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Using the Oxford Foot Model to assess construct validity of the AOFAS ankle-hindfoot scale and the Foot Function Index

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Using the Oxford Foot Model to assess construct validity of the AOFAS ankle-hindfoot scale and the Foot Function Index

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The authors declare the following potential conflicts of interests:

All authors declare no financial and personal relationships with other people or organizations that could inappropriately influence their work or the outcome of this publication.

The authors declare the following contribution of authorship:

TK: developing the concept of the study together with SL, writing of manuscript, recruiting of patients and financial support for the patients' insurance was made from a research funding price TK and SL got from the German foot and ankle society in 2010.

FS gait lab examination and data analysis, revising the manuscript with regard to gait lab examination), recruiting of healthy adults for standard values determination

KH gait lab examination and data analysis, revising the manuscript with regard to gait lab examination and as an American native speaker, recruiting of healthy adults for standard values determination

FK statistical concept and factor analysis, critical review of the manuscript concerning methods and statistics

AM providing the gait lab for carrying out the study (owner of gait lab), has made substantial contributions to data interpretation.

MA recruiting of patients, has made substantial contributions to revising the article critically for important intellectual content, approval of the submitted and final version.

MHB recruiting of patients, has made substantial contributions to revising the article critically for important intellectual content, approval of the submitted and final version.

KS doing the statistical analyses and has made substantial contributions regarding the approval of the final version.

SL developing the concept of the study together with TK, providing of a part of the literature, critical review of the manuscript concerning the study concept and financial support for the patients' insurance was made from a research funding price TK and SL got from the German foot and ankle society in 2010.

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Data sharing:

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No additionally data is available.

ABSTRACT

Objective:

After cross-cultural adaption for the German translation of the Ankle and Hindfoot Scale of the American Orthopaedic Foot and Ankle Society (AOFAS-AHS) and agreement analysis with the Foot Function Index (FFI-D), the following gait analysis study using the Oxford Foot Model (OFM) was carried out to show which of the two scores better correlates with objective gait dysfunction.

Design and participants:

Results of the AOFAS-AHS and FFI-D, as well as data from three-dimensional gait analysis were collected from 20 patients with mild to severe ankle and hindfoot pathologies.

Kinematic and kinetic gait data was correlated with the results of the total AOFAS scale and FFI-D as well as the results of those items representing hindfoot function in the AOFAS-AHS assessment. An analysis of correlations with confidence intervals between the FFI-D and the AOFAS-AHS items and the gait parameters was performed by means of Jonckheere-Terpstra test; furthermore, exploratory factor analysis was applied to identify common information structures and thereby redundancy in the FFI-D and the AOFAS-AHS items.

Results:

Objective findings for hindfoot disorders, namely a reduced range of motion (ROM) in the ankle and subtalar joints, respectively, as well as reduced ankle power generation during push-off, showed a better correlation with the AOFAS-AHS total score – as well as AOFAS-AHS items representing ROM in the ankle, subtalar joints and gait function - compared to the FFI-D score.

Factor analysis, however, could not identify FFI-D items consistently related to these three indicator parameters found in the AOFAS-AHS. Furthermore, factor analysis did not support stratification of the FFI-D into two subscales.

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Conclusions:

Use of gait analysis in combination with theoretical mathematical considerations for the evaluation of scores can make a valuable contribution to the development and evaluation of survey instruments and patient-reported outcome questionnaires in clinical research.

Article summary

Strengths and limitations of the study:

Strengths of this study are the objective gait parameters as well as the extensive statistical procedures.

Limitations of this study are the inhomogeneity of the group and the limited number of patients. When focusing on a certain group of foot disorders, a more homogenous group should be examined. In order to develop a new score dealing with different kinds of foot disorders using gait analysis, a larger group should be taken into account.

Keywords:

Gait analysis, foot and ankle surgery, questionnaires, scores, patient reported outcome measures

Main text:

Introduction

A variety of questionnaires are available for assessing pain, disability and functional limitations of patients suffering from foot and ankle pathologies. The Ankle and Hindfoot Scale of the American Orthopaedic Foot and Ankle Society (AOFAS-AHS) is one of them and is commonly used to estimate and describe the outcome of conservative or surgical treatment of ankle or hindfoot pathologies [1]. This score is widely used despite the legitimate criticism of its theoretical mathematical weaknesses [2, 3]. In contrast, several publications have shown a high level of

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responsiveness and acceptable criterion validity for the AOFAS-AHS [4], as well as a satisfactory degree of reliability for the subjective component of the AOFAS scale [5], which justifies its application. In addition, the Foot Function Index (FFI) is also commonly used in the clinical setting [6, 7, 8, 9].

Cross-cultural adaption of the AOFAS-AHS in its German translation and agreement analysis with the FFI-D by Naal et al. [10] were previously performed and published [11, 12]. The agreement analysis showed that the scores are not interchangeable, but rather complementary [12]. However, these self-reported questionnaires assess patient perception and are not necessarily indicative of actual disabilities. Therefore, it is important that research considers other methods of assessing functionality. Gait analysis has widely been accepted as an objective measure of physical function [13], allowing researchers and clinicians to better understand the biomechanics of gait. In particular, the Oxford Foot Model (OFM) [14] is a multi-segment kinematic model that can be used to quantify the functionality of the foot complex during gait in patients with different pathologies [15-17]. In patients with osteoarthritis and pre-osteoarthritic disorders in the ankle and subtalar joints, reduced walking speed, reduced step length, reduced range of motion (ROM) within different sections of the foot and ankle joint and reduced ankle power generation during push-off have been shown [18-21].

Since agreement analysis [12] did not determine which of the two scores is better suited to reflect function in patients with ankle and hindfoot disorders, the aim of the present study was to determine the association between physical foot dysfunction using the OFM and perceived disability in patients with mild to severe ankle and hindfoot pathologies. Higher correlation was expected for the FFI-D with respect to its rather elaborate scoring system as compared to the AOFAS-AHS scale system.

In addition, exploratory factor analysis was applied to identify common information structures and redundancy contained in the FFI-D and the AOFAS-AHS items.

Methods and materials

Subjects

AOFAS-AHS and FFI-D results were consecutively collected from 20 patients with mild to severe ankle and hindfoot pathologies (10 female and 10 male patients) and a median age of 45 (interquartile range 35-54) years. Body mass index (BMI) was 27.8

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(24.7-31.6) kg/cm² in median. We deliberately chose a heterogeneous group of patients to reflect the wide range of patients who were evaluated using the AOFAS-AHS. The 20 patients suffered from pathologies such as primary or post-traumatic osteoarthritis (10 / 20), osteochondral lesions / subchondral cysts (5 / 20), chondromatosis / corpora libra (2 / 20) or osteoarthritis due to hemophilia (3 / 20). Exclusion criteria included neuromuscular dysfunction (e.g., Parkinson's disease, stroke, epilepsy and Alzheimer's disease), a leg length discrepancy of more than 1 cm and chronic joint infection. All patients underwent three-dimensional gait analysis on the same day the two questionnaires AOFAS-AHS and FFI-D were applied.

Ethical approval

The approval of the local independent Ethics Committee (Ruhr University Bochum ICE; vote reference no. 4126-11) was obtained in 2011.

The study was carried out in accordance with the Helsinki Declaration. Accordingly, written informed consent was obtained from all patients prior to participation in the study.

Questionnaires

The FFI-D questionnaire is based on a ten-point scale for each item and enables overall continuous scoring by means of an equally weighted normalizing evaluation system and providing two subscales including eight items for pain and ten items for disability, respectively. The AOFAS-AHS includes nine items (five to be answered by patients and four to be answered by the physician) with two to four feature characteristics and an asymmetric assignment of score points. The AOFAS-AHS over represents the pain item with 40 of the maximum 100 score points assigned to this item alone.

Gait analysis methods

Three-dimensional gait analysis was performed using a 200 Hz, eight-camera motion capture system (VICON™ Motion Systems, Oxford, UK) in combination with a 1000 Hz AMTI™ force plate (Advanced Mechanical Technology, Inc., Watertown, MA,

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USA) to detect gait cycle events and to calculate ankle power generation during the push off phase. Reflective markers were placed over prominent anatomical landmarks along the lower extremity, as well as the ankle and foot complex according to the multi-segment OFM [14, 22, 23]. The OFM allows for a differentiated analysis of movement within different sections of the foot and ankle joint. Repeatability of the OFM has been demonstrated for healthy children and adults [18, 24, 25] and has also been applied in patients with foot pathologies/disorders [16, 22, 23, 26]).

Kinematic and kinetic data that represent mobility in the ankle and subtalar joints and that are relevant for osteoarthritis patients were collected from barefoot participants during level walking at a self-selected speed. In cases with bilateral pathology, the more severely affected side was analyzed. After each acquisition session, 3D marker trajectories were reconstructed and missing frames were handled with a fill-gap procedure. The data was smoothed with a Woltring filter and using spline smoothing [27]. Average values from three trials were selected based on good quality of marker trajectories and ground reaction forces.

Statistical analysis

A sample size calculation based on the fact that in healthy persons an AOFAS-Score of 80-100 points are expected, while in patients with relevant disorders a Score of 30-35 points is expected, was performed. The power was assumed with 80%. A group of 20 patients was calculated as suitable.

In a first step, basic spatio-temporal gait parameters (i.e., walking speed, cadence, step length, stride length, step width) as well as discrete kinematic and kinetic gait data were correlated with the total scores for the AOFAS-AHS (range 0 – 100 points) and the FFI-D. The FFI-D scale was transformed to the range 0 - 100 points with 100 points indicating optimum rating in all items to make the scores directly comparable to those derived from the AOFAS-AHS. Both overall scores were handled as continuous endpoints, i.e. methods for continuous data evaluation were applied. This means that score descriptions were based on medians and quartiles (graphic description on nonparametric box whisker plots, accordingly) with regard to the moderate sample size. Bivariate correlations between gait parameters and the total FFI-D and AOFAS-AHS scores were estimated by means of the Spearman coefficient and its asymptotic 95% confidence interval. For the sake of aggregation

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and interpretation of the various bivariate correlation profiles a previously established categorization of correlation ranges based on the Spearman point estimates was adopted [29, 30]: correlations were classified “low” for Spearman coefficients less than 0.30, as “medium” for coefficients between 0.30 and 0.65 and otherwise as high. For further correlation analyses AOFAS-AHS items were taken into account that represent the function of the subtalar and ankle joints, and were related to the corresponding gait analysis parameters representing the function of the respective joints. The respective bivariate associations were described by means of gait parameter distribution (medians and quartiles) stratified for the respective AOFAS item scale levels. Furthermore, Jonckheere-Terpstra test were applied to test for trends in the gait parameters levels alongside the respective AOFAS item scale levels. The results of these trend tests were summarized by means of p-values. In accordance with the exploratory character of this evaluation, the latter were not formally adjusted for multiplicity, but rather considered as indicators of local statistical significance in the case of p-values ≤ 0.05.

To determine those FFI-D items representing the ROM in the ankle and the subtalar joints as well as gait function – note, that these can be derived from the AOFAS items, but not from the FFI-D assessment– exploratory factor analysis for the total set of the 9 AOFAS-AHS and the 18 FFI-D items was performed. In the case of several FFI-D items being aggregated with the AOFAS item(s) of interest, these FFI-D items could be considered as ROM related. Since the AOFAS-AHS individual items are more or less categorical, whereas the FFI-D parameters should be treated as continuous, both score systems’ items were binarized for simultaneous use in factor analysis by means of the following criteria: the AOFAS-AHS item dealing with pain was defined to indicate a “negative response” for a score of 20 points or less. Accordingly, a score representing pathological findings (0-4 points) in one of the remaining AOFAS-AHS items was defined as a “negative response”. For the FFI-D, results of five or more points were regarded as a “negative response” (note the scaling direction of the FFI-D items). The total set of 9 binarized AOFAS-AHS items and of 18 binarized FFI-D items was then analyzed by means of exploratory factor analysis, where factors were identified by means of principle component analysis and application of the varimax criterion (75% variance to be explained by identified factors).

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Statistical and graphic analyses were performed using SPSS® for Windows 21.0™ (IBM Corporation, New York, USA)].

Results

Gait analysis

Only moderate correlation coefficients (r= 0.51-0.64) could be found between the total AOFAS-AHS / total FFI-D score and objective gait parameters as shown in Table 1. With moderate correlation coefficients between the AOFAS-AHS total score and six gait parameters representing mobility in the ankle joint, two representing the ROM in the subtalar joint, as well as ankle maximum power generation during the push-off phase (Table 1), the AOFAS-AHS showed slightly more and higher correlation coefficients with the gait parameters than the FFI-D total score. Regarding the FFI-D, only six moderate correlations could be found between the overall score and gait parameters representing mobility in the ankle (one parameter) and subtalar joints (five parameters, Table 1).

In addition, we focused on the individual items of the AOFAS-AHS that represent gait function and passive ROM (AOFAS-AHS items five to seven). The AOFAS-AHS items representing passive ROM in the ankle joint complex and the corresponding gait parameters representing the total ROM during the gait cycle in the ankle joint and the subtalar joints, respectively, as well as spatio-temporal gait parameters, showed encouraging association (Figures 1 and 2; all presented trends were found locally significant), as also demonstrated in terms of the Jonckheere-Terpstra test with a significance at the 5% level between the three groups (= three different items for the answer) indicating monotonic association. As a result of extensive exploratory analysis those gait parameters were taken into account, which best represented mobility (Figure 1) and gait function (Figure 2) in the respective joints.

Factor analysis

Factoranalysis based on the binarized individual AOFAS-AHS and FFI-D items proposed three factors arising out of the joint information pattern, but could not reveal

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any FFI-D items to represent either mobility in the ankle and subtalar joints or gait function (Table 2). Furthermore, although the FFI-D is divided into the two subscales “pain” and “disability” [7, 10] by its authors, this subdivision could not be reproduced in the factor analysis patterns. Only three items of the FFI-D pain subscale showed an involvement in factor 2 (representing “pain and disability”). In addition, only one item from the pain subscale and one item from the disability subscale were involved with factor 3 (representing “mobility and gait function”), while all remaining questions from the subscales were aggregated into factor 1. The authors could not construct a generic term for this predominant factor 1, as it encompasses a wide variety of items, which could hardly be assigned to one common category (Table 2). In contrast, the AOFAS-AHS items showed either a high involvement with factor 2 (representing “pain and disability”) or with factor 3 (representing “mobility and gait function”).

Discussion

Since both scores are still used throughout the world to evaluate treatment outcomes of foot and ankle disorders and a validated German translation of the AOFAS-AHS did not yet exist, we carried out a validation study for the German language version of the AOFAS-AHS [12]. The present study was the final step in this procedure. The main goal was to determine the association between objective foot function using the OFM and perceived disability in patients with mild to severe ankle and hindfoot pathologies.

Our expectation that – due to its better evaluation methodology and the two respective subscales – the FFI-D, in comparison with the AOFAS-AHS, is better suited to assess the functionality of the foot could not be supported. The comparison of the Spearman correlations between the overall results of both scores and functionality during gait indicates a slightly better suitability of the AOFAS-AHS. In particular, the analysis of the respective functional pattern under consideration of the individual items from the AOFAS-AHS was able to show good agreement with objective parameters from gait analysis. Additionally, the moderate positive correlation between the AOFAS-AHS and ankle power generation during push-off indicates that the AOFAS-AHS is well suited to evaluate limitations in foot function during gait.

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Although the FFI-D is divided into two subscales, this could not be confirmed by factor analysis. The opposite was found for the AOFAS-AHS, which represents pain and ability issues on the one hand and questions dealing with hindfoot and ankle function on the other hand. This was shown in the factor analysis for the transformed individual questions, even if this was not postulated by its developers themselves [1].

The mathematical weaknesses of the AOFAS-AHS - especially the over-representation of the pain question and the limited number of feature expressions, leading to a floor and ceiling-effect - are undeniable [2]. Nevertheless, the items in the AOFAS-AHS give a good representation of ankle and hindfoot disorders, as shown by the Spearman correlations with gait function, ROM in the ankle and subtalar joints, as well as by the Jonckheere-Terpstra test. Reduced ankle power generation during push-off showed a significant correlation with the AOFAS-AHS total score, which suggests that the AOFAS-AHS total score is a sensitive indicator for ankle osteoarthritis. Due to its mathematical weaknesses, the AOFAS-AHS should be applied with care, even if its individual questions show a good representation of pain, disability and function. These items can be used, but should be combined with better methods for scoring and interpreting the results.

In contrast, the FFI-D did not show the same clear correlations for these three functional items. The FFI-D did not show any clear items representing gait function or ROM in the ankle and subtalar joints in factor analysis. Therefore, it did not make any sense to compare the results of individual questions to corresponding gait parameters. As a consequence, the application of the FFI-D as a score to evaluate disability and functional limitations of patients suffering from foot and ankle pathologies should be critically discussed.

The best consequence would be to develop a new score with items derived from objective measurements such as gait analysis including mature biometrical means for scoring and evaluating results.

Limitations:

Limitations of this study are the inhomogeneity of the group and the limited number of patients. Nevertheless, we deliberately choose a heterogeneous group of patients to reflect the wide range of patients who were evaluated using the AOFAS-AHS. For

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focusing on a certain group of foot disorders, a more homogenous group should be examined. In order to develop a new score dealing with different kinds of foot disorders using gait analysis, a bigger group should be taken into account.

Conclusion:

Our findings show that the use of gait analysis in combination with theoretical mathematical considerations for the evaluation of scores will make a valuable contribution to the development and evaluation of survey instruments and patient-reported outcome questionnaires in clinical research. The AOFAS-AHS showed a good agreement with objective gait parameters and is therefore better suited to evaluate disability and functional limitations of patients suffering from foot and ankle pathologies compared to the FFI-D.

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494 # Tables:

Parameter	AOFAS-AHS total score r (95% CI)	FFI-D total score r (95% CI)
Hindfoot vs. tibia maximum dorsiflexion during stance [°]	0.51 **(-0.15; 0.83)**	0.16 (-0.40; 0.66)
Hindfoot vs. tibia ROM (plantarflexion/dorsiflexion) during gait cycle [°]	**0.53** (0.18; 0.75)	0.47 (0.00; 0.78)
Hindfoot vs. tibia ROM (inversion/eversion) during gait cycle [°]	**0.55 (0.24; 0.78)**	**0.55 (0.02; 0.85)**
Hindfoot vs. tibia ROM (internal/external rotation) during gait cycle [°]	0.41 (-0.06; 0.78)	**0.51 (0.03; 0.83)**
Forefoot vs. hindfoot maximum dorsiflexion during stance [°]	-0.57 (-0.83; 0.07)	-0.36 (-0.72; 0.3)
Forefoot vs. hindfoot maximum plantarflexion during push-off-phase [°]	**-0.64 (-0.87; -0.25)**	-0.26 (-0.76; 0.26)
Forefoot vs. hindfoot ROM (adduction/abduction) during gait cycle [°]	**0.63 (0.28; 0.86)**	**0.57 (0.12; 0.84)**
Forefoot vs. hindfoot ROM (supination/pronation) during gait cycle [°]	0.45 (0.14; 0.72)	**0.52 (0.10; 0.80)**
Forefoot vs. tibia ROM (adduction/abduction) during gait cycle [°]	0.45 (0.05; 0.77)	**0.57 (0.21; 0.79)**
Forefoot vs. tibia maximum plantarflexion during push-off-phase [°]	**-0.61 (-0.88; -0.29)**	**-0.55 (-0.84; -0.09)**
Forefoot vs. tibia ROM (plantarflexion/dorsiflexion) during gait cycle [°]	**0.57 (0.13; 0.87)**	0.38 (-0.10; 0.78)
Ankle maximum power generation during push-off-phase [W/kg]	**0.55 (0.18; 0.84)**	0.34 (-0.11; 0.72)

495 **ROM = range of motion; CI = confidence interval**

496

497 **Table 1:** Spearman correlation coefficients with 95% confidence intervals between the
498 AOFAS-AHS total score as well as the FFI-D total score, respectively and selected gait
499 parameters representing mobility in the ankle (six parameters) and the subtalar joint (five
500 parameters) as well as the ankle-osteoarthritis indicator-parameter ankle maximum power
501 generation during stance [W/kg], respectively. Significant correlations (>0.5 / <-0.5) are
502 printed in bold.

503

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(binarized) score items	factor and factor weight		
	1	2 “pain and disability”	3 “mobility and gait function”
AOFAS-AHS “pain”		.810	
AOFAS-AHS “activity restriction”		.807	
AOFAS-AHS “walking distance”			.597
AOFAS-AHS “walking surfaces”		.780	
AOFAS-AHS “gait abnormality”			.747
AOFAS-AHS “sagittal motion”			.747
AOFAS-AHS “hindfoot motion”			.780
AOFAS-AHS “ankle-hindfoot stability”			.480
AOFAS-AHS „alignment“			.508
FFI-D PAIN „worst pain“		.792	
FFI-D PAIN „pain in the morning“	.446		
FFI-D PAIN „pain while walking barefoot“	.741		
FFI-D PAIN „pain while standing barefoot“			.620
FFI-D PAIN „pain while walking with shoes“	.741		
FFI-D PAIN „pain while standing with shoes“	.704		
FFI-D PAIN „pain at the end of the day“		.824	
FFI-D PAIN „pain during the night“		.477	
FFI-D DISABILITY „problems while walking outside“			.656
FFI-D DISABILITY „problems while walking on uneven ground“	.846		
FFI-D DISABILITY „problems while walking distances ≥ 1 km“	.846		
FFI-D DISABILITY „problems while walking up the stairs“	.690		
FFI-D DISABILITY „problems while walking down the stairs“	.767		
FFI-D DISABILITY „problems while walking on tiptoes“	.767		
FFI-D DISABILITY „problems while standing up from a chair“	.442		
FFI-D DISABILITY „problems while walking fast or during running“	.846		
FFI-D DISABILITY „problems during leisure activities or sports“	.846		
FFI-D DISABILITY „problems while wearing special shoes (high heels, sandals etc.)“			

Table 2: Factor analysis results for the respective binarized 9 items of the AOFAS-AHS and the binarized 18 items of the FFI-D: rotated factor weights for the 9 + 18 items after identification of three joint factors by means of the variance maximization criterion. Factor weights < 0.500 have been omitted to emphasize the rotation-based aggregation of the 9 +

511 18 items into three factors, a posteriori declared representing “pain and disability” (factor 2)
512 and “mobility and gait function” (factor 3), respectively.
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Legend figures 1+2:

Figure 1:

Nonparametric box plots for an association analysis between AOFAS-AHS items 5 – 7 and respective content-corresponding gait parameters. Box plot horizontals indicate medians and quartiles, verticals indicate minimum and maximum observations, circles indicate statistical outliers with a deviation of at least 1.5 x interquartile range from the respective median.

AOFAS-AHS item 5 (gait abnormality) represents a normal gait or slight gait abnormality with 8 points, an obvious gait abnormality (walking/running is possible but irregular) with 4 points and a considerable gait abnormality with 0 points.

AOFAS-AHS item 6 (sagittal motion, flexion plus extension) represents a normal or mild restriction (30° or more) with 8 points, a moderate restriction (15°–29°) with 4 points and a severe restriction (less than 15°) with 0 points.

AOFAS-AHS item 7 (hindfoot motion, inversion plus eversion) represents a normal or mild restriction (75%–100% normal) with 6 points, a moderate restriction (25%–74% normal) with 3 points and a severe restriction (less than 25% normal) with 0 points

(a) box plots for the maximum ankle power generation during push-off stratified for AOFAS-AHS points achieved by 20 patients

(b) box plots for the total range of motion during gait cycle in dorsiflexion to plantarflexion of the forefoot vs. the tibia angle stratified for AOFAS-AHS points achieved by 20 patients

(c) box plots for the total range of motion during gait cycle in dorsiflexion to plantarflexion of the forefoot vs. the hindfoot angle stratified for AOFAS-AHS points achieved by 20 patients

(d) box plots for the total range of motion during gait cycle in internal to external rotation of the hindfoot vs. the tibia angle stratified for AOFAS-AHS points achieved by 20 patients

(e) box plots for the total range of motion during gait cycle in adduction to abduction of the forefoot vs. the tibia angle stratified for AOFAS-AHS points achieved by 20 patients

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Figure 2: Nonparametric box plots for an association analysis between AOFAS-AHS item 5 and corresponding spatio-temporal gait parameters with regard to content. Box plot horizontals indicate medians and quartiles, verticals indicate minimum and maximum observations, circles indicate statistical outliers with a deviation of at least 1.5 x interquartile range from the respective median.

AOFAS-AHS item 5 (gait abnormality) represents normal gait or a slight gait abnormality with 8 points, an obvious gait abnormality (walking/running is possible but irregular) with 4 points and a considerable gait abnormality with 0 points.

(a) box plots for walking speed stratified for AOFAS-AHS points achieved by 20 patients

(b) box plots for step length stratified for AOFAS-AHS points achieved by 20 patients

(c) box plots for step time stratified for AOFAS-AHS points achieved by 20 patients

(d) box plots for step width stratified for AOFAS-AHS points achieved by 20 patients

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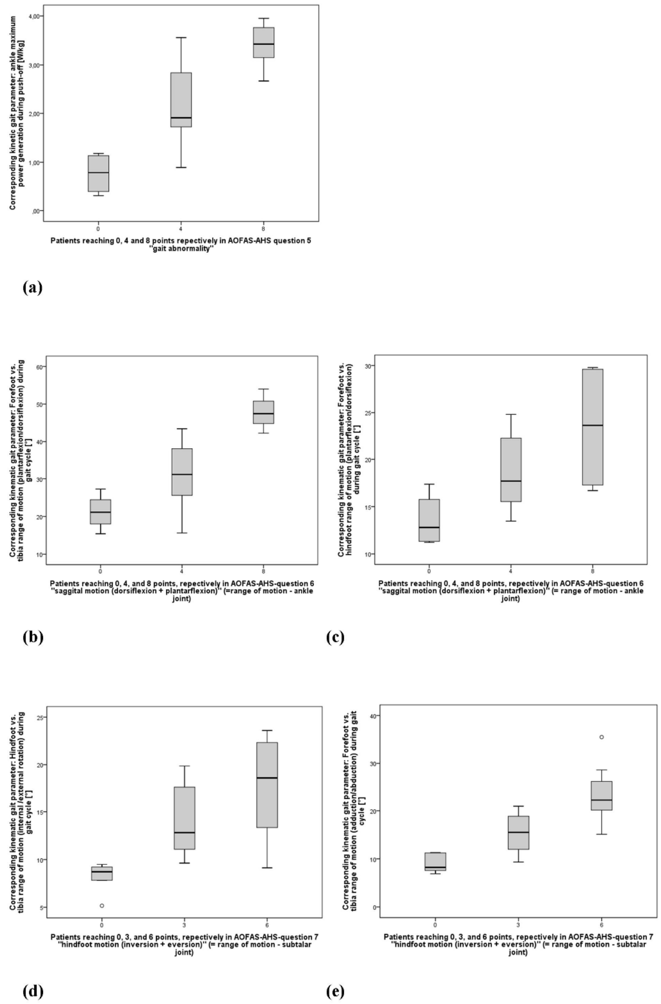

Nonparametric box plots for an association analysis between AOFAS-AHS items 5 – 7 and respective content-corresponding gait parameters. Box plot horizontals indicate medians and quartiles, verticals indicate minimum and maximum observations, circles indicate statistical outliers with a deviation of at least 1.5 x interquartile range from the respective median.

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(b) box plots for the total range of motion during gait cycle in dorsiflexion to plantarflexion of the forefoot vs. the tibia angle stratified for AOFAS-AHS points achieved by 20 patients
(c) box plots for the total range of motion during gait cycle in dorsiflexion to plantarflexion of the forefoot vs. the hindfoot angle stratified for AOFAS-AHS points achieved by 20 patients
(d) box plots for the total range of motion during gait cycle in internal to external rotation of the hindfoot vs. the tibia angle stratified for AOFAS-AHS points achieved by 20 patients
(e) box plots for the total range of motion during gait cycle in adduction to abduction of the forefoot vs. the tibia angle stratified for AOFAS-AHS points achieved by 20 patients

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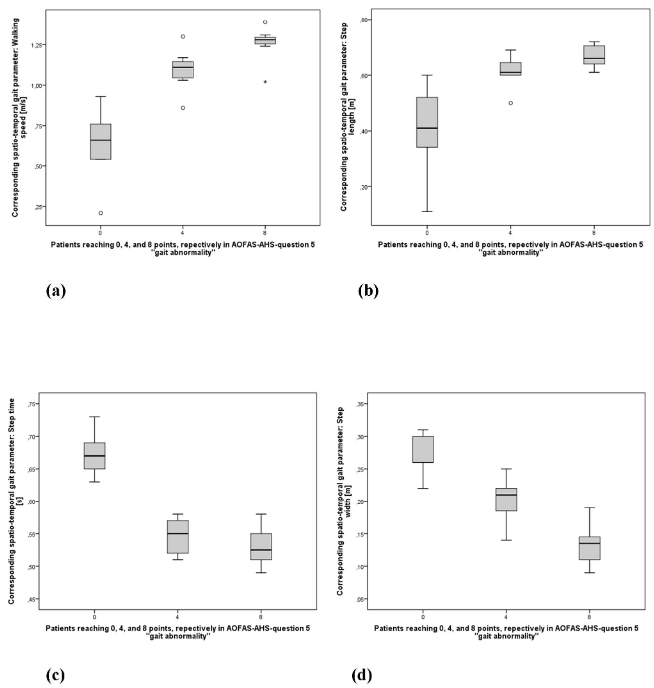

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(c) box plots for step time stratified for AOFAS-AHS points achieved by 20 patients
(d) box plots for step width stratified for AOFAS-AHS points achieved by 20 patients

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STROBE 2007 (v4) Statement—Checklist of items that should be included in reports of *cohort studies*

Section/Topic	Item #	Recommendation	Reported on page #
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract	4,6-8
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found	4/5
Introduction			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	5/6
Objectives	3	State specific objectives, including any prespecified hypotheses	6, 11
Methods			
Study design	4	Present key elements of study design early in the paper	6-9
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	6/7
Participants	6	(*a*) Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up	6/7
		(*b*) For matched studies, give matching criteria and number of exposed and unexposed	
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	13
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	*6/7*
Bias	9	Describe any efforts to address potential sources of bias	8 + 12/13
Study size	10	Explain how the study size was arrived at	8
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	9
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding	8-10
		(*b*) Describe any methods used to examine subgroups and interactions	---
		(*c*) Explain how missing data were addressed	---
		(*d*) If applicable, explain how loss to follow-up was addressed	---
		(*e*) Describe any sensitivity analyses	---
Results			

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Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	6/7
		(b) Give reasons for non-participation at each stage	---
		(c) Consider use of a flow diagram	---
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	6/7
		(b) Indicate number of participants with missing data for each variable of interest	---
		(c) Summarise follow-up time (eg, average and total amount)	---
Outcome data	15*	Report numbers of outcome events or summary measures over time	10
Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	10/11
		(*b*) Report category boundaries when continuous variables were categorized	9
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	---
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	---
Discussion			
Key results	18	Summarise key results with reference to study objectives	11
Limitations			
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	12/13
Generalisability	21	Discuss the generalisability (external validity) of the study results	13
Other information			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	3

*Give information separately for cases and controls in case-control studies and, if applicable, for exposed and unexposed groups in cohort and cross-sectional studies.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.

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Using the Oxford Foot Model to determine the association between objective measures of foot function and results of the AOFAS Ankle-Hindfoot Scale and the Foot Function Index - a prospective gait analysis study in Germany

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Primary Subject Heading:	Surgery
Secondary Subject Heading:	Sports and exercise medicine, Rehabilitation medicine
Keywords:	Gait analysis, foot and ankle surgery, questionnaires, scores, patient reported outcome measures

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Using the Oxford Foot Model to determine the association between objective measures of foot function and results of the AOFAS Ankle-Hindfoot Scale and the Foot Function Index - a prospective gait analysis study in Germany

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All authors declare no financial and personal relationships with other people or organizations that could inappropriately influence their work or the outcome of this publication.

The authors declare the following contribution of authorship:

TK: Substantial contributions to the conception or design of the work, drafting the article, final approval of the version published.

FS: acquisition, analysis or interpretation of data gait lab, revising it critically for important intellectual content. Final approval of the version published.

KH: acquisition, analysis or interpretation of data from gait lab, revising it critically for important intellectual content. Final approval of the version published.

FK: acquisition, analysis or interpretation of data from gait lab, revising it critically for important intellectual content.

AM: providing the gait lab for carrying out the study (owner of gait lab), has made substantial contributions to data interpretation.

MA: acquisition, analysis or interpretation of data from gait lab, revising it critically for important intellectual content.

MHB: acquisition, analysis or interpretation of data from gait lab, revising it critically for important intellectual content KS: acquisition, analysis or interpretation of data with respect to statistics (Jonckheere-Terpstra test, exploratory factor analysis), revising it critically for important intellectual content.

SL: Substantial contributions to the conception or design of the work, revising it critically for important intellectual content.

Funding:

In order to conduct this study, the ethics committee required participants to be insured for the procedure due to the fact that the gait lab examination was done for this study only. This insurance was funded through a research grant from the German Foot and Ankle Society.

Data sharing:

No additionally data is available.

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ABSTRACT

Objective:

After cross-cultural adaption for the German translation of the Ankle-Hindfoot Scale of the American Orthopaedic Foot and Ankle Society (AOFAS-AHS) and agreement analysis with the Foot Function Index (FFI-D), the following gait analysis study using the Oxford Foot Model (OFM) was carried out to show which of the two scores better correlates with objective gait dysfunction.

Design and participants:

Results of the AOFAS-AHS and FFI-D, as well as data from three-dimensional gait analysis were collected from 20 patients with mild to severe ankle and hindfoot pathologies.

Kinematic and kinetic gait data was correlated with the results of the total AOFAS scale and FFI-D as well as the results of those items representing hindfoot function in the AOFAS-AHS assessment. With respect to the foot disorders in our patients (osteoarthritis and prearthritic conditions) we correlated the total range of motion in the ankle and subtalar joints as identified by the OFM with values identified during clinical examination "translated" into score values. Furthermore, reduced walking speed, reduced step length and reduced maximum ankle power generation during push-off were taken into account and correlated to gait abnormities described in the scores. An analysis of correlations with confidence intervals between the FFI-D and the AOFAS-AHS items and the gait parameters was performed by means of the Jonckheere-Terpstra test; furthermore, exploratory factor analysis was applied to identify common information structures and thereby redundancy in the FFI-D and the AOFAS-AHS items.

Results:

Objective findings for hindfoot disorders, namely a reduced range of motion , in the ankle and subtalar joints, respectively, as well as reduced ankle power generation during push-off, showed a better correlation with the AOFAS-AHS total score – as

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well as AOFAS-AHS items representing ROM in the ankle, subtalar joints and gait function - compared to the FFI-D score.

Factor analysis, however, could not identify FFI-D items consistently related to these three indicator parameters (pain, disability and function) found in the AOFAS-AHS. Furthermore, factor analysis did not support stratification of the FFI-D into two subscales.

Conclusions:

The AOFAS-AHS showed a good agreement with objective gait parameters and is therefore better suited to evaluate disability and functional limitations of patients suffering from foot and ankle pathologies compared to the FFI-D.

Article summary

Strengths and limitations of the study:

- Strengths of this study are the objective gait parameters,
- as well as the extensive statistical procedures.
- Limitations of this study are the inhomogeneity of the group and the limited number of patients. When focusing on a certain group of foot disorders, a more homogenous group should be examined. In order to develop a new score dealing with different kinds of foot disorders using gait analysis, a larger group should be taken into account.

Keywords:

Gait analysis, foot and ankle surgery, questionnaires, scores, patient reported outcome measures

Main text:

Introduction

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A variety of questionnaires are available for assessing pain, disability and functional limitations of patients suffering from foot and ankle pathologies. The Ankle and Hindfoot Scale of the American Orthopaedic Foot and Ankle Society (AOFAS-AHS) is one of them and is commonly used to estimate and describe the outcome of conservative or surgical treatment of ankle or hindfoot pathologies [1]. This score is widely used despite the legitimate criticism of its theoretical mathematical weaknesses, such as over-representation of the pain question and the limited number of feature expressions, leading to a floor and ceiling-effect [2, 3]. In contrast, several publications have shown a high level of responsiveness and acceptable criterion validity for the AOFAS-AHS [4], as well as a satisfactory degree of reliability for the subjective component of the AOFAS scale [5], which justifies its application. In addition, the Foot Function Index (FFI) is also commonly used in the clinical setting [6, 7, 8, 9].

Cross-cultural adaption of the AOFAS-AHS in its German translation and agreement analysis with the FFI-D by Naal et al. [10] were previously performed and published [11, 12]. The agreement analysis showed that the scores are not interchangeable, but rather complementary [12]. However, these self-reported questionnaires assess patient perception and are not necessarily indicative of actual disabilities. Therefore, it is important that research considers other methods of assessing functionality. Gait analysis has widely been accepted as an objective measure of physical function [13], allowing researchers and clinicians to better understand the biomechanics of gait. In particular, the Oxford Foot Model (OFM) [14] is a multi-segment kinematic model that can be used to quantify the functionality of the foot complex during gait in patients with different pathologies [15-17]. In patients with osteoarthritis and pre-osteoarthritic disorders in the ankle and subtalar joints, reduced walking speed, reduced step length, reduced range of motion (ROM) within different sections of the foot and ankle joint and reduced ankle power generation during push-off have been shown [18-21].

Since agreement analysis [12] did not determine which of the two scores is better suited to reflect function in patients with ankle and hindfoot disorders, the aim of the present study was to determine the association between physical foot dysfunction using the OFM and perceived disability in patients with mild to severe ankle and hindfoot pathologies. Higher correlation was expected for the FFI-D with respect to its rather elaborate scoring system as compared to the AOFAS-AHS scale system. In

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addition, exploratory factor analysis was applied to identify common information structures and redundancy contained in the FFI-D and the AOFAS-AHS items.

Methods and materials

Subjects

AOFAS-AHS and FFI-D results were consecutively collected from 20 patients with mild to severe ankle and hindfoot pathologies (10 female and 10 male patients) and a median age of 45 (interquartile range 35-54) years. Body mass index (BMI) was 27.8 (24.7-31.6) kg/cm² in median. We deliberately chose a heterogeneous group of patients to reflect the wide range of patients who were evaluated using the AOFAS-AHS. The 20 patients suffered from pathologies such as primary or post-traumatic osteoarthritis (10 / 20), osteochondral lesions / subchondral cysts (5 / 20), chondromatosis / corpora libra (2 / 20) or osteoarthritis due to hemophilia (3 / 20). Exclusion criteria included neuromuscular dysfunction (e.g., Parkinson's disease, stroke, epilepsy and Alzheimer's disease), a leg length discrepancy of more than 1 cm and chronic joint infection. All selected patients were recruited during a policlinic consultation by an experienced foot and ankle surgeon and demonstrated pain, stiffness or reduced ROM in different sections of the foot and ankle joint. They all showed clearly osteoarthritis or preartritic conditions in X-rays as well as magnetic resonance imaging scans. All patients underwent three-dimensional gait analysis on the same day the two questionnaires AOFAS-AHS and FFI-D were applied.

Ethical approval

The approval of the local independent Ethics Committee (Ruhr University Bochum ICE; vote reference no. 4126-11) was obtained in 2011.

The study was carried out in accordance with the Helsinki Declaration. Accordingly, written informed consent was obtained from all patients prior to participation in the study.

Questionnaires

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The FFI-D questionnaire is based on a ten-point scale for each item and enables overall continuous scoring by means of an equally weighted normalizing evaluation system and providing two subscales including eight items for pain and ten items for disability, respectively. The AOFAS-AHS includes nine items (five to be answered by patients and four to be answered by the physician) with two to four possible responses and an asymmetric assignment of score points. The AOFAS-AHS over represents the pain item with 40 of the maximum 100 score points assigned to this item alone.

Gait analysis methods

Three-dimensional gait analysis was performed using a 200 Hz, eight-camera motion capture system (VICON™ Motion Systems, Oxford, UK) in combination with a 1000 Hz AMTI™ force plate (Advanced Mechanical Technology, Inc., Watertown, MA, USA) to detect gait cycle events and to calculate ankle power generation during the push off phase. Reflective markers were placed over prominent anatomical landmarks along the lower extremity, as well as the ankle and foot complex according to the multi-segment OFM [14, 22, 23]. The OFM allows for a differentiated analysis of movement within different sections of the foot and ankle joint. Repeatability of the OFM has been demonstrated for healthy children and adults [18, 24, 25] and has also been applied in patients with foot pathologies/disorders [16, 22, 23, 26]).

Kinematic and data that represent mobility in the ankle and subtalar joints (for example the ROM plantarflexion to dorsiflexion for the hindfoot versus tibia as well as inversion to eversion or forefoot versus hindfoot adduction to abduction) and that are relevant for osteoarthritis patients were collected from barefoot participants during level walking at a self-selected speed. In cases with bilateral pathology, the more severely affected side was analyzed. After each acquisition session, 3D marker trajectories were reconstructed and missing frames were handled with a fill-gap procedure. The data was smoothed with a Woltring filter and using spline smoothing [27]. Average values from three trials were selected based on good quality of marker trajectories and ground reaction forces.

Statistical analysis

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A sample size calculation was performed based on the fact that an AOFAS-Score of 80-100 points is expected for healthy people, while in patients with relevant foot and ankle disorders a score of 30-35 points is expected,. The power was assumed to be 80%. A group of 20 patients was calculated as suitable.

In a first step, basic spatio-temporal gait parameters (i.e., walking speed, cadence, step length, stride length, step width) as well as discrete kinematic and kinetic gait data were correlated with the total scores for the AOFAS-AHS (range 0 – 100 points) and the FFI-D. The FFI-D scale was transformed to the range 0 - 100 points with 100 points indicating optimum rating in all items to make the scores directly comparable to those derived from the AOFAS-AHS. Both overall scores were handled as continuous endpoints, i.e. methods for continuous data evaluation were applied. This means that score descriptions were based on medians and quartiles (graphic description on nonparametric box whisker plots, accordingly) with regard to the moderate sample size. Bivariate correlations between gait parameters and the total FFI-D and AOFAS-AHS scores were estimated by means of the Spearman coefficient and its asymptotic 95% confidence interval. For the sake of aggregation and interpretation of the various bivariate correlation profiles a previously established categorization of correlation ranges based on the Spearman point estimates was adopted [28, 29]: correlations were classified "low" for Spearman coefficients less than 0.30, as "medium" for coefficients between 0.30 and 0.65 and otherwise as high.

For further correlation analyses AOFAS-AHS items were taken into account that represent the function of the subtalar and ankle joints, and were related to the corresponding gait analysis parameters representing the function of the respective joints. The respective bivariate associations were described by means of gait parameter distribution (medians and quartiles) stratified for the respective AOFAS item scale levels. Furthermore, Jonckheere-Terpstra test were applied to test for trends in the gait parameters levels alongside the respective AOFAS item scale levels. The results of these trend tests were summarized by means of p-values. In accordance with the exploratory character of this evaluation, the latter were not formally adjusted for multiplicity, but rather considered as indicators of local statistical significance in the case of p-values ≤ 0.05.

To determine those FFI-D items representing the ROM in the ankle and the subtalar joints as well as gait function – note, that these can be derived from the AOFAS items, but not from the FFI-D assessment – exploratory factor analysis for the total

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set of the 9 AOFAS-AHS and the 18 FFI-D items was performed. In the case of several FFI-D items being aggregated with the AOFAS item(s) of interest, these FFI-D items could be considered as ROM related. Since the AOFAS-AHS individual items are more or less categorical, whereas the FFI-D parameters should be treated as continuous, both score systems' items were binarized for simultaneous use in factor analysis by means of the following criteria: the AOFAS-AHS item dealing with pain was defined to indicate a "negative response" for a score of 20 points or less. Accordingly, a score representing pathological findings (0-4 points) in one of the remaining AOFAS-AHS items was defined as a "negative response". For the FFI-D, results of five or more points were regarded as a "negative response" (note the scaling direction of the FFI-D items). The total set of 9 binarized AOFAS-AHS items and of 18 binarized FFI-D items was then analyzed by means of exploratory factor analysis, where factors were identified by means of principle component analysis and application of the varimax criterion (75% variance to be explained by identified factors).

Statistical and graphic analyses were performed using SPSS® for Windows 21.0™ (IBM Corporation, New York, USA)].

Results

Gait analysis

Only moderate correlation coefficients (r= 0.51-0.64) could be found between the total AOFAS-AHS / total FFI-D score and objective gait parameters as shown in Table 1. With moderate correlation coefficients between the AOFAS-AHS total score and six gait parameters representing mobility in the ankle joint, two representing the ROM in the subtalar joint, as well as ankle maximum power generation during the push-off phase (Table 1), the AOFAS-AHS showed slightly more and higher correlation coefficients with the gait parameters than the FFI-D total score. Regarding the FFI-D, only six moderate correlations could be found between the overall score and gait parameters representing mobility in the ankle (one parameter) and subtalar joints (five parameters, Table 1).

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In addition, we focused on the individual items of the AOFAS-AHS that represent gait function and passive ROM (AOFAS-AHS items five to seven). The AOFAS-AHS items representing passive ROM in the ankle joint complex and the corresponding gait parameters representing the total ROM during the gait cycle in the ankle joint and the subtalar joints, respectively, as well as spatio-temporal gait parameters, showed encouraging association (Figures 1 and 2; all presented trends were found locally significant), as also demonstrated in terms of the Jonckheere-Terpstra test with a significance at the 5% level between the three groups (= three different items for the answer) indicating monotonic association. As a result of extensive exploratory analysis those gait parameters were taken into account, which best represented mobility (Figure 1) and gait function (Figure 2) in the respective joints.

Factor analysis

Factor analysis based on the binarized individual AOFAS-AHS and FFI-D items proposed three factors arising out of the joint information pattern, but could not reveal any FFI-D items to represent either mobility in the ankle and subtalar joints or gait function (Table 2). Furthermore, although the FFI-D is divided into the two subscales "pain" and "disability" [7, 10] by its authors, this subdivision could not be reproduced in the factor analysis patterns. Only three items of the FFI-D pain subscale showed an involvement in factor 2 (representing "pain and disability"). In addition, only one item from the pain subscale and one item from the disability subscale were involved with factor 3 (representing "mobility and gait function"), while all remaining questions from the subscales were aggregated into factor 1. The authors could not construct a generic term for this predominant factor 1, as it encompasses a wide variety of items, which could hardly be assigned to one common category (Table 2). In contrast, the AOFAS-AHS items showed either a high involvement with factor 2 (representing "pain and disability") or with factor 3 (representing "mobility and gait function").

Discussion

Since both scores are still used throughout the world to evaluate treatment outcomes of foot and ankle disorders and a validated German translation of the AOFAS-AHS did not yet exist, we carried out a validation study for the German language version of

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the AOFAS-AHS [12]. The present study was the final step in this procedure. The main goal was to determine the association between objective foot function using the OFM and perceived disability in patients with mild to severe ankle and hindfoot pathologies.

Our expectation that – due to its better evaluation methodology and the two respective subscales – the FFI-D, in comparison with the AOFAS-AHS, is better suited to assess the functionality of the foot could not be supported. The comparison of the Spearman correlations between the overall results of both scores and functionality during gait indicates a slightly better suitability of the AOFAS-AHS. In particular, the analysis of the respective functional pattern under consideration of the individual items from the AOFAS-AHS was able to show good agreement with objective parameters from gait analysis. Additionally, the moderate positive correlation between the AOFAS-AHS and ankle power generation during push-off indicates that the AOFAS-AHS is well suited to evaluate limitations in foot function during gait.

Although the FFI-D is divided into two subscales, this could not be confirmed by factor analysis. The opposite was found for the AOFAS-AHS, which represents pain and ability issues on the one hand and questions dealing with hindfoot and ankle function on the other hand. This was shown in the factor analysis for the transformed individual questions, even if this was not postulated by its developers themselves [1].

The mathematical weaknesses of the AOFAS-AHS - especially the over-representation of the pain question and the limited number of feature expressions, leading to a floor and ceiling-effect - are undeniable [2]. Nevertheless, the items in the AOFAS-AHS give a good representation of ankle and hindfoot disorders, as shown by the Spearman correlations with gait function, ROM in the ankle and subtalar joints, as well as by the Jonckheere-Terpstra test. Reduced ankle power generation during push-off is discussed as a possible indicator for ankle arthritis [17, 19, 21]. Since reduced ankle power generation during push-off showed a significant correlation with the AOFAS-AHS total score, this suggests that the AOFAS-AHS total score migth be an indicator of ankle osteoarthritis.

Due to its mathematical weaknesses, the AOFAS-AHS should be applied with care, even if its individual questions show a good representation of pain, disability and function. These items can be used, but should be combined with better methods for

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scoring and interpreting the results. In contrast, the FFI-D did not show the same clear correlations for these three items (pain, disability and function). In addition, the FFI-D did not demonstrate any clear items representing gait function or ROM in the ankle and subtalar joints in the factor analysis. Therefore, it did not make any sense to compare the results of individual questions to corresponding gait parameters. As a consequence, the application of the FFI-D as a score to evaluate disability and functional limitations of patients suffering from foot and ankle pathologies should be critically discussed.

Our findings show that the use of gait analysis in combination with theoretical mathematical considerations for the evaluation of scores will make a valuable contribution to the development and evaluation of survey instruments and patient-reported outcome questionnaires in clinical research. The best consequence would be to develop a new score with items derived from objective measurements such as gait analysis including mature biometrical means for scoring and evaluating results.

Limitations:

Limitations of this study are the inhomogeneity of the group and the limited number of patients. Nevertheless, we deliberately choose a heterogeneous group of patients to reflect the wide range of patients who were evaluated using the AOFAS-AHS. For focusing on a certain group of foot disorders, a more homogenous group should be examined. In order to develop a new score dealing with different kinds of foot disorders using gait analysis, a bigger group should be taken into account.

Conclusion:

The AOFAS-AHS showed a good agreement with objective gait parameters and is therefore better suited to evaluate disability and functional limitations of patients suffering from foot and ankle pathologies compared to the FFI-D.

Acknowledgement:

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The gait analysis study was the subject of the doctoral thesis of co-author Kirsten Hartmann.

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Tables:

Parameter	AOFAS-AHS total score r (95% CI)	FFI-D total score r (95% CI)
Hindfoot vs. tibia maximum dorsiflexion during stance [°]	0.51 **(-0.15; 0.83)**	0.16 (-0.40; 0.66)
Hindfoot vs. tibia ROM (plantarflexion/dorsiflexion) during gait cycle [°]	**0.53** (0.18; 0.75)	0.47 (0.00; 0.78)
Hindfoot vs. tibia ROM (inversion/eversion) during gait cycle [°]	**0.55 (0.24; 0.78)**	**0.55 (0.02; 0.85)**
Hindfoot vs. tibia ROM (internal/external rotation) during gait cycle [°]	0.41 (-0.06; 0.78)	**0.51 (0.03; 0.83)**
Forefoot vs. hindfoot maximum dorsiflexion during stance [°]	-0.57 (-0.83; 0.07)	-0.36 (-0.72; 0.3)
Forefoot vs. hindfoot maximum plantarflexion during push-off-phase [°]	**-0.64 (-0.87; -0.25)**	-0.26 (-0.76; 0.26)
Forefoot vs. hindfoot ROM (adduction/abduction) during gait cycle [°]	**0.63 (0.28; 0.86)**	**0.57 (0.12; 0.84)**
Forefoot vs. hindfoot ROM (supination/pronation) during gait cycle [°]	0.45 (0.14; 0.72)	**0.52 (0.10; 0.80)**
Forefoot vs. tibia ROM (adduction/abduction) during gait cycle [°]	0.45 (0.05; 0.77)	**0.57 (0.21; 0.79)**
Forefoot vs. tibia maximum plantarflexion during push-off-phase [°]	**-0.61 (-0.88; -0.29)**	**-0.55 (-0.84; -0.09)**
Forefoot vs. tibia ROM (plantarflexion/dorsiflexion) during gait cycle [°]	**0.57 (0.13; 0.87)**	0.38 (-0.10; 0.78)
Ankle maximum power generation during push-off-phase [W/kg]	**0.55 (0.18; 0.84)**	0.34 (-0.11; 0.72)

ROM = range of motion; CI = confidence interval

Table 1: Spearman correlation coefficients with 95% confidence intervals between the AOFAS-AHS total score as well as the FFI-D total score, respectively and selected gait parameters representing mobility in the ankle (six parameters) and the subtalar joint (five parameters) as well as the ankle-osteoarthritis indicator-parameter ankle maximum power generation during stance [W/kg], respectively. Significant correlations (>0.5 / <-0.5) are printed in bold.

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(binarized) score items	factor and factor weight		
	1	**2 "pain and disability"**	**3 "mobility and gait function"**
AOFAS-AHS "pain"		.810	
AOFAS-AHS "activity restriction"		.807	
AOFAS-AHS "walking distance"			.597
AOFAS-AHS "walking surfaces"		.780	
AOFAS-AHS "gait abnormality"			.747
AOFAS-AHS "sagittal motion"			.747
AOFAS-AHS "hindfoot motion"			.780
AOFAS-AHS "ankle-hindfoot stability"			.480
AOFAS-AHS „alignment"			.508
FFI-D PAIN „worst pain"		.792	
FFI-D PAIN „pain in the morning"	.446		
FFI-D PAIN „pain while walking barefoot"	.741		
FFI-D PAIN „pain while standing barefoot"			.620
FFI-D PAIN „pain while walking with shoes"	.741		
FFI-D PAIN „pain while standing with shoes"	.704		
FFI-D PAIN „pain at the end of the day"		.824	
FFI-D PAIN „pain during the night"		.477	
FFI-D DISABILITY „problems while walking outside"			.656
FFI-D DISABILITY „problems while walking on uneven ground"	.846		
FFI-D DISABILITY „problems while walking distances ≥ 1 km"	.846		
FFI-D DISABILITY „problems while walking up the stairs"	.690		
FFI-D DISABILITY „problems while walking down the stairs"	.767		
FFI-D DISABILITY „problems while walking on tiptoes"	.767		
FFI-D DISABILITY „problems while standing up from a chair"	.442		
FFI-D DISABILITY „problems while walking fast or during running"	.846		
FFI-D DISABILITY „problems during leisure activities or sports"	.846		
FFI-D DISABILITY „problems while wearing special shoes (high heels, sandals etc.)"			

Table 2: Factor analysis results for the respective binarized 9 items of the AOFAS-AHS and the binarized 18 items of the FFI-D: rotated factor weights for the 9 + 18 items after identification of three joint factors by means of the variance maximization criterion. Factor weights < 0.500 have been omitted to emphasize the rotation-based aggregation of the 9 +

18 items into three factors, a posteriori declared representing “pain and disability” (factor 2) and “mobility and gait function” (factor 3), respectively.

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Legend figures 1+2:

Figure 1:

Nonparametric box plots for an association analysis between AOFAS-AHS items 5 – 7 and respective content-corresponding gait parameters. Box plot horizontals indicate medians and quartiles, verticals indicate minimum and maximum observations, circles indicate statistical outliers with a deviation of at least 1.5 x interquartile range from the respective median.

AOFAS-AHS item 5 (gait abnormality) represents a normal gait or slight gait abnormality with 8 points, an obvious gait abnormality (walking/running is possible but irregular) with 4 points and a considerable gait abnormality with 0 points.

AOFAS-AHS item 6 (sagittal motion, flexion plus extension) represents a normal or mild restriction (30° or more) with 8 points, a moderate restriction (15°–29°) with 4 points and a severe restriction (less than 15°) with 0 points.

AOFAS-AHS item 7 (hindfoot motion, inversion plus eversion) represents a normal or mild restriction (75%–100% normal) with 6 points, a moderate restriction (25%–74% normal) with 3 points and a severe restriction (less than 25% normal) with 0 points

(a) box plots for the maximum ankle power generation during push-off stratified for AOFAS-AHS points achieved by 20 patients

(b) box plots for the total range of motion during gait cycle in dorsiflexion to plantarflexion of the forefoot vs. the tibia angle stratified for AOFAS-AHS points achieved by 20 patients

(c) box plots for the total range of motion during gait cycle in dorsiflexion to plantarflexion of the forefoot vs. the hindfoot angle stratified for AOFAS-AHS points achieved by 20 patients

(d) box plots for the total range of motion during gait cycle in internal to external rotation of the hindfoot vs. the tibia angle stratified for AOFAS-AHS points achieved by 20 patients

(e) box plots for the total range of motion during gait cycle in adduction to abduction of the forefoot vs. the tibia angle stratified for AOFAS-AHS points achieved by 20 patients

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Figure 2: Nonparametric box plots for an association analysis between AOFAS-AHS item 5 and corresponding spatio-temporal gait parameters with regard to content. Box plot horizontals indicate medians and quartiles, verticals indicate minimum and maximum observations, circles indicate statistical outliers with a deviation of at least 1.5 x interquartile range from the respective median.

AOFAS-AHS item 5 (gait abnormality) represents normal gait or a slight gait abnormality with 8 points, an obvious gait abnormality (walking/running is possible but irregular) with 4 points and a considerable gait abnormality with 0 points.

(a) box plots for walking speed stratified for AOFAS-AHS points achieved by 20 patients

(b) box plots for step length stratified for AOFAS-AHS points achieved by 20 patients

(c) box plots for step time stratified for AOFAS-AHS points achieved by 20 patients

(d) box plots for step width stratified for AOFAS-AHS points achieved by 20 patients

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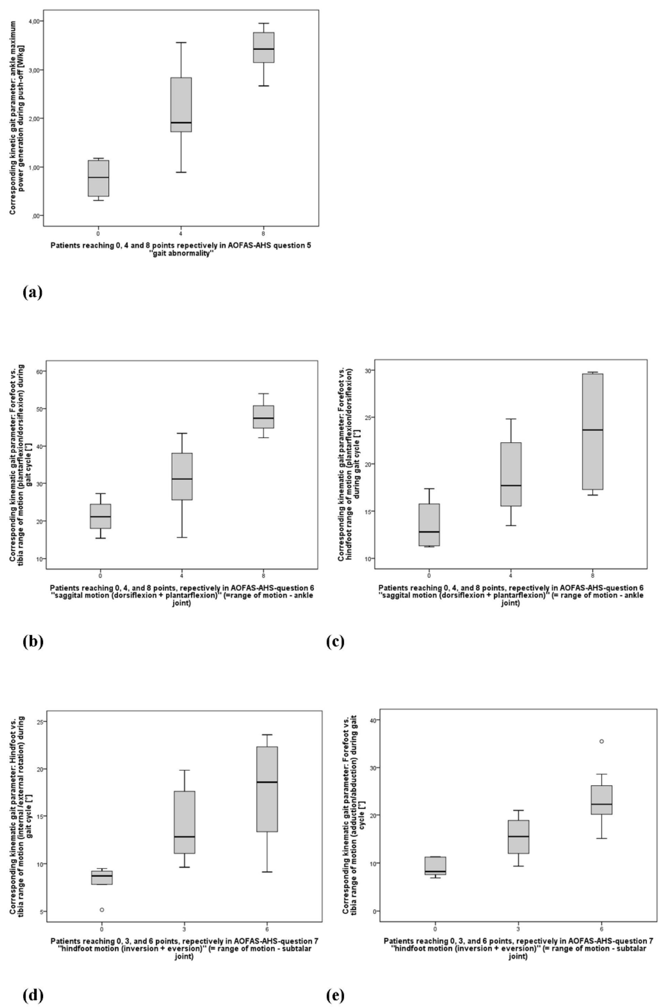

Nonparametric box plots for an association analysis between AOFAS-AHS items 5 – 7 and respective content-corresponding gait parameters. Box plot horizontals indicate medians and quartiles, verticals indicate minimum and maximum observations, circles indicate statistical outliers with a deviation of at least 1.5 x interquartile range from the respective median.

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(c) box plots for the total range of motion during gait cycle in dorsiflexion to plantarflexion of the forefoot vs. the hindfoot angle stratified for AOFAS-AHS points achieved by 20 patients
(d) box plots for the total range of motion during gait cycle in internal to external rotation of the hindfoot vs. the tibia angle stratified for AOFAS-AHS points achieved by 20 patients
(e) box plots for the total range of motion during gait cycle in adduction to abduction of the forefoot vs. the tibia angle stratified for AOFAS-AHS points achieved by 20 patients

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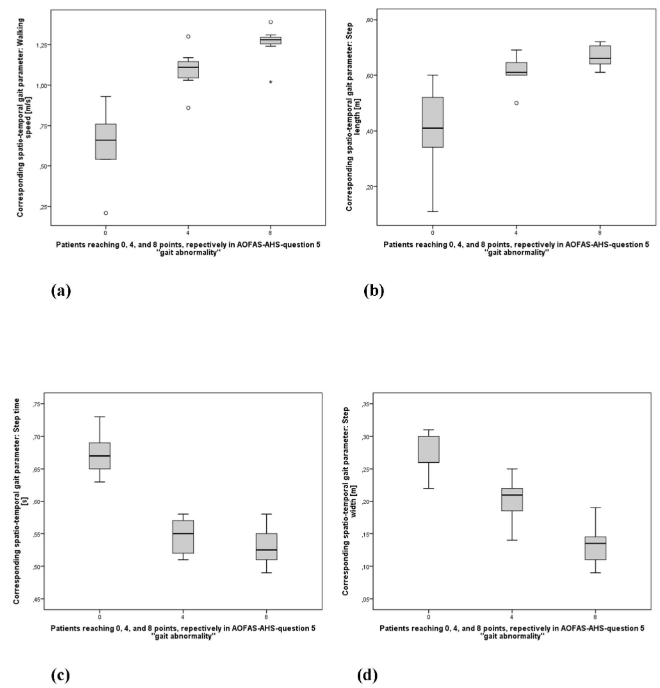

Nonparametric box plots for an association analysis between AOFAS-AHS item 5 and corresponding spatio-temporal gait parameters with regard to content. Box plot horizontals indicate medians and quartiles, verticals indicate minimum and maximum observations, circles indicate statistical outliers with a deviation of at least 1.5 x interquartile range from the respective median.
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(c) box plots for step time stratified for AOFAS-AHS points achieved by 20 patients
(d) box plots for step width stratified for AOFAS-AHS points achieved by 20 patients

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STROBE 2007 (v4) Statement—Checklist of items that should be included in reports of *cohort studies*

Section/Topic	Item #	Recommendation	Reported on page #
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract	4,6-8
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found	4/5
Introduction			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	5/6
Objectives	3	State specific objectives, including any prespecified hypotheses	6, 11
Methods			
Study design	4	Present key elements of study design early in the paper	6-9
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	6/7
Participants	6	(*a*) Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up	6/7
		(*b*) For matched studies, give matching criteria and number of exposed and unexposed	
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	13
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	*6/7*
Bias	9	Describe any efforts to address potential sources of bias	8 + 12/13
Study size	10	Explain how the study size was arrived at	8
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	9
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding	8-10
		(*b*) Describe any methods used to examine subgroups and interactions	---
		(*c*) Explain how missing data were addressed	---
		(*d*) If applicable, explain how loss to follow-up was addressed	---
		(*e*) Describe any sensitivity analyses	---
Results			

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Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	6/7
		(b) Give reasons for non-participation at each stage	---
		(c) Consider use of a flow diagram	---
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	6/7
		(b) Indicate number of participants with missing data for each variable of interest	---
		(c) Summarise follow-up time (eg, average and total amount)	---
Outcome data	15*	Report numbers of outcome events or summary measures over time	10
Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	10/11
		(*b*) Report category boundaries when continuous variables were categorized	9
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	---
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	---
Discussion			
Key results	18	Summarise key results with reference to study objectives	11
Limitations			
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	12/13
Generalisability	21	Discuss the generalisability (external validity) of the study results	13
Other information			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	3

*Give information separately for cases and controls in case-control studies and, if applicable, for exposed and unexposed groups in cohort and cross-sectional studies.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.

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