic review that would best inform efforts to improve the care of patients with diabetic foot ulcers in the United States. The global representation of English-language articles speaks to the widespread uptake of multidisciplinary team care for patients with diabetic foot ulcers. Our search identified 115 non-English language studies, some of which may have met the remaining inclusion criteria and reported a negative association between multidisciplinary teams and major amputation. Our results should be applied cautiously to settings outside of Europe and North America, where the excluded, non-English language articles may be more relevant. Finally, publication bias may have resulted in an overly favorable conclusion that multidisciplinary teams reduce the risk of major amputation for patients with diabetic foot ulcer.

CONCLUSIONS

Multidisciplinary teams—especially those able to address glycemic control, local wound management, vascular disease, and infection—are associated with a reduced risk of major amputation for patients with severe diabetic foot ulcerations. Further studies are needed to clarify core elements of these teams and the thresholds of patient severity served by these resource-intense, highly effective teams.

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AUTHOR CONTRIBUTIONS

Conception and design: CB, MB
Analysis and interpretation: JM, BS, MB
Data collection: BS, SK, PB, MB
Writing the article: JM, BS, SK, PB, CB, MB
Critical revision of the article: JM, BS, SK, PB, CB, MB
Final approval of the article: JM, BS, SK, PB, CB, MB
Statistical analysis: JM
Obtained funding: MB
Overall responsibility: MB

REFERENCES

1. Margolis DJ, Malay DS, Hoffstad OJ, Leonard CE, MaCurdy T, de Nava Karla López, et al. Incidence of diabetic foot ulcer and lower extremity amputation among Medicare beneficiaries, 2006 to 2008: Data Points #2 (prepared by the University of Pennsylvania DEcIDE Center, under Contract No. HHSA290200500411). Rockville, Md: Agency for Healthcare Research and Quality; 2011. AHRQ Publication No. 10(11)-EHC009-1-EF.
2. Brennan MB, Allen GO, Ferguson PD, McBride JA, Crnich CJ, Smith MA. The association between geographic density of infectious disease physicians and limb preservation in patients with diabetic foot ulcers. Open Forum Infect Dis 2017;4:ofx015.
3. Brennan MB, Hess TM, Bartle B, Cooper JM, Kang J, Huang ES, et al. Diabetic foot ulcer severity predicts mortality among veterans with type 2 diabetes. J Diabetes Complications 2017;31:556-61.
4. Walsh JW, Hoffstad OJ, Sullivan MO, Margolis DJ. Association of diabetic foot ulcer and death in a population-based cohort from the United Kingdom. Diabet Med 2016;33:1493-8.
5. Prompers L, Schaper N, Apelqvist J, Edmonds M, Jude E, Mauricio D, et al. Prediction of outcome in individuals with diabetic foot ulcers: focus on the differences between individuals with and without peripheral arterial disease. The EURODIALE Study. Diabetologia 2008;51:747-55.
6. Fitzgerald RH, Mills JL, Joseph W, Armstrong DG. The diabetic rapid response acute foot team: 7 essential skills for targeted limb salvage. Eplasty 2009;9:e15.
7. Rogers LC, Andros G, Caporusso J, Harkless LB, Mills JL Sr, Armstrong DG. Toe and flow: essential components and structure of the amputation prevention team. J Vasc Surg 2010;52:23S-7S.
8. Lipsky BA, Berendt AR, Cornia PB, Pile JC, Peters EJ, Armstrong DG, et al. 2012 Infectious Diseases Society of America clinical practice guideline for the diagnosis and treatment of diabetic foot infections. Clin Infect Dis 2012;54:e132-73.
9. Khan N, Sapsed S. Diabetes foot complication: assessing primary and secondary outcomes of multidisciplinary team versus standard care (a systematic review). Int J Diabetes Dev Ctries 2017;37:129-36.
10. Buggy A, Moore Z. The impact of the multidisciplinary team in the management of individuals with diabetic foot ulcers: a systematic review. J Wound Care 2017;26:324-39.

11. Moher D, Liberati A, Tetzlaff J, Altman DG; PRISMA Group. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. PLoS Med 2009;6: e1000097.
12. Stroup DF, Berlin JA, Morton SC, Olkin I, Williamson GD, Rennie D, et al. Meta-analysis of observational studies in epidemiology: a proposal for reporting. Meta-analysis Of Observational Studies in Epidemiology (MOOSE) group. JAMA 2000;283:2008-12.
13. Aksoy DY, Gurlek A, Cetinkaya Y, Oznur A, Yazici M, Ozgür F, et al. Change in the amputation profile in diabetic foot in a tertiary reference center: efficacy of team working. Exp Clin Endocrinol Diabetes 2004;112:526-30.
14. Aydin K, Isildak M, Karakaya J, Gürlek A. Change in amputation predictors in diabetic foot disease: effect of multidisciplinary approach. Endocrine 2010;38:87-92.
15. Williams DT, Majeed MU, Shingler G, Akbar MJ, Adamson DG, Whitaker CJ. A diabetic foot service established by a department of vascular surgery: an observational study. Ann Vasc Surg 2012;26:700-6.
16. Williams DT, Powell-Chandler A, Qureshi Q, Zaidi A, Whitaker CJ. Improved limb salvage for patients with vascular disease and tissue loss associated with new model of provision targeted at the diabetic foot. Diabetes Res Clin Pract 2018;135:50-7.
17. Jiménez S, Rubio JA, Álvarez J, Ruiz-Grande F, Medina C. Trends in the incidence of lower limb amputation after implementation of a Multidisciplinary Diabetic Foot Unit. Endocrinol Diabetes Nutr 2017;64:188-97.
18. Rubio JA, Aragón-Sánchez J, Jiménez S, Guadaliz G, Albarracín A, Salido C, et al. Reducing major lower extremity amputations after the introduction of a multidisciplinary team for the diabetic foot. Int J Low Extrem Wounds 2014;13: 22-6.
19. Carayon P, Schoofs Hundt A, Karsh BT, Gurses AP, Alvarado CJ, Smith M, et al. Work system design for patient safety: the SEIPS model. Qual Saf Health Care 2006;15:i50-8.
20. Downs SH, Black N. The feasibility of creating a checklist for the assessment of the methodological quality both of randomised and non-randomised studies of health care interventions. J Epidemiol Community Health 1998;52: 377-84.
21. Hooper P, Jutai JW, Strong G, Russell-Minda E. Age-related macular degeneration and low-vision rehabilitation: a systematic review. Can J Ophthalmol 2008;43:180-7.
22. Crane M, Werber B. Critical pathway approach to diabetic pedal infections in a multidisciplinary setting. J Foot Ankle Surg 1999;38:30-3.
23. Denjalić A, Bečulić H, Jusić A, Bečulić L. Evaluation of the surgical treatment of diabetic foot. Med Glas (Zenica) 2014;11: 307-12.
24. Gibbons GW, Marcaccio EJ Jr, Burgess AM, Pomposelli FB Jr, Freeman DV, Campbell DR, et al. Improved quality of diabetic foot care, 1984 vs 1990. Reduced length of stay and costs, insufficient reimbursement. Arch Surg 1993;128:576-81.
25. Setacci C, Sirignano P, Mazzitelli G, Setacci F, Messina G, Galzerano G, et al. Diabetic foot: surgical approach in emergency. Int J Vasc Med 2013;2013:296169.
26. Weck M, Slesaczeck T, Paetzold H, Muench D, Nanning T, von Gagern G, et al. Structured health care for subjects with diabetic foot ulcers results in a reduction of major amputation rates. Cardiovasc Diabetol 2013;12:45.
27. Dargis V, Pantelejeva O, Jonushaite A, Vileikyte L, Boulton AJ. Benefits of a multidisciplinary approach in the management of recurrent diabetic foot ulceration in Lithuania: a prospective study. Diabetes Care 1999;22:1428-31.
28. Crihana V. Improving outcomes in diabetic foot surgery after the implementation of measures for diagnosis and treatment. J Transl Med Res 2014;19:70-7.
29. Meltzer DD, Pels S, Payne WG, Mannari RJ, Ochs D, Forbes-Kearns J, et al. Decreasing amputation rates in patients with diabetes mellitus. An outcome study. J Am Podiatr Med Assoc 2002;92:425-8.
30. Chiu CC, Huang CL, Weng SF, Sun LM, Chang YL, Tsai FC. A multidisciplinary diabetic foot ulcer treatment programme significantly improved the outcome in patients with infected diabetic foot ulcers. J Plast Reconstr Aesthet Surg 2011;64:867-72.
31. Cahn A, Elishuv O, Olshtain-Pops K. Establishing a multidisciplinary diabetic foot team in a large tertiary hospital: a workshop. Diabetes Metab Res Rev 2014;30:350-3.
32. Martínez-Gómez DA, Moreno-Carrillo MA, Campillo-Soto A, Carrillo-García A, Aguayo-Albasini JL. Reduction in diabetic amputations over 15 years in a defined Spain population. Benefits of a critical pathway approach and multidisciplinary team work. Rev Esp Quimioter 2014;27:170-9.
33. Anichini R, Zecchini F, Cerretini I, Meucci G, Fusilli D, Alviggi L, et al. Improvement of diabetic foot care after the implementation of the International Consensus on the Diabetic Foot (ICDF): results of a 5-year prospective study. Diabetes Res Clin Pract 2007;75:153-8.
34. Armstrong DG, Bharara M, White M, Lepow B, Bhatnagar S, Fisher T, et al. The impact and outcomes of establishing an integrated interdisciplinary surgical team to care for the diabetic foot. Diabetes Metab Res Rev 2012;28:514-8.
35. Holstein P, Ellitsgaard N, Olsen BB, Ellitsgaard V. Decreasing incidence of major amputations in people with diabetes. Diabetologia 2000;43:844-7.
36. Alexandrescu V, Hubermont G, Coessens V, Philips Y, Guillaumie B, Ngongang C, et al. Why a multidisciplinary team may represent a key factor for lowering the inferior limb loss rate in diabetic neuro-ischaemic wounds: application in a departmental institution. Acta Chir Belg 2009;109:694-700.
37. Rerkasem K, Kosachunhanun N, Tongprasert S, Khwanngern K, Matanasarawoot A, Thongchai C, et al. Reducing lower extremity amputations due to diabetes: the application of diabetic-foot protocol in Chiang Mai University Hospital. Int J Low Extrem Wounds 2008;7:88-92.
38. Nason GJ, Strapp H, Kiernan C, Moore K, Gibney J, Feeley TM, et al. The cost utility of a multi-disciplinary foot protection clinic (MDFPC) in an Irish hospital setting. Ir J Med Sci 2013;182:41-5.
39. Laakso M, Honkasalo M, Kiiski J, Ala-Houhala M, Haapasalo H, Laine HJ, et al. Re-organizing inpatient care saves legs in patients with diabetic foot infections. Diabetes Res Clin Pract 2017;125:39-46.
40. McGill MN, Constantino M, Bolton T, Palmer E, Yue D. Diabetes Amputation Program: a structured systematic approach. Diabetic Foot J 2003;6:172-6.
41. Yesil S, Akinci B, Bayraktar F, Havitcioglu H, Karabay O, Yapar N, et al. Reduction of major amputations after starting a multidisciplinary diabetic foot care team: single centre experience from Turkey. Exp Clin Endocrinol Diabetes 2009;117:345-9.
42. Nather A, Siok Bee C, Keng Lin W, Xin-Bei Valerie C, Liang S, Tambyah PA, et al. Value of team approach combined with clinical pathway for diabetic foot problems: a clinical evaluation. Diabet Foot Ankle 2010;1.
43. Kim CH, Moon JS, Chung SM, Kong EJ, Park CH, Yoon WS, et al. The changes of trends in the diagnosis and treatment of diabetic foot ulcer over a 10-year period: single center study. Diabetes Metab J 2018;42:308-19.

44. Riaz M, Miyan Z, Waris N, Zaidi SIH, Tahir B, Fawwad A, et al. Impact of multidisciplinary foot care team on outcome of diabetic foot ulcer in term of lower extremity amputation at a tertiary care unit in Karachi, Pakistan. Int Wound J 2019;16:768-72.
45. Chung J, Modrall JG, Ahn C, Lavery LA, Valentine RJ. Multidisciplinary care improves amputation-free survival in patients with chronic critical limb ischemia. J Vasc Surg 2015;61:162-9.
46. Hsu CR, Chang CC, Chen YT, Lin WN, Chen MY. Organization of wound healing services: the impact on lowering the diabetes foot amputation rate in a ten-year review and the importance of early debridement. Diabetes Res Clin Pract 2015;109:77-84.
47. Plusch D, Penkala S, Dickson HG, Malone M. Primary care referral to multidisciplinary high risk foot services—too few, too late. J Foot Ankle Res 2015;8:62.
48. Hedetoft C, Rasmussen A, Fabrin J, Kølendorf K. Four-fold increase in foot ulcers in type 2 diabetic subjects without an increase in major amputations by a multidisciplinary setting. Diabetes Res Clin Pract 2009;83:353-7.
49. Wang C, Mai L, Yang C, Liu D, Sun K, Song W, et al. Reducing major lower extremity amputations after the introduction of a multidisciplinary team in patient with diabetes foot ulcer. BMC Endocr Disord 2016;16:38.
50. Witsø E, Lium A, Lydersen S. Lower limb amputations in Trondheim, Norway. Acta Orthop 2010;81:737-44.
51. Troisi N, Baggiore C, Landini G, Michelagnoli S. How daily practice changed in an urban area after establishing a multidisciplinary diabetic foot program. J Diabetes 2016;8:594-5.
52. Wennberg L, Widgren S, Axelsson R, Gerok-Andersson K, Åkerlund B. Multidisciplinary diabetic foot care in Sweden—a national survey. Diabetes Res Clin Pract 2019;149:126-31.
53. Barshes NR, Sigireddi M, Wrobel JS, Mahankali A, Robbins JM, Kougias P, et al. The system of care for the diabetic foot: objectives, outcomes, and opportunities. Diabet Foot Ankle 2013;4.
54. Shih CD, Shin L, Armstrong D. 4 building blocks for a successful limb preservation program. Podiatry Manag 2018;November/December:113-8.
55. Wrobel JS, Robbins JM, Charns MP, Bonacker KM, Reiber GE, Pogach L. Diabetes-related foot care at 10 Veterans Affairs medical centers: must do's associated with successful microsystems. Jt Comm J Qual Patient Saf 2006;32:206-13.
56. Paisey RB, Abbott A, Levenson R, Harrington A, Browne D, Moore J, et al. Diabetes-related major lower limb amputation incidence is strongly related to diabetic foot service provision and improves with enhancement of services: peer review of the South-West of England. Diabet Med 2018;35:53-62.
57. Damschroder LJ, Aron DC, Keith RE, Kirsh SR, Alexander JA, Lowery JC. Fostering implementation of health services research findings into practice: a consolidated framework for advancing implementation science. Implement Sci 2009;4:50.
58. Wrobel JS, Charns MP, Diehr P, Robbins JM, Reiber GE, Bonacker KM, et al. The relationship between provider coordination and diabetes-related foot outcomes. Diabetes Care 2003;26:3042-7.
59. Zhan Z, van den Heuvel ER, Doornbos PM, Burger H, Verberne CJ, Wiggers T, et al. Strengths and weaknesses of a stepped wedge cluster randomized design: its application in a colorectal cancer follow-up study. J Clin Epidemiol 2014;67:454-61.
60. Penfold RB, Zhang F. Use of interrupted time series analysis in evaluating health care quality improvements. Acad Pediatr 2013;13:S38-44.

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Additional material for this article may be found online at www.jvascsurg.org.

Supplementary Table I (online only). Search strategy

PubMed	((((((((((((((diabetic foot[tw] OR leg ulcer[mh] OR foot ulcer*[tw] OR high-risk foot[tw] OR plantar ulcer*[tw] OR (diabetic[tiab] OR diabetes[tw])) AND (foot[tiab] OR lower extremity[tiab])))))) AND ((Multidisciplinary[tw] OR multi-disciplinary[tw]OR interdisciplinary[tw] OR inter-disciplinary[tw] OR patient care team[mh] OR multispecialty[tw] OR specialty[tw] OR specialist[tw])))) AND (amputat*[tw] OR (limb[tw] OR "lower extremity"[tw] AND (salvage[tw] OR preserv*[tw])))))))))))) NOT (("Comment" [Publication Type]) OR "Editorial" [Publication Type])
Scopus	((TITLE-ABS-KEY ("diabetic foot" OR "foot ulcer" OR "high risk foot" OR "plantar ulcer")) OR (TITLE-ABS-KEY (diabetic OR diabetes) AND TITLE-ABS-KEY (foot OR "lower extremity"))) AND (TITLE-ABS-KEY (multidisciplinary OR interdisciplinary OR team OR multispecialty OR specialty OR specialist)) AND (TITLE-ABS-KEY (amputat*) OR (TITLE-ABS-KEY ("lower extremity" OR limb) AND TITLE-ABS-KEY (salvage OR preserv*)))
Cumulative Index to Nursing and Allied Health	((MH "Diabetic Foot") OR "diabetic foot" OR (MH "Foot Ulcer") OR "plantar ulcers" OR "high risk foot") AND ((MH "Multidisciplinary Care Team") OR "patient care team" OR "team" OR “multispecialty” OR “specialty” OR “specialist”) AND ("amputation" OR (MH "Below-Knee Amputation") OR (MH "Limb Salvage") OR "limb preservation")
Cochrane	'("diabetic foot" OR "foot ulcer" OR "high risk foot") AND (multidisciplinary OR interdisciplinary OR team OR multispecialty OR specialty OR specialist) AND (amputat* OR (limb AND (salvage OR preserv*)

Supplementary Table II (online only). Study descriptions

Study	Bias score	Brief description of case and control patients
Chung,[45] 2015	20	All patients referred to a vascular surgery group during the study period were assigned to receive multidisciplinary team care or standard care on the basis of the referring physician's preference.
Weck,[26] 2013	18.5	One hospital system formed a multidisciplinary team, whereas a neighboring hospital system did not. Case patients received care within the first system, and control patients received care in the second, recruited during the same period.
Laakso,[39] 2017	17.5	A multidisciplinary team formed in 2012 and subsequently cared for all patients at their hospital. Case patients were admitted between 2012 and 2013. Control patients were admitted between 2006 and 2007 (before multidisciplinary team formation).
Chiu,[30] 2011	17	A multidisciplinary team formed in 2004. From 2004 to 2009, case patients were randomly chosen to receive multidisciplinary team care. Control patients received care at the same center before team formation (2000-2003). Case and control patients were matched on patient-level variables.
Riaz,[44] 2019	16.5	A multidisciplinary team formed in 2006 and subsequently cared for all patients with a diabetic foot ulcer at their center. Case patients presented from 2006 to 2016. Control patients presented from 1997 to 2006.
Kim,[43] 2018	16.5	A multidisciplinary team formed in 2012 and subsequently cared for all patients admitted to their hospital. Case patients were admitted in the period 2012 to 2015, and control patients were admitted in the period 2002 to 2012.
Crihana,[28] 2014	16.5	A multidisciplinary team was formed in 2011 and subsequently cared for all patients admitted to their hospital. Case patients were admitted in the period January 2011 to December 2013. Control patients were admitted in the period January 2007 to December 2010.
Setacci,[25] 2013	16.5	A multidisciplinary team formed in 2010 and subsequently treated all patients admitted to their hospital. Case patients were treated in the period January 2010 to December 2011. Control patients were admitted between January 2008 and December 2009.
Alexandrescu,[36] 2009	16.5	Multidisciplinary team care for admitted patients was optional until 2005, after which team care was mandatory. Case patients were treated between 2005 and 2008. Control patients were treated between 2001 and 2005. An additional analysis was performed with a group treated in the first 16 months of the mandatory multidisciplinary service.
Martínez-Gómez,[32] 2014	16	An inpatient multidisciplinary team and critical pathway formed in 2000. An outpatient diabetic foot clinic was established in 2005. Control patients without access to either team were treated from 1998 to 2000. Control patients with access to inpatient services only were treated from 2001 to 2005. Case patients with access to both services were treated from 2006 to 2012.
Yesil,[41] 2009	16	A multidisciplinary team formed in 2002 and subsequently treated all patients admitted to the hospital. Case patients were treated from 2002 to 2008. Control patients were treated from 1999 to 2002.
Hedetoft,[48] 2009	16	Control patients received multidisciplinary care after undergoing amputation only. Case patients received multidisciplinary care in the same period (1998-2003) both before and after amputation.
Rerkasem,[37] 2008	16	A multidisciplinary team formed in August 2005 and subsequently treated all patients with diabetic foot ulcers at the hospital. Case patients were treated between August 2005 and March 2007. Control patients were treated between August 2003 and July 2005.
Dargis,[27] 1999	16	Multidisciplinary team care was determined by the patient's geographic location. Case patients were treated at the hospital within the same period. Control patients were treated in outpatient clinics in other cities.
Jiménez,[17] 2017	15.5	A multidisciplinary team formed in 2008 and subsequently treated patients enrolled in the diabetic foot ulcer clinic. Case patients were treated from 2008 to 2014. Control patients were treated from 2001 to 2007.
Wang,[49] 2016	15.5	A multidisciplinary team was formally implemented in 2006 and subsequently cared for all patients admitted. Case patients were treated from 2006 to 2013. Control patients were treated from 2004 to 2006 while the multidisciplinary team was being trained.

Supplementary Table II (online only). Continued.

Study	Bias score	Brief description of case and control patients
Plusch,[47] 2015	15.5	Control group patients did not interface with the outpatient multidisciplinary team in the 12 months leading up to hospitalization for diabetic foot infection. Concurrent case patients attended at least one appointment with the outpatient team up to 12 months before their admission.
Cahn,[31] 2014	15.5	A multidisciplinary team was formed at the end of 2010. Case patients were treated between January and October 2011. Control patients were treated between January and October 2010.
Denjalić,[23] 2014	15	A standardized, conservative multidisciplinary approach was implemented in 2003 and subsequently treated all admitted patients. Case patients were treated between 2003 and 2006. Control patients were treated between 1999 and 2003.
Nather,[42] 2010	15	A multidisciplinary team was formed in 2003 and subsequently treated all admitted patients. Control patients were treated before team formation in 2002 as well as in the year of transition to the multidisciplinary approach in 2003. Case patients were treated between 2004 and 2007.
Crane,[22] 1999[a]	15	A multidisciplinary critical pathway was formed in 1995 and subsequently treated hospitalized patients at an admitting physician's discretion, yielding a "non-pathway" control as well as a historical control. The historical control group was treated in 1993. The non-pathway control group was treated between 1995 and 1996. Case patients were also treated between 1995 and 1996.
Hsu,[46] 2015	14.5	A multidisciplinary team formed in 2010 and subsequently enrolled patients through various inpatient and outpatient avenues as well as through the emergency department. Case patients were treated between 2010 and 2013. Control patients were treated between 2004 and 2010.
Armstrong,[34] 2012	14.5	A multidisciplinary team was formed in 2008 and subsequently treated all patients at the center who had undergone surgery for diabetic foot ulcer. Case patients were treated between 2008 and 2010. Control patients were treated between 2006 and 2008.
Witsø,[50] 2010	14.5	A multidisciplinary diabetic foot team was established in 1996 and subsequently treated referred outpatients. Case patients were treated between 2004 and 2007. Control patients were treated between 1994 and 1997.
Aydin,[14] 2010	14.5	A multidisciplinary team was formed in 2000 and subsequently cared for all patients in the hospital. One control group was treated before the team formed between 1992 and 1996. A second control group was treated just after implementation of the team from 2000 to 2002. These groups were compared with case patients treated between 2002 and 2007.
Meltzer,[29] 2002	14.5	A multidisciplinary team was formed in the mid-1990s. The exact date is unclear. Case patients were treated from 1995 to 1998. Control patients were treated before team formation between 1990 and 1993.
Anichini,[33] 2007	14	A multidisciplinary team and referral pathway established in 1999 subsequently treated outpatients captured or referred in. Case patients were treated from 2000 to 2003. Control patients were treated in 1999.
Nason,[38] 2013	13.5	A multidisciplinary team was formed in 2008 and subsequently treated all patients admitted to the hospital. Case patients were treated between 2008 and 2010. Control patients were treated between 2006 and -2008.
Holstein,[35] 2000	2000	A multidisciplinary team was formed in 1993 and subsequently treated all patients admitted to the hospital. Case patients were treated between 1993 and 1996. Control patients were treated between 1981 and 1993.
Gibbons,[24] 1993		It is unclear when a multidisciplinary approach was formally implemented. Case patients were treated in 1990 and control patients in 1984 before the team implementation.
Troisi,[51] 2016	11.5	A multidisciplinary team was established in March 2014 and subsequently treated all patients in the region. Case patients were treated between March 2014 and February 2015. Control patients were treated between March 2013 and February 2014.
McGill,[40] 2003		Case patients were treated at an outpatient multidisciplinary clinic and control patients were treated at another facility.

[a]Crane et al 1999 used both retrospective cohort and historically controlled (pre-post) designs.