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REVIEW ARTICLE

PREDICTING WALKING ABILITY FOLLOWING LOWER LIMB AMPUTATION: A SYSTEMATIC REVIEW OF THE LITERATURE

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Objective: **To investigate factors that predict walking with a prosthesis after lower limb amputation.**
Design: **Systematic literature review.**
Methods: **A computer-aided literature search of MEDLINE, EMBASE, CINAHL and the Cochrane Library was performed to identify studies published up to August 2007 that investigated factors that predicted walking ability after lower limb amputation.**
Results: **A total of 57 studies were selected. Predictors of good walking ability following lower limb amputation include cognition, fitness, ability to stand on one leg, independence in activities of daily living and pre-operative mobility. Longer time from surgery to rehabilitation and stump problems are predictors of poor outcome. The impact of the cause of amputation on walking varies between studies. In general, unilateral and distal amputation levels, and younger age were predictive of better walking ability. Sex probably does not have a significant influence on walking ability.**
Conclusion: **The heterogeneity of methods and outcome measures used in the identified studies make comparison difficult and, in part, explains conflicting conclusions in relation to predictive factors. Further investigation of predictive factors is needed to estimate walking potential more accurately and guide targeting of modifiable factors to optimize outcome after lower limb amputation.**

Key words: amputation, rehabilitation, prognosis, mobility limitation, review.

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INTRODUCTION

Lower limb amputation not only affects people's ability to walk, but may impact on their participation in valued activities, body image perception and quality of life. However, quality of life after lower limb amputation is significantly associated with mobility (1), and reduced ability to walk with a prosthesis is associated with lower activities of daily living scores (2, 3) and a lower level of social activity (4).

Lower limb amputation incidence rates vary greatly in the literature. In part, this reflects the variation between countries, but also the study population selected in each. It ranges from 0.2 per 10,000 total population for first major amputation in Japan, to 115.7 per 10,000 population aged over 90 years in Sweden (5). There is similar diversity in the cause of amputation, with trauma accounting for the majority of amputations in India, and dysvascularity the predominant cause in most developed countries (6).

Following lower limb amputation a proportion of individuals will successfully learn to use a prosthetic limb. Depending on the sample studied and the definition of what constitutes "success", this proportion may be as low as 5% (7) or as high as 100% (8). Better walking ability with a prosthesis is associated with its increased use following rehabilitation (9) and successful prosthetic rehabilitation has been shown to be significantly associated with an increased chance of living at home after lower limb amputation (10). However, it is difficult accurately to predict mobility following rehabilitation with a prosthetic limb.

The ability to estimate an individual's potential to walk with a prosthesis is important as this influences the type of prosthesis that will be suitable. This prediction can also be useful in informing amputees as to the likely outcome of rehabilitation and thus help them plan for future environmental requirements, such as at home, work or for social activities. A better understanding of the influence of various factors on walking potential will assist with this.

This systematic review forms the first part of a larger research project investigating mobility following lower limb amputation. The purpose of the review is to establish which factors are already known to predict walking ability with a prosthesis following lower limb amputation and which require further investigation to clarify their impact.

METHODS

Search strategy for identification of studies

A computer-aided literature search was performed using MEDLINE (from 1950), EMBASE (from 1974), CINAHL (from 1982) and the Cochrane Library using the following keywords: amput*, ambulat*, mobil*, walk, predict*, prognos* and probability. References from the identified studies were also examined to extend the search.

Studies that satisfied the following inclusion criteria were selected:

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- the studies involved adult subjects with unilateral or bilateral amputation of a lower limb;
- the studies were published before August 2007, and;
- the studies examined the relationship between predictor variables recorded prior to amputee rehabilitation and measures of walking ability following rehabilitation. Studies using health outcomes with a mobility component, such as the Functional Independence Measure, were also included.

No language restriction was applied. Retrospective studies were included if data were available regarding one or more predictor variables prior to rehabilitation. Studies evaluating prosthetic devices or rehabilitation interventions were not included. Animal studies, case reports, letters and editorials were also excluded. Two authors (KS and VN) independently assessed selected papers for quality. Where there was disagreement these papers were also reviewed by a third author (ROC).

The quality of each study was assessed using the rating method from the UK National Service Framework for Long-term Conditions (11). Unlike other assessments of methodological quality designed for reviews of randomized controlled trials, this allows assessment of quality in non-randomized cohort studies, such as those included in this review. This approach has face validity and has been used in other rehabilitation systematic reviews and in the formulation of national guidelines in the UK (12).

Using this method articles were scored out of 10, with up to 2 points awarded for each of the following 5 items:

- Are the research question/aims and design clearly stated?
- Is the research design appropriate for the aims and objectives of the research?
- Are the methods clearly described?
- Is the data adequate to support the authors' interpretations/conclusions?
- Are the results generalizable?

Those scoring 3 or less are considered of poor quality, scores of between 4 and 6 are regarded as medium quality and those scoring 7 or more are judged as high quality.

Using a standardized checklist, data were abstracted regarding each study's methodology, population, what outcome measures were used and what predictive factors were investigated. These data were independently verified by 2 authors (KS and VN). Owing to the heterogeneity of the selected studies in terms of wide variations in the timing of data collection, selection of subjects and outcome measures used, it was not possible to perform a meta-analysis of the data.

The International Classification of Functioning, Disability and Health (ICF) (13) was used to present the predictive factors identified from these studies. This approach allows integration of the biomedical and social models of functioning and disability into a single classification system. Functioning is divided into the components of *Body Functions and Structures* and *Activities and Participation,* which interact with contextual factors (*Environmental and Personal Factors*) and the *Health Condition* to determine an individual's health experience (Fig. 1).

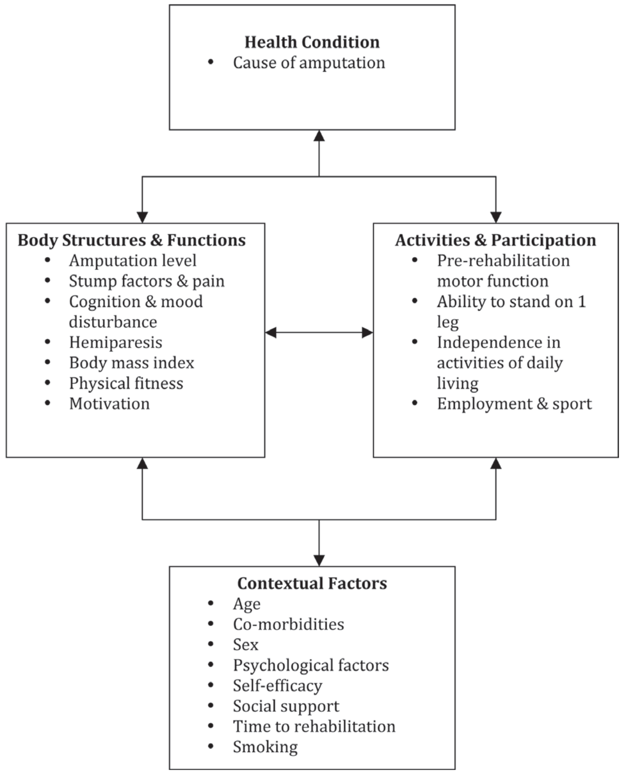

Fig. 1. Predictive factors of walking ability after lower limb amputation investigated in the literature.

RESULTS

A total of 57 studies satisfying the inclusion criteria were identified. These are summarized in Table I. Nineteen were of high quality, 25 were of medium quality and 13 of poor quality.

Due to the variation in methods used, comparison of the results was difficult. The time at which information about predictive factors was collected differed between studies, with some factors recorded pre-amputation and others retrieved retrospectively in established prosthetic users. Thirty-five (61%) were retrospective cohort studies, gathering data from clinical records or participant recall. The remainder used a prospective cohort design. The majority of studies looked at more than one factor, and the potential for each factor to predict walking ability, although multivariate regression analysis was used infrequently, with simple tests of association such as χ^2 more commonly employed (Table II).

Selection of subjects varied. Some studies included only certain age groups, amputation levels or causes, whereas others included all subjects who had undergone a lower limb amputation. Many studies only included subjects thought to have good ambulatory potential, often assessed using non-standardized methods, such as clinician evaluation. There was also great diversity in the measures used to assess walking ability, ranging from validated measures, such as the Timed Up and Go test, to patient reported use of prostheses.

Health condition

Cause of amputation. An association between the cause of amputation and walking potential was reported in 5 studies (14–18), with subjects undergoing an amputation for dysvascularity achieving a poorer outcome than those due to trauma or other non-vascular causes. Four studies did not find any significant relationship between the cause of amputation and achieved walking ability (19–22). However, the sizes of the groups undergoing amputation following trauma in these 4 studies were small, ranging from 12 to 17 individuals, which may explain the lack of significance of their findings.

After amputation for dysvascularity, no difference in walking ability was found when comparing primary amputation

Table I. *Summary of studies included in literature review*

First author/year	Population	*n*	Walking ability measure(s)	Results	Quality
Datta 1992 (2)	Bilateral	41	Modified Volpicelli mobility grade	Trend towards poorer mobility with bilateral AKA or stump problems.	High
Collin 1992 (3)	All levels	37	10 timed walk, use of prosthesis & wheelchair	Age related to walking speed, but not walking status. Pre-amputation walking status correlated with walking outcome, but not speed.	Medium
Gerhards 1984 (4)	Unilateral AKA, Trauma	178	Rated by interviewer – exact method not stated	Better walking pattern in those more involved in sports at the time of amputation.	Poor
Narang 1984 (6)	All levels	500	Ambulatory ability	More independent walking after BKA than AKA or bilateral amputation.	Medium
Brunelli 2006 (8)	Hemiplegia, unilateral TFA	45	Locomotor Capabilities Index	Better outcome with ipsilateral disability and mild hemiparesis.	Medium
Dawson 1995 (10)	PVD	81	Ability to walk with prosthesis	Dependency for self-care is an independent predictor of poor walking ability.	Medium
Geertzen 2005 (14)	All fitted with a prosthesis	437	Patient reported walking distance	More likely to report able to walk more than 500 m if amputation not due to diabetes or PVD and TTA rather than TFA.	Medium
Volpicelli 1983 (15)	Bilateral	103	Ambulatory ability with prosthesis (Volpicelli mobility grade)	Age <60 years, distal amputation and non-dysvascular predictive of better ambulation status.	Medium
Davies 2003 (16)	Unilateral	281	Harold Wood Stanmore Mobility Grade	Better mobility with distal level and younger age. Better mobility with non-vascular cause, only significant after TTA.	Medium
Ng 1996 (17)	TTA	59	Volpicelli mobility grade	Better outcome in younger and non-dysvascular subjects.	High
Burger 2001 (18)	Unilateral, >60 years,	28	9 min timed walk and 10 m Timed Up and Go test	Subjects after TTA or amputation due to trauma walked faster and further than those with TFA or amputation due to dysvascularity.	Medium
Johnson 1995 (19)	Unilateral TTA	120	Volpicelli mobility grade	Better pre-amputation mobility, younger age and absence of cardiac disease and diabetes predictive of better mobility.	Medium
Chin 2006 (20)	Unilateral AKA, >60 years	49	Able to walk at least 100 m with no aids or one cane	Higher $\%VO_{2max}$ associated with success. No association of walking ability and age, cause or level of amputation	High
Munin 2001 (21)	Unilateral	75	Ability to walk at least 45 m with prosthesis	Younger age and absence of contractures predictive of success. BMI, sex, smoking, co-morbidities and living alone not predictive.	High
Melchiorre 1996 (22)	50% trauma, 50% PVD	24	FIM and amputation FIM subscores	No difference between trauma and PVD groups.	Poor
Nehler 2003 (23)	PVD	79	Ambulatory ability with prosthesis	Ambulatory outcome the same following primary amputation or after attempted revascularization. No effect of mental illness and/or substance abuse on walking.	Medium
Hubbard 1989 (24)	PVD	92	Ambulatory ability	Fewer subjects with AKA achieved ambulation with 1 or 2 sticks.	Medium
Gauthier-Gagnon 1999 (25)	Unilateral	396	Locomotor Capabilities Index	More likely to be able to walk indoors without aids and achieve higher Locomotor Capabilities Index advanced scores after TTA than TFA.	High
Burger 1997 (26)	Traumatic amputation	223	Reported use of walking aids and outdoor walking distance	Subjects walking without aids were on average 6 years younger at the time of amputation. Greater daily walking distances after TTA than TFA.	Medium
Viejo 1998 (27)	Unilateral	78	Day's Assessment of Amputee Activity	More likely to use wheelchair after AKA than BKA. Younger age associated with better mobility.	Medium
Varghese 1978 (28)	Hemiplegia	30	Ambulatory ability	Better outcome with age ≤ 65 years, more distal amputation level, right hemiplegia and amputation preceding stroke (no statistical analysis reported).	Poor
McWhinnie 1994 (29)	PVD, unilateral	100	Walking ability with prosthesis	Trend toward better walking rates after below knee amputation, but only significant in first 3 months.	Poor
Gugulakis 2000 (30)	PVD, unilateral	64	Walking ability with prosthesis	Non significant trend for better walking ability after BKA.	Medium
Taylor 2005 (31)	All levels	553	Ambulatory ability	Maintenance of ambulation predicted by preoperative mobility, level, heart disease, age and dementia. Diabetes, smoking and previous vascular surgery not predictive.	High

Table I. *Contd.*

First author/year	Population	*n*	Walking ability measure(s)	Results	Quality
Moore 1989 (32)	All levels	157	Daily use of prosthesis for ambulation	Better outcome after distal and unilateral amputation. Worse if heart disease and bilateral or AKA, but not BKA. No difference in relation to sex, diabetes, lung disease or severe musculoskeletal disease.	Medium
Gauthier-Gagnon 1998 (33)	Unilateral	396	Prosthetic Profile of the Amputee	Age, amputation level and co-morbidities associated with increased use of prosthesis, but not independent factors in the regression model.	High
O'Connell 1989 (34)	Hemiplegia	46	Independence in ambulation	Milder hemiplegia, BKA, ability to walk after first disability and continence were predictors of independence.	High
Helm 1986 (35)	All levels	107	Functional use of prosthesis	Poorer outcome with increasing age, AKA or bilateral amputation and post-operative stump pain.	Poor
Steinberg 1985 (36)	> 65 years	114	Functional use of prosthesis	More likely to use a prosthesis after BKA. Better outcome if age < 75 years.	Poor
Pöhlmann 1994 (37)	PVD, unilateral	277	Ambulation with aids or wheelchair	Better outcome with younger age, male, BKA, absence of co-morbidities.	Medium
Turney 2001 (38)	All levels	87	Harold Wood Stanmore Mobility grade	Better mobility after BKA than AKA. No association between mobility and age, sex, diabetes, amputation cause and previous vascular surgery.	Poor
Siriwardena 1991 (39)	PVD	598	Walking Ability Index	Better outcome with distal and unilateral level, < 60 years, no heart disease, hemiplegia or bronchitis. No effect with diabetes.	Poor
Larsson 1998 (40)	Diabetic with foot ulcers	189	Walking distance	More likely to regain ability to walk ≥ 1 km at one year after amputation below rather than above level of the ankle.	High
O'Toole 1985 (41)	PVD, unilateral	60	Barthel mobility subscores	Age > 70 years associated with poorer mobility outcome	Poor
Heinemann 1994 (42)	All rehabilitation admissions	1400	FIM	Younger age and higher admission cognitive scores associated with higher motor FIM scores on discharge	High
MacKenzie 2004 (44)	Trauma Unilateral	161	Sickness Impact Profile, FIM and 100ft timed walk	Walking speed fastest after BKA, slowest after TKA. Men faster than women. Poorer independence in functional mobility following TKA.	High
Chakrabarty 1998 (45)	Unilateral	85	Harold Wood Stanmore mobility grade and modified Day activity score	Trend towards better outcome with higher quality stumps.	Poor
Pohjolainen 1991 (46)	Unilateral	155	Functional use of prosthesis	Younger age, absence of cardiovascular disease or pain, shorter time to fitting and employed at fitting associated with better outcome	High
Traballesi 2007 (47)	Bilateral AKA PVD	30	Locomotor Capabilities Index	Stump flexion deformity negatively predictive of walking ability.	High
Blume 2007 (48)	Transmetatarsal amputation	80	Not stated	More likely to be ambulant if wound healed at 3 months post-surgery.	Medium
Hanspal 1997 (49)	Unilateral	32	Harold Wood Stanmore mobility grade	Cognitive and psychomotor assessment scores were positively correlated with mobility outcome	Medium
Larner 2003 (50)	PVD, unilateral	43	Able to don/doff and walk with prosthesis ± aids independently	Memory test (Kendrick Object Learning Test) and distal amputation predictive of outcome. Age, anxiety, depression and locus of control measures not predictive.	High
Chiu 2000 (51)	Hemiplegia, unilateral	23	Ability to walk indoors and in community	Intact mental status associated with successful community ambulation.	Medium
Schoppen 2003 (52)	PVD, > 60 years unilateral	46	Timed Up and Go test, ambulatory ability with prosthesis, Groningen activity restriction scale	1-leg balance and depression score at 2 weeks associated with Timed Up and Go test at one year. Age, co-morbidity, 1-leg balance, depression score and cognition associated with Groningen activity restriction scale at one year. Social support not predictive.	High
Altner 1987 (53)	Hemiplegia, PVD	52	Ambulatory ability with prosthesis	No effect of side of hemiplegia, laterality of dual disability, order of impairment, gender or age on outcome.	High
Kalbaugh 2006 (54)	PVD	434	Ambulatory ability with prosthesis	Pre-operative BMI not an independent predictor of maintenance of ambulation status	High

Table I. *Contd.*

First author/year	Population	*n*	Walking ability measure(s)	Results	Quality
Chin 2002 (55)	Unilateral TFA, >60 years	17	Able to walk at least 100 m	Higher %VO_{2max}, better ability to stand on one leg and older age associated with ability to walk 100 m.	Medium
Zijp 1992 (56)	All levels	61	Able to walk ± aids	MDT graded motivation significantly associated with walking ability. Sex, cardiac problems and diabetes not associated.	High
Hermodsson 1998 (57)	Unilateral TTA, PVD	112	Functional use of a prosthesis	Male gender and pre-op ability to walk outdoors independently predictive of good outcome at 6 months.	Medium
Leung 1996 (58)	All levels	41	Houghton Scale	Age and admission FIM motor subscore did not predict success.	Medium
Traballesi 1995 (59)	Unilateral, PVD, AKA, ≥65 years	59	Rivermead Mobility Index	Admission Barthel Index and shorter time to rehabilitation predictive. Admission mobility, age, sex, and side of amputation not predictive.	Medium
Traballesi 1998 (60)	PVD, unilateral TFA	144	Rivermead Mobility Index	Better outcome if age < 65 years, high admission Barthel Index and normal Doppler. No effect from gender or diabetes.	Poor
Greive 1996 (61)	Unilateral	20	ICIDH questionnaire	Those with diabetes reported poorer mobility than those without diabetes.	Poor
Czyrny 1994 (62)	All levels, PVD	38	Ability to ambulate with prosthesis	No difference between groups with and without end stage renal disease.	Medium
Neumann 1998 (63)	10% prior stroke	194	Distance walked & walking aid use	Less likely to be able to walk more than 30 m if prior stroke	Medium
Pinzur 1988 (64)	All levels	60	Volpicelli ambulation grade	Poorer ambulatory outcome in those with abnormalities on cognitive or personality testing.	Poor
Williams 2004 (65)	Unilateral	89	Mobility subscale of the CHART	Greater perceived social support, younger age and male sex associated with better reported mobility at 1 and 6 months.	High

AKA: above knee amputation; BKA: below knee amputation; BMI: body mass index; CHART: Craig Handicap Assessment and Reporting Technique; FIM: Functional Independence Measure; ICIDH: International Classification of Impairments, Disabilities, and Handicaps; PVD: peripheral vascular disease; TFA: transfemoral amputation; TKA: through knee amputation; TTA: transtibial amputation.

with amputation following attempted revascularization (23, 24).

Body functions and structures

Amputation level. The majority of studies reported better walking ability after distal and unilateral amputations compared with more proximal or bilateral amputations (2, 6, 14–16, 18, 24–40). As well as longer walking distances and greater domestic activity levels measured by Day's Assessment of Amputee Activity, individuals after transtibial amputation used a wheelchair less frequently than those after transfemoral amputation (27). A trend towards increased frequency of independent wheelchair use and transfers in those with through knee compared with above knee amputations has been reported (15). The long residual limb after through knee amputation acts as a long lever to aid sitting balance and has been advocated in those amputees unlikely to be able to walk. The finding that those with more distal amputations achieve better walking ability has also been identified in a population with levels ranging from transfemoral to toe amputation (40). Those with an amputation distal to the ankle were significantly more likely to regain the ability to walk 1 km one year post-surgery than those with more proximal amputations.

Not all articles reported an association between amputation level and walking outcome (20, 21, 41, 42). Although mostly of medium to high quality, limitations in the methodology used may explain the findings. Two studies only selected subjects thought to have good potential to walk with a prosthesis (20, 21). Two others used generic measures: Barthel mobility scores and FIM motor scores (41, 42). Neither outcome measure captures specific attributes of interest, such as walking speed, and both display a ceiling effect in lower limb amputees (43). When self-selected walking speed was compared in subjects with unilateral below, through or above knee amputation after trauma (44), significant differences were found after adjustment for potential confounders between the groups, with the below knee group walking the fastest.

Stump factors and pain. A trend towards better walking ability has been reported in those with better quality stumps (45) and fewer stump problems (2) after amputation. Poorer functional use of a prosthesis (35) and shorter walking distances at one year (46) have also been associated with pain in the stump and phantom pain. However, one high quality study exploring walking ability after bilateral above knee amputation for vascular disease concluded that stump pain was not a significant predictor in this group (47).

Longer stump length is significantly associated with superior walking distance at one year after below knee amputation (46). A similar association was found in the above knee amputation group in the study, but this did not reach significance.

As expected, contractures in the remaining lower limb joints has a negative effect on walking potential (21, 47),

Table II. *Methods and predictive factors investigated by included studies*

First author/year	Main analysis	Predictive factors investigated: Cause of amputation	Amputation level	Stump factors & pain	Cognition & mood disturbance	Hemiparesis	Body Mass Index	Physical fitness	Motivation	Pre-rehabilitation motor function	Ability to stand on one leg	Independence in activities of daily living	Employment & sport	Age	Co-morbidities	Sex	Psychological factors	Self-efficacy	Social support	Time to rehabilitation	Smoking
Datta 1992 (2)	Descr	×	×	×										×		×					
Collin 1992 (3)	Ass/corr									×				×							
Gerhards 1984 (4)	Discr an												×								
Narang 1984 (6)	Descr		×																		
Brunelli 2006 (8)	Mult reg	×				×								×		×					
Dawson 1995 (10)	Mult reg		×									×		×							
Geertzen 2005 (14)	Mult reg	×	×																		
Volpicelli 1983 (15)	Ns	×	×											×	×	×					
Davies 2003 (16)	Ass/corr	×	×											×							
Ng 1996 (17)	Descr	×												×	×						
Burger 2001 (18)	Ass/corr		×																		
Johnson 1995 (19)	Ass/corr	×								×				×	×						
Chin 2006 (20)*	Ass/corr	×	×					×						×		×					
Munin 2001 (21)	Mult reg	×	×	×			×							×	×	×					×
Melchiorre 1996 (22)	Ass/corr	×												×							
Nehler 2003 (23)	Ass/corr													×			×				
Hubbard 1989 (24)	Ass/corr		×											×	×	×					
Gauthier-Gagnon 1999 (25)	Ass/corr		×																		
Burger 1997(26)	Ass/corr		×											×							
Viejo 1998 (27)	Ass/corr		×											×							
Varghese 1978 (28)	Descr		×			×								×							
McWhinnie 1994 (29)*	Ass/corr		×											×							
Gugulakis 2000 (30)*	Ass/corr		×																		
Taylor 2005 (31)	Mult reg	×	×							×				×	×	×					×
Moore 1989 (32)	Ns		×											×	×	×					
Gauthier-Gagnon 1998 (33)	Mult reg	×	×											×	×	×					
O'Connell 1989 (34)	Ass/corr		×			×								×	×						
Helm 1986 (35)	Mult reg	×	×	×										×	×						
Steinberg 1985 (36)*	Ns		×											×	×	×					
Pöhlmann 1994 (37)	Ass/corr		×											×	×	×					
Turney 2001 (38)*	Ass/corr	×	×											×	×	×					
Siriwardena 1991 (39)*	ANCOVA		×											×	×						
Larsson 1998 (40)*	Ass/corr		×																		
O'Toole 1985 (41)*	2-way ANOVA		×											×	×	×					
Heinemann 1994 (42)	Mult reg		×		×					×				×		×					
MacKenzie 2004 (44)*	Mult reg		×											×	×	×		×	×		×
Chakrabarty 1998 (45)*	Descr		×	×										×							
Pohjolainen 1991 (46)*	Mult reg			×			×						×	×	×	×					×
Traballesi 2007 (47)	Ass/corr	×		×																	
Blume 2007 (48)	Ass/corr			×																	
Hanspal 1997 (49)*	Ass/corr				×										×						
Larner 2003 (50)*	Mult reg		×		×																
Chiu 2000 (51)	Ass/corr		×		×	×								×							
Schoppen 2003 (52)*	Mult reg		×	×	×						×			×	×				×		
Altner 1987 (53)	Ass/corr		×		×	×								×		×					
Kalbaugh 2006 (54)	Mult reg						×														
Chin 2002 (55)*	Ass/corr			×				×		×	×			×	×						
Zijp 1992 (56)	Ass/corr		×						×					×	×	×					
Hermodsson 1998 (57)*	Mult reg									×					×						×
Leung 1996 (58)*	Ass/corr		×							×				×	×	×					
Traballesi 1995 (59)*	Mult reg	×								×		×		×		×				×	
Traballesi 1998 (60)*	Mult reg	×		×								×		×	×	×				×	
Greive 1996 (61)*	Descr														×						
Czyrny 1994 (62)	Ass/corr														×						
Neumann 1998 (63)	Ass/corr														×						
Pinzur 1988 (64)*	Descr									×							×				
Williams 2004 (65)*	Mult reg	×	×											×		×			×		

*Indicates prospective studies. Descr: descriptive; Ass/corr: association/correlation; Discr an: discriminant analysis; Mult ref: multivariate regression; ns: not specified; ANCOVA: analysis of covariance; 2-way ANOVA: 2-way analysis of variance.

as does delayed wound healing (48). Individuals with healed transmetatarsal amputation sites at 3 months following surgery were significantly more likely to be walking than those whose wounds persisted longer. Delayed wound healing was also significantly associated with an increased risk of re-amputation to a more proximal level (48), which did not appear to have been adjusted for in the analysis.

Cognition and mood disturbance. Cognitive ability has consistently been found to be a significant predictor of walking ability following rehabilitation (31, 42, 49–52), with a superior outcome reported in those with better cognitive ability. One study investigated the predictive abilities of measures of anxiety, depression, memory and locus of control (50). In a stepwise logistic regression analysis memory, measured using the Kendrick Object Learning Test, was found to be the only independent predictor of successfully learning to don, doff and walk with a prosthetic limb, correctly predicting outcome in 70% of cases (50). When amputation level was also considered the predictive power increased to 81%. However, Hanspal & Fisher (49) found no such interaction between cognition, amputation level and walking ability, but did report that exclusion of patients with co-existing medical conditions increased the explained variance in walking outcome to 85% from 20% when cognition was considered alone. Although no association was found between mobility and depression as measured by the Hospital Anxiety and Depression Scale (50), a significant association has been reported between the Beck Depression Inventory measured 2 weeks after amputation and the Timed Up and Go test and the Groningen Activity Restriction Scale at one year (52).

Hemiparesis. Several small studies have looked specifically at individuals with the dual disability of lower limb amputation and hemiplegia, attempting to identify factors associated with walking potential. It has been proposed that walking ability may be inferior with ipsilateral impairments (8), or left-sided hemiplegia due to the increased incidence of visuospatial deficits (28). The latter study was, however, of poor quality with no statistical analysis reported. Three studies of medium to high quality found no significant association between walking ability and side of hemiplegia, laterality of the dual disability (ipsilateral or contralateral) or order of impairment (amputation before or after hemiplegia) (34, 51, 53). The only feature of hemiplegia consistently predictive of walking ability after amputation is the degree of motor impairment, with milder weakness associated with a better outcome (8, 34).

Body mass index. One high quality study investigated the impact of body mass index (BMI) prior to amputation on the ability to learn to walk with a prosthesis as its primary objective (54). Only those able to walk pre-operatively were included in the analysis. Those who were underweight (BMI < 18.5 kg/m^2) were significantly less likely to maintain their pre-operative ambulatory status at 3 years than those who were overweight (BMI 25–29.9 kg/m^2). However, after adjusting for medical co-morbidities, age and sex, BMI was not a significant predictor of walking ability (54). A similar finding was reported in 2 further high quality studies where BMI was included as one of many pre-rehabilitation variables investigated (21, 46).

Physical fitness. Two medium to high quality studies with the same first author have looked at physical fitness and its relationship to walking ability following unilateral above knee amputation (20, 55). Both studies used $\%VO_{2max}$ during 1-leg cycling prior to rehabilitation as an index of physical fitness. $\%VO_{2max}$ is the maximum oxygen uptake expressed as a percentage of predicted uptake. Subjects were all aged 60 years or over. In both studies those individuals who were able to walk at least 100 m after rehabilitation had significantly higher pre-rehabilitation $\%VO_{2max}$. The authors concluded that a $\%VO_{2max}$ of at least 50% could be regarded as a guideline value for the level of fitness required for successful ambulation with an above knee prosthesis.

Motivation. A statistically significant association has been reported between patient "motivation" and the ability to learn to walk with a prosthesis (56).This result should, however, be interpreted with caution as the method of grading participants' motivation was subjective, based on a retrospective review of the multidisciplinary patient discussion and physiotherapy records.

Activities and participation

Pre-rehabilitation motor function. Pre-amputation walking status is predictive of walking ability (3, 19, 31, 57), but no correlation has been found between post-operative mobility measured on admission to a rehabilitation facility using the FIM motor subscale or Rivermead Mobility Index and walking outcome (58, 59). It is possible that the presence of transient post-operative complications, such as delayed wound healing, may temporarily affect those motor functions measured by these scales without adversely affecting the ability to learn to walk with a prosthetic limb.

Ability to stand on one leg. The ability to stand on one leg is indicative of better walking potential after unilateral lower limb amputation (52, 55). In one study the addition of this assessment increased the explained variance in the Timed Up and Go test to 42% from 10% when age was considered alone (52).

Independence in activities of daily living. Dependency for self-care prior to amputation is an independent negative predictor of walking ability up to 18 years after surgery (10). A significant association between post-operative Barthel Index scores and walking ability after rehabilitation with a prosthesis has also been described (59, 60).

Employment and sport. One high quality study found that those employed at the time of prosthetic provision achieved a significantly better walking distance, maximum continuous walking time and overall functional use of the prosthesis at one year, even after adjustment for age (46).

Participation in sports prior to an above knee amputation due to trauma has been associated with a better walking pattern (4), although this single study was of poor quality. Researchers rated 7 dimensions of ambulatory performance on 4-point scales, but further details regarding the 7 dimensions, or the scale used were not stated. The association was described as significant although the level of significance was not quoted. This potential association requires further exploration.

Contextual factors

Age. In most studies older age at the time of amputation had an adverse effect on walking potential (15–17, 19, 21, 26, 28, 31, 33–37, 39, 41, 42, 46, 52, 60). There were a number of studies finding no association (3, 20, 24, 38, 53, 55, 58, 59) although 2 of these only selected subjects aged over 60 and 65 years, respectively (20, 59), which may explain their findings. It has been proposed that the apparent association of age with walking ability may be confounded by co-morbidity, as age at amputation is significantly associated with the number of medical conditions an individual has (19). However, 6 studies using multiple regression analyses reported a much stronger dependence of walking ability on age than on co-morbidity (21, 31, 35, 46, 52, 60).

Co-morbidities. The effect of co-morbid conditions on walking outcome is not clear. In the majority of studies investigating the role of co-morbidities the conclusions have been drawn from secondary analyses or in conjunction with other factors. An association between co-morbid conditions and poorer walking has been reported by some (19, 22, 31, 33, 37, 39, 46, 52, 61), with others finding no significant relationship (21, 24, 32, 34–36, 38, 39, 47, 56, 60). Most studies using multiple regression analyses reported no significant independent association between co-morbidity and walking outcome (21, 33, 35, 44, 52, 57, 60), although this was not consistently found in all such studies (46).

Two medium quality studies have investigated the effect of a specific medical condition on walking potential. In the first study (62), a group of 19 lower limb amputees receiving dialysis for renal disease were compared with a group without renal disease, matched for age and, where possible, sex. No significant differences were found between the groups in relation to admission and discharge FIM scores and ability to walk with a prosthetic limb by discharge. These findings are weakened by the small sample size and selection of subjects with good rehabilitation potential. It is possible that a smaller proportion of amputees with renal disease were considered suitable for rehabilitation than those without, although this was not examined.

The potential for referral bias associated with co-morbid conditions was examined in a study looking at the impact of stroke on amputee rehabilitation (63). Stroke was present in a significantly greater proportion of the group not referred for rehabilitation than in the referred group. In subjects prescribed a functional prosthesis, a significantly smaller proportion of those with prior stroke were able to walk more than 30 m. However, similar proportions of those with and without stroke were still using their prosthesis at one year. These findings indicate that lower limb amputees with prior stroke are less likely to be referred for prosthetic rehabilitation. Although they may not achieve as good mobility as those without stroke, they nevertheless can benefit from, and continue to use, a prosthesis, at least in the first year.

Sex. Most studies found no association between sex and walking ability after lower limb amputation (3, 15, 20, 21, 24, 32, 35, 36, 38, 41, 46, 53, 56, 59, 60). In those studies where a significant difference was found, the results were divided, with 3 reporting superior walking ability in men (37, 44, 57) and one reporting a better outcome in women (42).

Psychological factors. The use of psychological testing to predict walking ability after lower limb amputation has been evaluated (64) in subjects who were at least limited household ambulators before amputation. On the basis of psychological testing using a variety of cognitive and personality tests, subjects were classified as good or poor rehabilitation candidates. A greater proportion of those considered good candidates maintained their pre-amputation walking status. However, specific criteria, such as predetermined test cut-off points, were not stated and the article was of poor quality. One study with a high proportion of subjects with mental illness and/or substance abuse at the time of amputation reported no difference in walking outcome in this subgroup (23).

Self-efficacy. One high quality article investigated the impact of self-efficacy, amongst other factors, on walking outcome (44) and used multivariate regression to adjust for potential confounders. Self-efficacy was measured using a 100-point scale before hospital discharge, following amputation due to trauma, and was found to be significantly associated with scores on the Sickness Impact Profile, but not self-selected walking speed.

Social support. Greater perceived social support is predictive of higher mobility subscores from the Craig Handicap Assessment and Reporting Technique (65). Another study using more robust walking ability measures, including the Timed Up and Go, found no significant association with social support (52), although their results should be interpreted with caution as only 46 out of a planned 100 participants completed the study.

Time to rehabilitation. A shorter time interval between surgery and admission for rehabilitation is related to better walking potential (59). Similarly, the length of time taken from surgery to fitting a definitive prosthesis is significantly associated with outcome, with those waiting longer having poorer walking ability at one year (46). These findings could be explained by post-operative complications, such as wound infections, which may delay referral for rehabilitation.

Smoking. A significant association between smoking and walking ability after lower limb amputation was reported by one high quality article (46) in a subgroup consisting of male dysvascular below knee amputees, but this association was not significant when data from the whole of their study population was considered. A second study (37) found walking to be better amongst smokers, but noted that this finding was likely to be confounded by age as smoking was more common in the younger patient groups. No significant association was found in a further 4 studies (21, 31, 44, 57). It would therefore appear that, although smoking is implicated in the aetiology of many amputations, it is unlikely to have a significant impact on mobility outcome.

DISCUSSION

The heterogeneity of methodologies, inclusion criteria and outcome measures used in the studies reviewed makes comparison difficult and, at least in part, may explain the lack of agreement between studies. The literature suggests that those who undergo lower limb amputation due to vascular disease have poorer walking potential than those due to other causes, such as trauma, but to what extent this is attributable to the generally older age and inferior health status in the dysvascular group is uncertain.

By comparison, the evidence for superior walking ability after more distal and unilateral amputation levels is strong. This is likely to be related to the increased energy requirements to walk with above knee and bilateral prostheses (66).

Better walking is also achieved in those without stump problems, such as delayed wound healing and contractures. There is, however, greater uncertainty regarding the effect of pain on walking potential. In part this may reflect the variety of outcome measures used in the different studies, as pain may have a smaller influence on performance in short tests than those requiring prolonged use of a prosthesis. The finding that longer stump length is associated with greater walking distances in transtibial amputees (46) is potentially due to reduced energy requirements from what is effectively a longer lever arm. These findings, however, should be treated with caution as a longer stump may take longer to heal, particularly in individuals with dysvascularity, and may also make prosthetic fitting more challenging and reduce the choice of prosthetic limb components.

Impaired cognitive ability is predictive of poorer walking ability following lower limb amputation. There is evidence to suggest that mood disturbance negatively influences walking potential, but this is inconclusive and warrants further investigation. Cognitive impairment can often be linked to mood disorders and further research should attempt to disentangle their effects. There is also uncertainty regarding the influence specific features of hemiplegia have on walking in those who also have a lower limb amputation. This is not surprising as only a minority of amputees will also have hemiplegia, making larger adequately powered studies difficult.

Body mass index does not independently influence walking potential, although low weight can be a marker of poorer health status that may adversely affect outcome. Perhaps not surprisingly, there is strong evidence that physical fitness is predictive of walking ability.

To many working in the field it may seem self-evident that motivation influences outcome following amputation. However, the evidence to support this assertion is weak, as the single study in which this factor was considered used subjective grading of motivation by clinicians working with the patient. Given also that it was graded during, rather than before rehabilitation, it is possible that superior functional progression may have been the cause, rather than the result of better motivation. Further research which adequately addresses the difficulties in measuring motivation is needed to clarify this potential association.

Pre-operative walking status is positively predictive of walking ability after rehabilitation. However, post-operative motor function was not. This may be due to transient impairment of mobility by post-operative complications in this early period, which have a lesser impact on eventual mobility. There is good evidence that independence in activities of daily living and the ability to stand on one leg are associated with better walking outcome. It is likely that these factors are acting as markers of other attributes, such as physical strength, balance or cognition, rather than having a direct impact on outcome.

The evidence to suggest that participation in sporting activities and employment prior to rehabilitation leads to better walking outcomes is limited, although potential confounding factors such as better health status or motivation were not examined in these studies and so warrant further examination.

There is reasonably strong evidence that younger age at amputation results in superior walking ability, which is not unexpected given that fitness levels tend to decrease with age. However, this should not be the only factor considered when deciding whether someone would be suitable for provision of a prosthesis, as it is still possible for individuals over 90 years of age to walk independently following lower limb amputation (67).

The literature indicates that sex is unlikely to have a significant influence on walking ability after lower limb amputation. There is greater uncertainty regarding the influence of co-morbidities however. This is surprising, in that it could be assumed that poorer health status would impact negatively on walking ability, particularly given the additional energy requirements to walk with a prosthesis. The disagreement between studies may, at least in part, be related to variability in methodology, with definitions of medical conditions differing between studies. For example, only participants on diabetic medication were classified as diabetic by Moore et al. (32), while others included those using diet control in their analyses. Moore et al. also included symptomatic vascular claudication in the contralateral limb in their musculoskeletal disease category, although the reasons for doing so were not stated. Another methodological consideration is that many studies did not control for confounding factors associated with co-morbid conditions, such as the association of diabetes with amputation at a younger age (61) and a greater ratio of below to above knee amputations (68).

The effect of psychological factors on walking ability is uncertain. The single study in which these were considered was of poor quality and used a variety of psychological measures differing between subjects (64). Statistical analysis of the results was not reported and it did not appear that potential confounders, such as age or level of amputation, were controlled for.

There is weak evidence that self-efficacy is not predictive of walking ability. The single study in which this was included did not use a validated measure of self-efficacy and only recruited those whose amputation was due to trauma. Further investigation using a more robust scale in a less selective population is required to draw any conclusions regarding the impact of self-efficacy on outcome. There is also uncertainty regarding the influence of social support on walking after rehabilitation given the weaknesses present in the studies that included it. Further, adequately powered studies using validated outcome measures are required to clarify its effect. There is good evidence that a shorter length of time between amputation surgery and rehabilitation is predictive of better walking ability, although this could be due to postoperative complications, which may impact negatively on mobility as well as delaying rehabilitation. Smoking is a risk factor for amputation due to dysvascularity, but it appears to have little effect on eventual mobility.

Outcome after lower limb amputation is multidimensional. This review was limited to walking outcome only and therefore did not consider other consequences of amputation that may also be important, such as changes in body image and psychological effects. The impact of different prostheses and rehabilitation methods was also not examined.

Although there have been many studies investigating predictors of walking ability, given the limitations discussed in this review, prospective adequately powered studies controlling for relevant factors are required to look at the predictive ability of factors measured before the onset of rehabilitation. This knowledge could then be used to estimate an individual's walking potential more accurately, which in turn would help both patients and clinicians. The effect of changing those predictive factors that are modifiable, such as mood disturbance, could be explored further in order to establish whether targeting these factors would lead to improvements in walking outcome.

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