Gait Analysis of the Lower Limb in Patients with Rheumatoid Arthritis: A Systematic Review

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Introduction: In rheumatoid arthritis (RA), signs and symptoms of feet and ankle are common. To evaluate the dynamic function of feet and ankles, namely walking, a variety of gait studies have been published. In this systematic review, we provide a systematic overview of the available gait studies in RA, give a clinimetrical assignment, and review the general conclusions regarding gait in RA.

Methods: A systematic literature search within the databases PubMed, CINAHL, sportdiscus, Embase, and Scopus was described and performed and delivered 78 original gait studies that were included for further data extraction.

Results: The clinimetrical quality of the 78 included RA gait studies measured according a tailored QUADAS item list and proposed clinimetrical criteria by Terwee and coworkers are moderate. General conclusions regarding the walking abnormalities of RA patients point to a slower walk, longer double support time, and avoidance of extreme positions. Frequently found static features in RA are hallux valgus, pes planovalgus, and hind foot abnormalities.

Conclusions: Gait studies in RA patients show moderate clinimetrical properties, but are a challenging way of expressing walking disability. Future gait research should focus on more uniformity in methodology. When this need is satisfied, more clinical applicable conclusions can be drawn.
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In rheumatic conditions, especially rheumatoid arthritis (RA), signs and symptoms of the feet are prevalent. The majority of the RA patients present with arthritis of the feet and 20% of them have radiographic damage at the time of diagnosis (1). The prevalence of radiographic damage of the feet increases over time up to 80% at a disease duration of 5 years (2). Obviously, other involvement of the lower limb such as involvement of the ankle can additionally result in substantial disability (3).

When measuring disease activity, damage, or function of the foot, the applied instruments like radiograph, magnetic resonance imaging, laboratory tests, and questionnaires are static. The obtained information is used for decisions on intervention, follow-up, and outcome evaluation. These methods fail however by definition to give information on dynamic function. With the development of clinical gait analysis (especially 3D kinetics and kinematics), a dynamic instrument is within reach, and it is possible to describe normal walking patterns and distinguish them from pathological patterns. Advancing computer technology and software facilitate the investigator in gathering, adapting, and interpreting the gait data and have since led to an increasing interest for gait analysis as a tool for measuring joint function in RA, in particular, of the foot and ankle (4-16).

A variety of gait studies have been published. These studies are heterogeneous. The lack of uniformity in methodology and gait models often prevents comparison. A systematic review on foot and ankle instruments has been published earlier (15), but this review included other functional outcome measures than gait alone, like self-reported questionnaires and a variety of pain- and function-related scoring systems. Moreover, it was mainly fo-

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cused on the clinimetrical properties of the studies and did not include the knee and hip. Another review by Rankine and coworkers describes multisegmental foot models, but this was not a systematic review and focuses solely on kinematic foot models (16).

In the present study, we systematically reviewed all gait studies involving adult RA patients. All studies reporting kinetic, kinematic, plantar pressure data, muscle mechanics, and electromyographic data were investigated.

Kinematic variables address motion, independent of the forces that cause the movement. Linear and angular displacements and velocities of the joint as well as of whole body mass are measured. For example, the foot models used in gait analysis of RA patients are based on the protocol of Carson or a variation, like the protocol developed by the Heidelberg group (17,18). Reflective markers are attached to the skin in a standardized manner and patients are asked to walk several times a certain distance up and down at a self-selected speed. Several cameras record the course of the markers (raw data) and afterward intersegment and joint angles are calculated using special software. Then postprocessing is performed for averaging, normalization of the data to the gait cycle, graphical representation, and temporospatial calculations.

Kinetics is the term that describes the forces that cause the movement. Force is that which can cause an object with mass to change its acceleration and consequently its position. Forces can be internal (from muscles, ligaments) or external (gravity). Kinetic variables are important in gait analysis, because they give information on what causes the movement of the joint or the limb, movement strategies, and neural compensation.

Muscle mechanics describes the variation in mechanical properties and characteristics of the muscles, how they can vary in length and tension with every action, and how neural recruitment affects this.

EMG (electromyography) is the registration of the primary signal to describe the input to the muscular system. EMG shows a nonlinear relationship with muscle tension. Sometimes there is significant neural activation, without a single muscle movement. Therefore, EMG covers more than the resulting movement of the muscle. This has especially been useful in the assessment and treatment of cerebral palsy and has led to new operation techniques and better planning of surgical procedures.

In the present study, we aim to give a systematic overview of gait analysis in RA. The first goal of this study is to provide a complete overview of gait studies in RA patients and to review the clinimetrical properties of them. The second goal is to outline the main results and conclusions regarding the aberrant walking pattern of RA patients.

METHODS

All studies included in this systematic review were original articles addressing gait in RA patients. The selected studies used kinematic, kinetic, muscle mechanics, and EMG data as outcome measure. We searched the electronic databases PubMed, CINAHL, Embase, Scopus, and Sportdiscus. Pertinent narrative review articles and reference lists of key articles were searched for further relevant publications. Two authors (HB and RD) independently screened articles for inclusion in the full-text review by an initial screen of all titles and abstracts retrieved from the search strategy. Articles were included if they reported data from an original study in which RA patients or at least a subcohort were subjected to gait analysis. Any articles identified from the first screen by either reviewer as possibly relevant to the study question were brought forward to the full-text review.

Full text review was undertaken as the next step. Articles were included in the systematic review if (1) they reported original data on RA patients >17 years; (2) the language was English, Dutch or German; (3) they reported original data on foot/ankle, knee, or hip gait analysis. Moreover, abstracts, books, theses, and conference proceedings were not included. Finally, all articles' references were searched manually for additional eligible studies. A description of the aim and methodology was extracted from the selected articles, including used measures, study population, aim, and, when applicable, intervention. For the purpose of clinimetrical assignment, we used a tailored QUADAS item list, as proposed by the QUADAS study group. Only the items that applied to this type of research were used (ie, the items regarding the comparison of a new instrument compared with the reference standard were left out). The used QUADAS items were scored as yes, no, or unclear and are summarized in Table 1. Moreover, according to the proposed quality criteria on clinimetric properties by Terwee and coworkers (17), the following items were assessed: internal consistency, agreement, reliability, construct validity, responsiveness, and interpretability. They are summarized in Table 2.

RESULTS

On November 17, 2010, we conducted the search of PubMed, EMBASE, CINAHL, and Scopus according to the methodology described. We searched for publications in English, German, or Dutch language on the following search terms: RA AND foot OR ankle OR rear foot OR hind foot OR hip OR knee AND gait OR kinematics OR kinetics OR plantar pressure. Appendix 1 supplies the complete search strategy. We obtained the following number of abstracts from the searches: 565 in PubMed, 117 in Embase, 172 in CINAHL, and 473 in Scopus. After screening abstracts, 249 studies seemed eligible for full text review. Completing full-text reading, 73 studies remained eligible for review and data extraction. After checking the references of the included studies, another 5 articles were added, resulting in 78 full-text articles.

The included studies all fulfilled the listed criteria and reported original gait data on RA patients, the language was English, Dutch or German, and foot/ankle, knee, or hip gait analysis studies were included.

Table 1 Summary of the Used QUADAS Items

QUADAS 1 item	Was the spectrum of patients representative of the patients who will receive the test in practice?	Addresses the generalizability
QUADAS 2 item	Were selection criteria clearly described?	Concerns all relevant information regarding how participants were selected for inclusion in the study
QUADAS 8 item	Was the execution of the index test described in sufficient detail to permit replication of the test?	Addresses whether a study reports a sufficient detailed description of the execution of test method to permit replication of the test
QUADAS 10 item	Were the index test results interpreted without knowledge of the results of the reference standard?	Checks if the study clearly states that the test results were interpreted blind to the results of the other tests.
QUADAS 12 item	Were the same clinical data available when test results were interpreted as would be available when the test is used in practice?	Addresses the availability of clinical data during interpretation of test results that may affect estimates of test performance.
QUADAS 13 item	Were uninterpretable/intermediate test results reported?	A diagnostic test can produce an uninterpretable/indeterminate/intermediate result with varying frequency depending on the test. These problems are often not reported in diagnostic accuracy studies with the uninterpretable results simply removed from the analysis. This may lead to the biased assessment of the test.
QUADAS 14	Were withdrawals from the study explained?	If patients lost to follow-up differ systematically from those who remain, for whatever reason, then estimates of test performance may be biased.

The selected studies were classified according to their measurement concept and method to the following categories:

- Plantar pressure measurement with the EMED system
- Plantar pressure measurement using F-scan
- Other or not specified plantar pressure measurement methods
- Studies reporting temporospatial data
- 3D gait studies
- EMG studies

A mixed group with studies of range of motion, kinetic data, nerve conduction, and röntgen stereophotogrammetry.

Forty-seven of the 78 publications reported on plantar pressure measurement data; 18 used EMED; 6 used F-scan, and there was a miscellaneous group. Thirty-five of the 78 studies reported data regarding temporospatial variables. Only 16 studies reported on 3-dimensional variables, 2 used EMG, 1 used Rontgen stereophotogrammetry, 6 used range of motion, 3 reported on kinetic data, and 1 article studied nerve conduction.

For the results of the description of the studies concerning the methodology, measurement concept, study population, aim, and intervention, Table 3 gives a complete overview.

In Table 4, which is supplementary data that can be found at http://www.semarthritisrheumatism.com, we present the results of the scoring of the tailored QUADAS list. The first QUADAS item (Was the spectrum of patients representative of the patients who will receive the test in practice?) was nearly always scores as yes. In 3 studies, the studied population was not described adequately. The second QUADAS item (Were selection criteria described?) was present in 59 of the 78 studies. QUADAS item 8 (Was sufficient description of the index test reported) was met in 68 of the 78 studies. QUADAS item 10 (Were the test results interpreted without knowledge of the results of the reference standard?) was positive in 24 of the studies, and most of them scored NA. QUADAS Item 12 (Were the same clinical data available when test results were interpreted as would be available when the test is used in practice?) was scored as a yes in 74 of the studies. QUADAS item 13 (Were uninterpretable/intermediate test results reported?) was scored in 47 studies, and QUADAS item 14 (Were withdrawals from the study explained?) was only mentioned in 14 of the 78 studies.

The clinimetric properties are shown in Table 5, supplementary data found at http://www.semarthritisrheumatism.com. None of the studies reported on all items. Only 18 of the 78 (23%) studies fulfilled (positive or indeterminate) more than 1 of the criteria. The studies that scored positive (+) or indeterminate (?) on 1 or more items are summarized in Table 2. The item internal consistency was given an indeterminate score in only 2 studies. The item agreement was indeterminate 13 times and a positive score once. Reliability was scored as indeterminate 21 times and as positive 4 times. Construct validity was scored as indeterminate 35 times and given a positive score 3 times. Responsiveness was indeterminate 15 times and positive 2 times. Interpretability was the most frequently met criterion; it was assessed as indeterminate 52 times and as positive 15 times.

The second goal of our review was to summarize the results and the findings of the studies regarding the gait of

Table 2 Quality Criteria on Clinimetric Properties

Item	Definition	Scoring
Internal consistency	The extent to which items in a (sub)scale are intercorrelated, thus measuring the same construct	+ Factor analyses performed on adequate sample size (7 × no of items) AND Cronbach's alpha(s) calculated per dimension in a sample size of at least 50 patients AND Cronbach's alpha(s) >0.70 ? No factor analysis OR doubtful design or method OR sample size too small − Cronbach's alpha(s) <0.70, despite adequate design and method 0 No information found on internal consistency
Agreement	The extent to which the scores on repeated measures are close to each other (absolute measurement error)	+ (Minimal important change (MIC) OR 0.5 × standard deviation (SD)) > Smallest detectable change (SDC) OR (MIC OR 0.5 SD) outside the limits of agreement (LOA) AND SDC and MIC both determined in a sample size of at least 50 patients ? Doubtful design or method or sample size <50 − (MIC OR 0.5 × SD) < SDC OR (MIC OR 0.5 SD) inside LOA, despite adequate design 0 No information found on agreement
Reliability	The extent to which patients can be distinguished from each other, despite measurement errors	+ Intraclass correlation coefficient (ICC) or kappa >0.70 with the lower limit of the confidence interval >0.60 or a sample size of at least 50 patients ? Doubtful design or method (eg, time interval not mentioned, Pearson correlation) OR ICC or kappa >0.70 with the lower limit of the confidence interval 0.60 or sample size <50 − ICC or kappa <0.70, despite adequate design and method 0 No information found on reliability
Construct validity	The extent to which scores on a particular instrument relate to other measures in a manner that is consistent with theoretically derived hypotheses concerning the concepatients that are being measured	+ Specific hypotheses were formulated AND at least 75% of the results are in accordance with these hypotheses in a sample of at least 50 patients ? Doubtful design or method OR sample size <50 − Less than 75% of the hypotheses were confirmed despite adequate design and methods 0 No information found on construct validity
Responsiveness	The instrument's ability to detect important change over time in the concept being measured	+ Specific hypotheses were formulated AND at least 75% of the results are in accordance with these hypotheses in a sample of at least 50 patients ? Doubtful design or method OR sample size <50 − Less than 75% of the hypotheses were confirmed despite adequate design and methods 0 No information found on responsiveness
Interpretability	The degree to which one can assign qualitative meaning to quantitative scores	+ Mean and SD scores presented of at least 2 relevant subgroups of patients in a sample size of at least 50 patients ? Doubtful design or method OR less than 2 subgroups OR sample size <50 0 No information found on interpretation

RA patients, that what is traditionally known as the "rheumatoid shuffle" can be more meticulously defined. Some plantar measurement studies revealed that plantar pressures in RA patients are higher, especially the static plantar pressure (19,20). This may not be true for early RA patients (21). Some investigators found a higher pressure under the first and second ray of the metatarsals (22,23); others report that on the outer metatarsals, especially, the pressure was higher (24). There are however studies that could not confirm a higher plantar pressure in RA patients (25,26). When higher plantar pressure was found in RA patients, it was in most studies, but not in all, associated with clinical variables like pain and erosions. Exact reasons for high pressures in RA are not given, but it has been suggested that antalgic walking patterns, to avoid pain under the forefoot while walking, may lead to higher pressures elsewhere. Hallux valgus, lesser toe deformities, and severe hind foot disease also cause higher forefoot pressures (27). When corrective measures were applied (ie, orthoses or corrective surgery), both plantar pressure distribution and clinical signs and symptoms can improve, but are not necessarily correlated (28-31).

With respect to temporospatial parameters, RA patients tend to walk slower, with a longer gait cycle, a

Table 3 Description of the Studies

Method/Measurement Concept	Year of Publication	Target Population	Study Population	Study Number
Plantar pressure EMED (1-20)				
Bitzan (1)	1997	RA patients	26 feet in 16 patients after forefoot surgery	16
Davys (3)	2005	RA	RA patients	38
Giacomozzi (4)	2009	RA, selection on basis of the HAQ	RA and healthy subjects	112 RA patients; 30 healthy
Hodge (5)	1999	RA	RA with forefoot pain	12
Mulcahy (6)	2003	RA patients after forefoot surgery	RA patients after forefoot surgery	100 feet in 61 patients
Philipson (7)	1994	Inflammatory arthritis	11 RA, 1 SLE, 3 nonspecific foot deformities	15
Rosenbaum (8)	2006	RA	25 RA patients, 21 healthy controls	46
Samnegard (9)	1990	RA	10 RA patients, post surgery feet	10 RA patients, 10 healthy controls
Schmiegel (10)	2008	RA	RA patients and healthy controls	112
Schmiegel (11)	2008	RA	RA patients and healthy controls	16 RA patients, 21 healthy controls
Semple (12)	2007	RA	RA patients and healthy controls	74 RA, 53 matched controls
Tastekin (13)	2009	RA	RA and heel valgus	50 RA patients
Tuna (14)	2005	RA	RA	50 RA patients, 50 healthy controls
Turner 2006 (15)	2006	RA	RA with foot problems	12 RA patients, 12 controls
Turner 2008 (16)	2008	RA	RA	74 RA patients, 54 controls
Turner 2008 (17)	2008	RA	RA with forefoot/hind foot or combined problems	28 RA patients, 50 healthy controls
Van de Leeden (18)	2004	RA	RA	20 patients with inflammatory disease, 15 RA, 1 SpA, 1 JIA, 2 PsA

Table 3 Continued

Measure(s)	AIM	Intervention/Treatment
Plantar pressure	To evaluate resection of all MT heads in RA patients	Forefoot surgery. Resection of metatarsal heads
Plantar pressure	To compare forefoot pain, pressure, and function before and after normal and sham callus treatment in RA	Prescription of insoles for patients with painful rheumatic foot deformities
Pressure, peak force, pressure time integral, force time integral, PPC, and NFC	To detect gait alterations in RA patients using peak pressure curves (PPC) and normalized force curves (NFC) in comparison wit the HAQ	None
Plantar pressure gait velocity	To investigate the effectiveness of foot orthoses in the management of plantar pressure and pain in subjects with RA	Four styles of foot orthosis were compared
Area of contact (cm^2), pressure time integral (PTI; Ns/cm^2), and peak pressures (N/cm^2)	To compare the functional, radiographic, and pedobarographic results of different reconstructive methods for severe rheumatoid forefoot deformities	Two types of reconstructive forefoot surgery were compared:
Plantar pressure, peak pressure. PTI. Contact areas	To determine how effective forefoot arthroplasty is at reducing the pressures under the forefoot	Forefoot arthroplasty
Dynamic plantar pressure. Plantar sensitivity	To investigate the tactile sensitivity of the plantar surface in rheumatoid feet and its relationship to walking pain and plantar foot loading characteristics	None
Plantar pressures	Examination of 10 RA patients with an EMED gait analysis system in a mean 4 yr after foot surgery and compared that with 10 normal subjects	Four years after forefoot surgery. No preoperative measurement
Pedobarography	To evaluate the use of pedobarographic measurements for detecting changes in plantar loading characteristics and their relationship to foot pain in RA	None
Pedobarography	To compare RA patients' clinical, radiographic, and pedographic status to investigate the relationship between mechanical damage and plantar pressure distribution under the forefoot	None
Pedobarography	To undertake a comparison of the regionalized duration and velocity of the center of pressure between RA patients with foot impairments and healthy able-bodied adults	None
Plantar pressure	To document the plantar pressure distribution changes in RA patients with heel valgus and to compare results in those without valgus.	None
Plantar pressure	To assess probable plantar pressure alterations in RA patients compared with normals and the probable relation between pressure and radiologic foot erosion score	None
Temporospatial data, plantar pressure. Gait analysis	To compare clinical disease activity, impairment, disability, and foot function in normal and early RA	None
Temporospatial data, plantar pressure. Gait analysis	To evaluate biomechanical foot function and determine factors associated with localized disease burden in patients with this disease.	None
Temporospatial data, plantar pressure. Gait analysis	To describe the clinical and biomechanical characteristics of patients with severe rearfoot, forefoot, or combined deformities and determine localized disease impact	None
Plantar pressure	To compare the reproducibility of measurements among 1-step, 2-step, and 3-step protocols for data collection in patients with arthritis	None

Table 3 Continued

Method/Measurement Concept	Year of Publication	Target Population	Study Population	Study Number
Van de Leeden (19)	2006	RA	RA	62 RA patients with foot complaints
Woodburn (20)	2000	RA	RA	8 RA patients with 14 callosities
Plantar pressure				
F-scan (21-26)				
Grondal (21)	2006	RA patients	RA patients	14 plantar pressure, 12 gait data.
Jackson (22)	2004	RA	RA patients, 9 female, 1 male	10
Li (23)	2000	RA	RA	12 RA patients, 8 healthy controls
Novak (24)	2009	RA patients	RA patients	12
Vidmar (25)	2009	RA	RA patients with forefoot complaints	12 RA
Woodburn (26)	1996	RA	RA and healthy controls	104 RA, 42 controls
Plantar pressure otherwise or not specified (27-49)				
Andriacchi (27)	1977	Patients with knee disability	Patients with knee disability. 11 OA, 5 RA; 17 healthy normals	16
Barrett (28)	1976	RA patients	RA patients with callosities at the MTPs	25
Beauchamp (29)	1984	RA patients	RA patients who underwent forefoot surgery	37
Betts (30)	1988	RA patients	RA patients pre- and post-Kates Kessel	60 feet in 35 RA patients, 18 feet in 10 controls
Carl (2)		RA	20 RA patients with painful foot deformities who were provided with insoles	20
Collis (31)	1972	RA	RA patients	10 healthy feet, 10 rheumatoid feet
Dereymaeker (32)	1997	RA	RA patients who underwent forefoot reconstruction	38
Firth (33)	2007	RA patients	RA	10
Godfrey (34)	1967	RA	RA? and volunteers	?
Hamilton (48)	2001	RA	24 early RA patients	24 early RA
Harris (49)	1997	RA	RA patients who underwent forefoot surgery	35

Table 3 Continued

Measure(s)	AIM	Intervention/Treatment
Plantar pressure	To assess the relationship between forefoot joint damage and foot function, pain, and disability in patients with foot complaints secondary to RA	None
Plantar pressure	To determine the effect of expert debridement of foot callosities on forefoot pain and plantar pressure distribution in RA	Debridement of callosities
Stride data, plantar pressure	To study the effect of the difference between the Mayo resection vs arthrodesis in RA forefoot reconstruction	Forefoot surgery in RA patients
Plantar pressure	To determine which design could better manage high forefoot plantar pressures in patients with RA	Two prefab insoles
Plantar pressure	To compare the foot pressures and loading forces during gait in RA patients and healthy subjects and evaluate the effects of foot orthoses in RA	Prescription of foot orthoses
Plantar pressure	To compare foot orthoses and unshaped orthotic material on plantar pressure, pain reduction, and walking ability in RA	Foot orthosis (functional or unshaped)
Plantar pressure	To assess reliability of the F-scan plantar pressure measurement system in RA patients	None
Plantar pressure	To investigate the relation between the position of the rearfoot and the distribution of forefoot plantar pressures and skin callosities in RA.	None
Temporospatial parameters, plantar pressure	To examine 2 types of gait parameters (temporal and ground reaction force) obtained from normal subjects and patients with knee joint disabilities	None
Plantar pressure points	To discuss the role of shoe-wear in the treatment of painful metatarsalgia in RA patients and to evaluate a special sandal developed for this purpose	Treatment of metatarsalgia with special sandal
Plantar pressure	To compare joint fusion MTP1 with excision of the MTP1	To compare 2 types of forefoot arthroplasty (MTP1 fusion or excision)
Plantar pressure	To assess the results of forefoot arthroplasty in both a prospective study group of 60 feet and in a retrospective study group of 18 feet	Forefoot surgery (Kates Kessel)
Plantar pressure	To examine the clinical effectiveness of insoles and to establish pedobarography as a means of quality control for orthotic management of the rheumatic foot	Insoles
Plantar pressure	To measure the pressures under the different parts of the foot and describe the pressure pattern for normal feet and some of the changes that occur in RA	None
Plantar pressure	To evaluate the results after forefoot reconstruction	Forefoot reconstruction
Plantar pressure	Validity and reliability of pressurestat in patients with RA	None
Plantar pressure	To introduce a new method of pressure measurement during walking	None
Plantar pressure, stride data	To assess the clinical usefulness of a prototype walkmat system in patients with early RA	None
Plantar pressure	To present a prospective 10- to 16-yr clinical and pedobarographic evaluation of a modification to the Kates et al forefoot arthroplasty	Kates forefoot arthroplasty

Table 3 Continued

Method/Measurement Concept	Year of Publication	Target Population	Study Population	Study Number
Henessy (35)	2007	RA	RA with forefoot pain	20
Masson (36)	1989	RA, DM	RA and diabetes patients	37 RA patients, 38 diabetic patients
Minns (37)	1984	RA/normals	RA patients and healthy controls	124 RA, 67 normal subjects
Otter (39)	2004	RA	RA patients	25 early RA. 25 controls
Rome (40)	2009	RA	RA patients	19 RA, 21 healthy controls
Sharma (41)	1979	RA	RA patients and controls	27 RA patients, 30 volunteers
Siegel (42)	1995	RA	6: 4 RA, 1 excessive pronation, 1 healthy subject	6: 4 RA, 1 excessive pronation, 1 healthy subject
Simkin (43)	1981	RA	RA	18 RA. 20 controls
Stauffer (44)	1977	Knee diseased, OA and RA	OA and RA	65 OA (108 knees) and 30 RA (54 knees). 29 healthy volunteers
Stockley (45)	1989	RA	RA after surgery	35 patients
Stockley (46)	1990	RA	RA	47 feet in 28 RA patients
Turner 2003 (47)	2003	RA	RA patients with pes planovalgus	23 RA patients 23 age-matched controls
Temporospatial data (4,5,14-17,21,27,43,44, 47,48,50-72)				
Giacomozzi (4)	2009	RA, selection on basis of the HAQ	RA and healthy subjects	112 RA patients; 30 healthy
Hamilton (48)	2001	RA	24 early RA patients	24 early RA
Hodge (5)	1999	RA	RA with forefoot pain	12
Tuna (14)	2005	RA	RA	50 RA patients, 50 healthy controls
Turner (15)	2006	RA	RA with foot problems	12 RA patients, 12 controls
Turner (16)	2008	RA	RA	74 RA patients, 54 controls
Turner (17)	2008	RA	RA with forefoot/hind foot/combined problems	28 RA patients, 50 healthy controls
Grondal (21)	2006	RA patients	RA patients	14 plantar pressure, 12 gait data.
Andriacchi (27)	1977	Patients with knee disability	Patients with knee disability. 11 OA, 5 RA; 17 healthy normals	16
Simkin (43)	1981	RA	RA	18 RA. 20 controls

Table 3 Continued

Measure(s)	AIM	Intervention/Treatment
Plantar pressures and pressure time integral	To evaluate the effect of running footwear as an alternative to off-the-shelf orthopaedic footwear on plantar pressure	Running shoes vs orthopaedic footwear
Plantar pressure, nerve conduction velocity	To examine the relationship between high foot pressure, neurological abnormalities, and ulceration in RA and DM	None
Plantar pressure	To compare static and dynamic forces in a large cohort	None
Plantar pressure	To investigate the magnitude and duration of peak forefoot plantar pressures in RA	None
Gait data, center of pressure	To evaluate postural stability in RA patients	None
Plantar pressure	To quantify the force distribution under the feet of patients and controls of similar age and weight.	None
Gait variables, plantar pressure	A technique to measure foot function during the stance phase of gait is described. Advantages of the method include its 3-dimensional approach with anatomically based segment coordinate systems	None
Stride parameters, vertical + local forces	Measuring the dynamic force distribution under the foot in RA and normals	None
Stride parameters, vertical forces	Biomechanical parameters of knee joint function for 95 patients (162 knees) with RA and degenerative joint disease were studied and compared with those for 29 normal subjects	None
Pressure under forefoot	The modified Kates et al. metatarsal head resection arthroplasty has been evaluated in RA	A modified Kates procedure
Pressure under forefoot	To assess the relationship between hind foot deformity and forefoot pressure in 28 RA after forefoot	Forefoot reconstruction Kates. Kessel. Kay (1967)
Temporospatial data, joint angles, plantar pressures	To compare gait and foot function between RA patients with painful pes planovalgus deformity and healthy age- and sex-matched adults	None
Pressure, peak force, pressure time integral, force time integral, PPC, and NFC	To detect gait alterations in RA patients using peak pressure curves (PPC) and normalized force curves (NFC) in comparison wit the HAQ	None
Plantar pressure. Stride data	To assess the clinical usefulness of a prototype walkmat system in patients with early RA	None
Plantar pressure gait velocity	To investigate the effectiveness of foot orthoses in the management of plantar pressure and pain in RA	Four styles of foot orthosis were compared
Plantar pressure	To assess plantar pressure alterations in RA patients compared with normal and in relation with erosion scores	None
Temporospatial data, plantar pressure. Gait analysis	To compare clinical disease activity, impairment, disability, and foot function in normal and early RA	None
Temporospatial data, plantar pressure. Gait analysis	To evaluate biomechanical foot function and determine factors associated with localized disease burden in patients with this disease	None
Temporospatial data, plantar pressure. Gait analysis	To describe the clinical and biomechanical characteristics of patients with severe rearfoot, forefoot, or combined deformities and determine localized disease impact	None
Stride data, plantar pressure	To study the effect of the difference between the Mayo resection vs arthrodesis in RA forefoot reconstruction	Forefoot surgery in RA patients
Temporospatial parameters, plantar pressure	To examine 2 types of gait parameters (temporal and ground reaction force) obtained from normal subjects and patients with knee joint disabilities	None
Stride parameters, vertical + local forces	Measuring the dynamic force distribution under the foot in RA and normals	None

Table 3 Continued

Method/Measurement Concept	Year of Publication	Target Population	Study Population	Study Number
Stauffer (44)	1977	Knee diseased, OA and RA	OA and RA	65 OA and 30 RA, 29 normals
Turner 2003 (47)	2003	RA	RA patients with pes planovalgus	23 RA patients 23 age-matched controls
Brinkmann (50)	1985	Patients with arthritis of the knee	RA/OA	72 healthy adults, 69 RA, and 20 OA
Eastlack (51)	1991	RA patients	RA patients with abnormal gait	3
Eppeland (52)	2009	RA patients	Asymptomatic RA patients	17
Fransen (53)	1997	RA patients	RA patients	30
Fransen (54)	1999	RA patients	RA patients	31
Fransen (55)	1994	RA patients	RA patients and normal subjects	113 RA patients, 104 normal subjects
Gyory (56)	1976	Knee patients	RA, OA, and healthy controls	65 OA, 29 healthy, 30 RA patients
Isacson (57)	1988	RA	Female RA patients <50 yr	17
Kavlak (58)	2003	RA	RA patients	18
Keenan (59)	1991	RA	RA patients	20
Kettelkamp (60)	1972	RA	RA patients with knee problem?	27
Khazzam (61)	2007	RA	RA patients	22 RA patients, 29 feet
Laroche (62)	2007	RA with forefoot damage	RA patients	9 RA patients with malalignment of the forefeet, 7 controls
Laroche (63)	2005	RA with forefoot damage	RA patients	9 RA patients with malalignment of the forefeet, 7 controls
Locke (64)	1984	RA with ankle and subtalar	25 RA patients, 20 healthy subjects	25 RA patients, 20 healthy subjects
Long (65)	2003	RA patients	RA patients before + after surgery	10 RA
MacSween (66)	1999	RA patients	RA patients with and without orthoses	8 RA patients
Marshall (67)	1980	RA patients	RA patients with subtalar involvement	6 RA patients with subtalar involvement
Mejjad (68)	2004	RA	RA patients with metatarsalgia	16
Murray (69)	1975	Total hip patients	Total hip patients	30 patients with total hip, of which 4 RA patients

Table 3 Continued

Measure(s)	AIM	Intervention/Treatment
Stride parameters, vertical forces	To compare biomechanical parameters of knee joint function for 95 patients (162 knees) with RA and normal subjects.	None
Temporospatial data, joint angles, plantar pressures	To compare gait and foot function between RA patients with painful pes planovalgus deformity and healthy age- and sex-matched adults	None
Gait velocity, range of motion	To determine the relationship between gait velocity and rate and ROM knee, during ambulation, for healthy and arthritic subjects	Total knee replacement
Videotaped observational gait-analysis (VOGA)	To determine the interrater reliability of videotaped observational gait-analysis (VOGA) assessments	None
Gait parameters	To investigate the characteristics of gait in RA vs controls	None
Gait variables	To assess the effectiveness of off-the-shelf orthopedic footwear in RA	Prescription of orthopedic footwear
Gait variables	To assess the reliability and responsiveness of gait speed, cadence, and stride length at 2 self-selected speeds (SSS) in RA	None
Gait/stride parameters	Differences in the gait parameters at 3 different self-selected speeds between 113 subjects with RA and 104 normal controls	None
Gait variables, motion of the knee	To study functional performance of the knee joints of 29 normal volunteers, 65 OA patients, and 30 RA patients	None
ROM, gait velocity stride parameters	Detecting early aberrations of gait in RA 17 women suffering from that disease were examined	None
Physiologic cost index (PCI), stride data, VAS pain	To determine the effect of foot orthoses on pain, gait, and energy expenditure in patients with RA	Different orthotic interventions
Electromyography, gait/stride data, ROM	To investigate the cause of valgus hind foot in RA and to characterize the effects of the deformity on gait	None
Stride data, floor reaction force	To correlate various clinical characteristics to gait abnormalities in the rheumatoid knee	None
Temporospatial parameters	To examine specific changes in segmental foot motion in patients with RA as compared to normals subjects	None
Stride parameters, duration, kinematic data	To investigate the modifications of gait parameters in RA. To extract the mechanisms used to compensate for these impairments	None
Walking frequency, walking velocity, stride length, duration	To evaluate the effects of loss of ROM of the MTP joint on the kinematic parameters of walking in RA	None
ROM, stride data	To document ankle and subtalar motion during gait in 20 healthy subjects and in 25 RA patients, to determine stride characteristics with and without the use of an extended orthosis in RA patients	Use of an extended University of California Biomechanics Laboratory orthosis
Temporospatial, kinematic	A new series of 10 RA patients are evaluated before and after surgical intervention	Forefoot surgery, not specified
Temporospatial parameters	To study the effect of custom molded EVA foot orthoses on walking ability in RA	Use of a custom molded foot orthosis
Temporospatial, kinematic	To describe changes in the orientation of ankle and subtalar axes in RA	None
Spatiotemporal gait variables	To assess the efficacy of foot orthoses in RA patients with pain and if improvement of pain was related to an improvement in gait	Cross over design: orthotics of 10 mm semiflexible mat
ROM, muscle strength, CoP, stride parameters. Forces cane/crutch	To measure function before and at 6 and 24 mo after 100 McKee-Farrar total hip replacements in 83 patients	McKee-Farrar total hip replacement

Table 3 Continued

Method/Measurement Concept	Year of Publication	Target Population	Study Population	Study Number
Platto (70)	1991	RA	RA patients	31
Weiss (71)	2007	RA + ankle surgery	RA	14 RA patients, 14 matched controls
Woodburn (72)	2004	RA	RA	11 RA, 5 healthy volunteers
3D gait (14-17,38,42,47,51,57,65,67,71-75)				
Tuna (14)	2005	RA	RA	50 RA patients, 50 healthy controls
Turner (15)	2006	RA	RA with foot problems	12 RA patients, 12 controls
Turner (16)	2008	RA	RA	74 RA patients, 54 controls
Turner (17)	2008	RA	RA with forefoot/hind foot or combined problems	28 RA patients, 50 healthy controls
O'Connell (38)	1998	RA	10 RA, 7 healthy subjects	17
Siegel (42)	1995	RA	6: 4 RA, 1 excessive pronation, 1 healthy subject	6: 4 RA, 1 excessive pronation, 1 healthy subject
Turner (47)	2003	RA	RA patients with pes planovalgus	23 RA patients 23 age-matched controls
Eastlack (51)	1991	RA patients	RA patients with abnormal gait	3
Isacson (57)	1988	RA	Female RA patients <50 yr	17
Long (65)	2003	RA patients	RA patients before + after surgery	10 RA
Marshall (67)	1980	RA patients	RA patients with subtalar involvement	6 RA patients with subtalar involvement
Weiss (71)	2007	RA + ankle surgery	RA	14 RA patients, 14 matched controls
Woodburn (72)	2004	RA	RA	11 RA, 5 healthy volunteers
Weiss (73)	2008	RA	RA and controls	50 RA, 37 healthy subjects
Woodburn (74)	2002	RA	RA	50 RA + orthosis, 48 RA controls, and 45 controls
Woodburn (75)	1999	RA	RA and healthy	10 RA, 10 controls
EMG (59,76)				
Keenan (59)	1991	RA	RA patients	20
Garling (76)	2005	RA with TKA	RA with TKA	7

Table 3 Continued

Measure(s)	AIM	Intervention/Treatment
Stride data	We evaluated the relationships among pain, structural deformity of the foot, 4 variables of gait, and an index of function in 31 RA patients	None
3D gait analysis, kinetic, and time distance parameters	To evaluate the effects of ankle/hind foot arthrodesis in RA on gait pattern of the knee and hip	Ankle joint surgery
3D kinematics, temporospatial parameters	To test a multisegment foot model for kinematic analysis during walking in RA patients with foot impairments	None
Plantar pressure	To assess plantar pressure alterations in RA patients compared with normal and in relation with erosion scores	None
Temporospatial data, plantar pressure. Gait analysis	To compare clinical disease activity, impairment, disability, and foot function in normal and early RA	None
Temporospatial data, plantar pressure. Gait analysis	To evaluate biomechanical foot function and determine factors associated with localized disease burden in patients with this disease	None
Temporospatial data, plantar pressure. Gait analysis	To describe the clinical and biomechanical characteristics of patients with severe rearfoot, forefoot, or combined deformities and determine localized disease impact	None
Plantar pressure, ankle ROM	To evaluate how painful metatarsal arthritis affects foot and ankle mechanics and mobility	None
Gait variables, plantar pressure	A technique to measure foot function during the stance phase of gait is described. Advantages of the method include its 3-dimensional approach with anatomically based segment coordinate systems	None
Temporospatial data, joint angles, plantar pressures	To compare gait and foot function between RA patients with painful pes planovalgus deformity and healthy age- and sex-matched adults	None
Videotaped observational gait-analysis (VOGA)	To determine the interrater reliability of videotaped observational gait-analysis (VOGA) assessments	None
ROM, gait velocity stride parameters	Detecting early aberrations of gait in RA, 17 women suffering from that disease were examined	None
Temporospatial, kinematic	A new series of 10 RA patients are evaluated before and after surgical intervention	Forefoot surgery, not specified
Temporospatial, kinematic	To describe changes in the orientation of ankle and subtalar axes in RA	None
3D gait analysis, kinetic, and time distance parameters	To evaluate the effects of ankle/hind foot arthrodesis in RA on gait pattern of the knee and hip	Ankle joint surgery
3D kinematics, temporospatial parameters	To test a multisegment foot model for kinematic analysis during walking in RA patients with foot impairments	None
3D gait analysis, ground reaction forces	To analyze kinematic and kinetic gait changes in RA in comparison to healthy controls and to examine whether HAQ scores were associated with gait parameters	None
3D kinematics of the AJC	To evaluate the efficacy of custom foot orthoses for the management of painful rearfoot in RA	Prescription of custom foot orthoses
3D kinematics of the AJC	To determine the feasibility of using electromagnetic tracking (EMT) for quantifying 3D kinematics at the ankle joint complex (AJC)	Footwear/orthotic intervention in 10 RA
Electromyography, gait/stride data, ROM	To investigate the cause of valgus hind foot in RA and to characterize the effects of the deformity on gait	None
EMG	To assess the differences in muscle activity (surface EMG) between 2 types of TKA in RA	TKA

Table 3 Continued

Method/Measurement Concept	Year of Publication	Target Population	Study Population	Study Number
Other: Rontgen stereophotogrammetry (77)				
ROM (38,52,56,57,64,69)				
Kinetic data (71,73,78)				
Nerve conduction (36)				
Rontgen stereophotogrammetry				
Eberhardt (77)	1986	RA patients	RA patients with knee damage	4
ROM				
O'Connell (38)	1998	RA	10 RA, 7 healthy subjects	17
Eppeland (52)	2009	RA patients	Asymptomatic RA patients	17
Gyory (56)	1976	Knee patients	RA, OA and healthy controls	65 OA, 29 healthy, 30 RA patients
Isacson (57)	1988	RA	Female RA patients <50 yr	17
Locke (64)	1984	RA with ankle and subtalar	25 RA patients, 20 healthy subjects	25 RA patients, 20 healthy subjects
Murray (69)	1975	Total hip patients	Total hip patients	30 patients with total hip, of which 4 were RA patients
Kinetic data				
Weiss (71)	2007	RA + ankle surgery	RA	14 RA patients, 14 matched controls
Weiss (73)	2008	RA	RA and controls	50 RA, 37 healthy subjects
Sakauchi (78)	2001	RA	RA patients with knee problems	14 RA patients, 7 healthy subjects
Nerve conduction				
Masson (36)	1989	RA, DM	RA and diabetes patients	37 RA patients, 38 diabetic patients

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Table 3 Continued

Measure(s)	AIM	Intervention/Treatment
Roentgen stereo photogrammetry	To demonstrate the usefulness of röntgen stereophotogammetry, to locate the axis of rotation	None
Plantar pressure, ankle ROM	To evaluate how painful metatarsal arthritis affects foot and ankle mechanics and mobility	None
Gait parameters	To investigate the characteristics of gait in RA vs controls	None
Gait variables, motion of the knee	To study functional performance of the knee joints of 29 normal volunteers, 65 OA patients, and 30 RA patients	None
ROM, gait velocity stride parameters	Detecting early aberrations of gait in rheumatoid arthritis, 17 women suffering from that disease were examined	None
ROM, stride data	To document ankle and subtalar motion during gait in 20 healthy subjects and in 25 RA patients, to determine stride characteristics with and without the use of an extended orthosis in RA patients	Use of an extended University of California Biomechanics Laboratory orthosis
ROM, muscle strength, CoP, stride parameters. Forces cane/crutch	To measure function before and at 6 and 24 mo after 100 McKee-Farrar total hip replacements in 83 patients	McKee-Farrar total hip replacement
3D gait analysis, kinetic, and time distance parameters	To evaluate the effects of ankle/hind foot arthrodesis in RA on gait pattern of the knee and hip	Ankle joint surgery
3D gait analysis, ground reaction forces	To analyze kinematic and kinetic gait changes in RA in comparison to healthy controls and to examine whether HAQ scores were associated with gait parameters	None
Angular changes were analyzed by an EM tracking instrument	To analyze abnormal gait patterns in patients with rheumatoid arthritis involving the knee joint	None
Plantar pressure, nerve conduction velocity	To examine the relationship between high foot pressure, neurological abnormalities, and ulceration in RA and DM	None

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Table 3 Continued

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shorter step length, a longer double support time, and a lower cadence (when compared with similar walking speed in healthy subjects) (32-35). Definite conclusions have to be drawn with care, because speed-dependent gait variables are affected when controlling for the effect of speed in subjects with RA (36). The reduction in walking speed can be related to an increase in Metatarsophalangeal (MTP)1 stiffness (37). Furthermore, it was suggested that reduced speed may be caused by antalgic walking patterns, the need for "pain control," and muscle weakness (38).

Regarding kinematic features, smaller ranges of motion combined with reduced joint moments and power of the hip flexion/extension, the hip abduction/adduction, the knee flexion/extension, and the ankle plantar flexion occur in RA and influence the Health Assessment Questionnaire as a measure of functional disability (39). There is an increased internal rotation of the tibia, a delayed heel rise, a decreased plantar flexion at toe-off, and an abnormal eversion of the hind foot. Often a reduction of MTP1 dorsiflexion is observed and an increased abduction of the forefoot. Aforementioned features can cause a considerable loss of normal rocker function (38,40-44).

Static features are hallux valgus, an exaggerated valgus heel posture and collapse of the medial longitudinal arch with decreased navicular height. Although often occurring in combination, abnormalities of the hind foot more than of the forefoot seem to affect gait in RA. Greater levels of foot-related disability and a greater number of abnormal kinematic features were found in patients if the hind foot was severely deformed, compared with those with severe forefoot deformity (27). Whether static hind foot or midfoot deviations were caused by insufficiency of the tibialis posterior, or the other way around, is still the subject of debate (38,45). Another association with stance abnormalities of the hind foot is increased muscle activity of the gastrocnemius and the soleus (45), to compensate for increasing valgus.

DISCUSSION

Combining the 78 gait studies in patients with RA, our data show that measurement and clinimetrical properties can be improved. However, consistently the studies reveal a slower walk, longer double support time, and avoidance of extreme positions during walking of RA patients.

None of the 78 included studies has been tested for all measurement properties. Part of the moderate results regarding the measurement properties of the selected studies can be explained by the fact that we did not select clinimetrical properties to avoid selection bias. The limitation of using the QUADAS criteria lies in the fact that the QUADAS is a list that is meant for assessing the quality of diagnostic tests. Most of the used methods or measurement concepts in our selected studies were not compared with a golden standard or a more validated test, simply because there is none. The criteria list proposed by Terwee and coworkers that we used for measurement properties performed equally moderate. The majority of the items could not be scored positive, but only indeterminate, because of the small sample size or nonoptimal methodology and analysis. We do acknowledge that this is a very strict set of criteria, but this was predominantly done so to avoid drawing conclusions from underpowered studies. There is however no standard set of criteria applicable to the elaboration and the rating of gait analysis. It would be very helpful if the professional association or the experts came up with one. Agreement and reliability can improve by reporting standard results of between-day, between-trial, between-subject, and between-clinician repeatability. Construct validity and interpretability may improve, when gait parameters are compared with clinically meaningful outcome measures (ie, of function or damage). More practical conclusions and recommendations can make a translation to daily practice easier and might benefit the patient directly. To facilitate the comparability between studies and centers, it would help if there were a larger uniformity in methodology. Within the group of the 3D studies, 4 up to 11 segmented models are used, based on functional or either anatomical segments. The labor-intensive methods of gathering and processing the data vary widely, which makes a proper comparison difficult. Also the lack of normative data for normal as well as pathological subjects is counteracting the interpretation of the findings. Furthermore, especially in RA, it would be helpful to have more longitudinal data to investigate the natural course of RA or to measure the effect of targeted interventions. Future research should focus on more uniformity of measurement methodology and terminology, for a proper validation of the motion analysis system, and strive for a more thorough clinical translation and interpretation, leading eventually to better understanding and treatment of gait problems in RA. Moreover, longitudinal studies are needed. Despite varying methods of research, there is a great deal of consensus on the interpretation of gait abnormalities in RA in these 78 studies. Static features frequently encountered are hallux valgus or lesser toe deformities, more often a pes planovalgus, sometimes associated with severe stance abnormalities of the hind foot. This results in the following kinematic features: patients with RA walk slower, with a longer double support time. They tend to avoid extreme positions of the joints. These gait abnormalities are caused by structural damage like erosions or stance deviations or by active inflammation of the joints, both hallmarks of rheumatoid disease. For another, gait in patients with RA is determined by avoiding pain. They tend therefore to walk slower to control the speed of heel strike and toe-off.

In conclusion, gait studies in RA patients show moderate clinimetrical properties, but are a challenging way of expressing walking disability. Future gait research should focus first on more uniformity in methodology. Second, longitudinal studies are needed to be able to work out more exactly the sequence of inflammatory and destructive events that lead to walking disability in RA. When these needs are satisfied, the treatment of walking problems in RA patients can be improved.

APPENDIX 1

Search Terms

("arthritis, rheumatoid" [MeSH Terms] OR ("arthritis" [All Fields] AND "rheumatoid" [All Fields]) OR "rheumatoid arthritis" [All Fields] OR ("rheumatoid" [All Fields] AND "arthritis" [All Fields])) AND (("biomechanics" [MeSH Terms] OR "biomechanics" [All Fields]) OR ("gait" [MeSH Terms] OR "gait" [All Fields]) OR (pedobarogr*) OR mechanical [All Fields] OR ("biomechanics" [MeSH Terms] OR "biomechanics" [All Fields] OR "kinematics" [All Fields]) OR "kinetics" [MeSH Terms]) OR (plantar [All Fields] AND ("pressure" [MeSH Terms] OR "pressure" [All Fields]))) AND (("foot" [MeSH Terms] OR "foot" [All Fields]) OR ("ankle" [MeSH Terms] OR "ankle" [All Fields] OR "ankle joint" [MeSH Terms] OR ("ankle" [All Fields] AND "joint" [All Fields]) OR "ankle joint" [All Fields]) OR (hind [All Fields] AND ("foot" [MeSH Terms] OR "foot" [All Fields])) OR (rear [All Fields] AND ("foot" [MeSH Terms] OR "foot" [All Fields])) OR ("knee" [MeSH Terms] OR "knee" [All Fields] OR "knee joint" [MeSH Terms] OR ("knee" [All Fields] AND "joint" [All Fields]) OR "knee joint" [All Fields]) OR ("hip" [MeSH Terms] OR "hip" [All Fields]) OR ("lower extremity" [MeSH Terms] OR ("lower" [All Fields] AND "extremity" [All Fields]) OR "lower extremity" [All Fields] OR ("lower" [All Fields] AND "limb" [All Fields]) OR "lower limb" [All Fields]) OR ("lower extremity" [MeSH Terms] OR ("lower" [All Fields] AND "extremity" [All Fields]) OR "lower extremity" [All Fields])) AND (English [la] OR German [la] OR Dutch [la] OR French [la]) NOT ("animals" [MeSH Terms:noexp] OR animals [All Fields]).

APPENDIX 2. SUPPLEMENTARY DATA

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.semarthrit.2011.11.009.

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Table 4 Results of Scoring of Selected QUADAS Items

Method	QUADAS 1	QUADAS 2	QUADAS 8	QUADAS 10	QUADAS 12	QQUADAS 13	QUADAS 14
Plantar pressure EMED (1-20)							
Bitzan (1)	Yes	Yes	Yes	NA	Yes	No	Yes
Davys (3)	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Giacomozzi (4)	Yes	Yes	Yes	Yes	Yes	Yes	NA
Hodge (5)	Yes	Yes	Yes	Yes	Yes	Yes	NA
Mulcahy (6)	Yes	Yes	Yes	NA	Yes	Yes	Yes
Phillipson (7)	Yes	Yes	Yes	NA	Yes	Yes	NA
Samnegard (9)	Yes	No	Yes	NA	Yes	No	NA
Schmiegel (10)	Yes	Yes	Yes	NA	Yes	Yes	NA
Schmiegel (11)	Yes	Yes	Yes	NA	Yes	No	NA
Semple (12)	Yes	Yes	Yes	NA	Yes	Yes	NA
Tastekin (13)	Yes	Yes	Yes	NA	Yes	Yes	NA
Tuna (14)	Yes	Yes	Yes	NA	Yes	Yes	NA
Turner 2006 (15)	Yes	Yes	Yes	NA	Yes	Yes	NA
Turner 2008 (16)	Yes	Yes	Yes	NA	Yes	Yes	NA
Turner 2008 (17)	Yes	Yes	Yes	NA	Yes	Yes	NA
Van de Leeden (18)	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Van de Leeden (19)	Yes	Yes	Yes	NA	Yes	Yes	NA
Woodburn (20)	Yes	No	Yes	NA	Yes	Yes	Yes
Plantar pressure F-scan (21-26)							
Grondal (21)	Yes	Yes	Yes	Yes	Yes	No	Yes
Jackson (22)	Yes	Yes	Yes	NA	Yes	No	Yes
Li (23)	Yes	Yes	Yes	NA	Yes	Yes	NA
Novak (24)	Yes	Yes	Yes	NA	NA	No	NA
Vidmar (25)	Yes	No	Yes	Yes	Yes	No	NA
Woodburn (26)	Yes	No	Yes	NA	Yes	Yes	NA
Plantar pressure otherwise or not specified (27-49)							
Andriacchi (27)	Yes	No	Yes	NA	Yes	Yes	No
Barrett (28)	Yes	Yes	Yes	NA	Yes	No	No
Beauchamp (29)	Yes	No	No	NA	Yes	No	No
Betts (30)	Yes	No	Yes, in other study	NA	Yes	Yes	No
Carl (2)	Yes	Yes	Yes	NA	Yes	Yes	No
Collis (31)	Yes	No	Yes	NA	Yes	No	No
Dereymaeker (32)	Yes	No	Yes	No	Yes	Yes	Yes
Firth (33)	Yes	No	Yes	Yes	Yes	Yes	NA
Godfrey (34)	No	No	No	Yes	Yes	No	No
Henessy (35)	Yes	Yes	Yes	Yes	Yes	Yes	NA
Hamilton (48)	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Harris (49)	Yes	No	No	NA	Yes	No	Yes
Masson (36)	Yes	Yes	Earlier study	NA	Yes	Yes	NA
Minns (37)	Yes	Yes	Yes	MA	Yes	No	NA
Otter (39)	Yes	Yes	Yes	NA	Yes	Yes	Yes
Rome (40)	Yes	Yes	Yes	NA	Yes	No	NA
Sharma (41)	Yes	No	No	NA	Yes	No	NA
Siegel (42)	Yes	Yes	Yes	NA	Yes	Yes	NA
Simkin (43)	Yes	No	1, in another study	NA	Yes	No	NA
Stauffer (44)	Yes	Yes	Yes	NA	Yes	Yes	NA
Stockley (45)	Yes	No	No	NA	No	No	No
Stockley (46)	Yes	No	No	NA	Yes	No	No
Turner 2003 (47)	Yes	Yes	Yes	NA	Yes	Yes	NA
Temporospatial data (4,5,14-17,21,27,43,44,47,48,50-72)							
Giacomozzi (4)	Yes	Yes	Yes	Yes	Yes	Yes	NA

Table 4 Continued

Method	QUADAS 1	QUADAS 2	QUADAS 8	QUADAS 10	QUADAS 12	QQUADAS 13	QUADAS 14
Hamilton (48)	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Hodge (5)	Yes	Yes	Yes	Yes	Yes	Yes	NA
Tuna (14)	Yes	Yes	Yes	NA	Yes	Yes	NA
Turner (15)	Yes	Yes	Yes	NA	Yes	Yes	NA
Turner (16)	Yes	Yes	Yes	NA	Yes	Yes	NA
Turner (17)	Yes	Yes	Yes	NA	Yes	Yes	NA
Grondal (21)	Yes	Yes	Yes	Yes	Yes	No	Yes
Andriacchi (27)	Yes	No	Yes	NA	Yes	Yes	No
Simkin (43)	Yes	No	Yes, in another study	NA	Yes	No	NA
Stauffer (44)	Yes	Yes	Yes	NA	Yes	Yes	NA
Turner (47)	Yes	Yes	Yes	NA	Yes	Yes	NA
Brinkmann (50)	Yes	Yes	Yes	NA	Yes	No	No
Eastlack (51)	Yes	Yes	Yes	Yes	Yes	Yes	NA
Eppeland (52)	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Fransen (53)	Yes	Yes	Yes	No	Yes	Yes	Yes
Fransen (54)	Yes	Yes	Yes	Yes	Yes	No	NA
Fransen (55)	Yes	Yes	Yes	NA	Yes	Yes	NA
Gyory (56)	Yes	Yes	Yes	Yes	Yes	No	NA
Isacson (57)	No	Yes	No	NA	Yes	No	No
Kavlak (58)	Yes	Yes	Yes	Yes	Yes	No	No
Keenan (59)	Yes	Yes	Yes	Yes	Yes	Yes	NA
Kettelkamp (60)	Yes	No	No	Yes	Yes	No	NA
Khazzam (61)	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Laroche (62)	Yes	Yes	Yes	Yes	Yes	Yes	NA
Laroche (63)	Yes	Yes	Yes	Yes	Yes	Yes	NA
Locke (64)	Yes	Yes	Yes	NA	Yes	Yes	NA
Long (65)	Yes	No	Yes	NA	Yes	No	No
MacSween (66)	Yes	Yes	Yes	NA	Yes	Yes	NA
Marshall (67)	Yes	Yes	No	NA	Yes	No	NA
Mejjad (68)	Yes	Yes	Yes	NA	Yes	No	NA
Murray (69)	Yes	Yes	No	NA	No	No	No
Platto (70)	Yes	Yes	Yes	NA	Yes	Yes	NA
Weiss (71)	Yes	Yes	Yes	NA	Yes	Yes	Yes
Woodburn (72)	Yes	Yes	Yes	NA	Yes	Yes	NA
3D gait (14-17, 38, 42, 47, 51, 57, 65, 67, 71-75)	Yes	Yes	Yes		Yes	Yes	
Tuna (14)	Yes	Yes	Yes	NA	Yes	Yes	NA
Turner (15)	Yes	Yes	Yes	NA	Yes	Yes	NA
Turner (16)	Yes	Yes	Yes	NA	Yes	Yes	NA
Turner (17)	Yes	Yes	Yes	NA	Yes	Yes	NA
O'Connell (38)	Yes	Yes	Yes	NA	NA	No	NA
Siegel (42)	Yes	Yes	Yes	NA	Yes	Yes	NA
Turner (47)	Yes	Yes	Yes	NA	Yes	Yes	NA
Eastlack (51)	Yes	Yes	Yes	Yes	Yes	Yes	NA
Isacson (57)	No	Yes	No	NA	Yes	No	No
Long (65)	Yes	No	Yes	NA	Yes	No	No
Marshall (67)	Yes	Yes	No	NA	Yes	No	NA
Weiss (71)	Yes	Yes	Yes	NA	Yes	Yes	Yes
Woodburn (72)	Yes	Yes	Yes	NA	Yes	Yes	NA
Weiss (73)	Yes	Yes	Yes	Yes	Yes	Yes	NA
Woodburn (74)	Yes	Yes	Yes	Yes	Yes	Yes	No
Woodburn (75)	Yes	No	Yes	NA	Yes	Yes	NA
EMG (59,76)							
Keenan (59)	Yes	Yes	Yes	Yes	Yes	Yes	NA
Garling (76)	No	Yes	Yes	NA	Yes	Yes	NA

Table 4 Continued

Method	QUADAS 1	QUADAS 2	QUADAS 8	QUADAS 10	QUADAS 12	QQUADAS 13	QUADAS 14
Other: Rontgen stereophotogrammetry (77) ROM (38,52,56,57,64,69) Kinetic data (71,73,78) Nerve conduction (36)							
Rontgen stereophotogrammetry							
Eberhardt (77)	Yes	Yes	Yes	Yes	Yes	No	NA
ROM							
O'Connell (38)	Yes	Yes	Yes	NA	NA	No	NA
Eppeland (52)	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Gyori (56)	Yes	Yes	Yes	Yes	Yes	No	NA
Isacson (57)	No	Yes	No	NA	Yes	No	No
Locke (64)	Yes	Yes	Yes	NA	Yes	Yes	NA
Murray (69)	Yes	Yes	No	NA	No	No	No
Kinetic data							
Weiss (71)	Yes	Yes	Yes	NA	Yes	Yes	Yes
Weiss (73)	Yes	Yes	Yes	Yes	Yes	Yes	NA
Sakauchi (78)	Yes	Yes	Yes	NA	Yes	No	NA
Nerve conduction	Yes	Yes			Yes		
Masson (36)	Yes	Yes	Earlier study	NA	Yes	Yes	NA

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Table 4 Continued

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Table 5 Summary of the Evaluation of the Clinimetric Measures

Method	Internal Consistency	Agreement	Reliability
Plantar pressure EMED			
Semple (1)	0	? CoV 3.5% to 14.3% control 5.7% to 19.3%	0
Tastekin (2)	0	0	0
Tuna (3)	0	0	0
Turner 2008 (4)	0	0	0
Van de Leeden (5)	0	0	? Max Pearson's CC 0352
Plantar pressure F-scan			
Woodburn (6)	0	0	0
Plantar pressure otherwise or not specified			
Hamilton (7)	?	?, CoV <4% kinematic parameters, <7% kinetic parameters	? In another study
Masson (8)	0	0	0
Minns (9)	0	0	?
Temporospatial data			
Hamilton (7)	?	?, CoV <4% kinematic parameters, <7% kinetic parameters	? In another study
Tuna (3)	0	0	0
Turner (4)	0	0	0
Fransen (10)	0	? Sample size 31 ICC CI 0.60-0.96	0
Hamilton (11)	0	0	? MWU, $P > 0001$ for differences in fast stride data
Gyory (12)	0	0	? Statistical method ? Sign differences between RA and normals
Keenan (13)	0	0	? No differences between the 2 groups
MacSween (14)	0	? ICC 0.91-0.96 in 22 normal controls	? Small sample size (8), only sign difference in velocity
Woodburn (15)	0	? MC 0.677-0.982 in healthy, 0.830-0.981 in RA	? Sample size 11
3D gait			
Tuna (3)	0	0	0
Turner (4)	0	0	0
Woodburn (15)	0	? CoMC 0.677-0.982 in healthy, 0.830-0.981 in RA	? Sample size 11
Weiss (16)	0	0	? Sign. mean differences with 95% CI
Woodburn (17)	0	CoMC 0.97-0.77 in former study	? Sample size 45
Woodburn (18)	0	? CoMC 0.81-0.97	? Sample size 20
EMG			
Keenan (13)	0	0	? No differences between the 2 groups
Other: ROM			
Gyory (12)	0	0	? Statistical method ? Sign differences between RA and normals
Kinetic data			
Weiss (16)	0	0	? Sign. mean differences with 95% CI
Sakauchi (19)	0	0	? Sample size 21
Nerve conduction			
Masson (8)	0	0	0

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Table 5 Continued

Construct Validity	Responsiveness	Interpretability
0	0	+
?	0	+
0	0	+
?	0	+
+	0	+
+	0	+
? (sample size <50)	? (sample size <50)	? (sample size <50)
? Differences DM/RA (statistic method NS) $P < 0.01$	0	+
?	0	+
? (sample size <50)	? (sample size <50)	? (sample size <50)
0	0	+
? Sample size < 50	0	? sample size <50
? Sample size < 50	0	? Sample size <50
0	0	+
0	0	+
?	0	? Sample size <50
0	0	? Sample size 8
0	0	? Sample size 11
0	0	+
? Sample size < 50	0	? Sample size <50
0	0	? Sample size 11
—	0	+
? Sample size 45	? Sample size 45	? Sample size 45
? Sample size 20	? Sample size 20	? Sample size 20
?	0	? Sample size <50
0	0	+
—	0	+
? Sample size 21	0	? Sample size 21
? Differences DM/RA (statistic method NS) $P < 0.01$	0	+

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