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Development and validation analysis of a corrected axial spondyloarthritis metrology index (CASMI)

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ABSTRACT

Objectives: To adjust the BASMI for measurement bias related to age, sex and height, and to compare scores and construct validity of a corrected metrology index (CASMI) against BASMI.

Methods: Spinal mobility data from non-axSpA individuals and severe axSpA patients were used to develop CASMI. For each BASMI component, the anchors for normal (score=0) and severe (score=10) mobility were redefined based on the 50th percentiles of non-axSpA individuals and the 95th percentile of patients with severe axSpA respectively. These anchors were individually adjusted for age, sex, and height using the regression coefficients from the MOBILITY study of non-axSpA individuals. Score ranges, floor/ceiling and construct validity (correlations and know-group discrimination) of BASMI and CASMI were assessed in an r-axSpA-population (OASIS cohort). It was hypothesized that CASMI would reduce correlations with age/height, while maintaining construct validity.

Results: Applying these corrections resulted in lower CASMI scores compared with BASMI (3.2 (2.0) vs 3.8 (1.6)), particularly in older and shorter individuals. Floor effects increased as more subjects were correctly classified within the normal mobility range, while ceiling effects remained unchanged. CASMI showed markedly reduced correlations with age and height, confirming a lower influence of these non-disease factors. Construct validity was maintained, as correlations with functional, disease activity, and structural outcomes were comparable to BASMI. Known-group discrimination also remained good, with standardized mean differences consistently above 0.80.

Conclusions: An age-, sex- and height-corrected mobility score, the CASMI, has been developed as a more personalised and valid measure of mobility in axSpA, compared to BASMI.

Introduction

Axial Spondyloarthritis (axSpA) is a chronic inflammatory rheumatic and musculoskeletal disease that can lead to progressive structural damage of sacro-iliac joints, spine or hips, ultimately resulting in impaired mobility. Clinicians have traditionally used simple tools (such as goniometers and tape measures) to assess cervical rotation, lumbar flexion (Schober's test), lateral spinal flexion (LSF), hip abduction (intermalleolar distance (IMD)), and spinal deformity (initially measured as occiput-to-wall distance (OTW), later expanded with

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tragus-to-wall distance (TTW)). These assessments were integrated into the Bath Ankylosing Spondylitis Metrology Index (BASMI), a composite score introduced in 1994 [1,2] and widely applied in clinical research. Over time, BASMI has been refined from nominal (BASMI2 and BASMI10) to continuous scoring (BASMI-linear) [3], the latter being the preferred measure in recent clinical trials due to its higher sensitivity, while preserving ease of computation.

In the last decades, the diagnostic landscape has evolved with the wider adoption of magnetic resonance imaging (MRI), which enables earlier detection of axSpA by identifying signs of active inflammation. This advancement has led to the recognition of axSpA as a disease spectrum that includes both non-radiographic (nr-axSpA) and radiographic (r-axSpA) phenotypes, defined according to the presence or absence of structural sacroiliac damage on radiographs [4] In this context, trials in nr-axSpA populations (usually earlier stages of the disease, including patients with less structural damage) have often reported limited responsiveness of BASMI, despite frequent spinal and hip involvement in this group, [5] suggesting that the BASMI may have limitations in certain parts of the disease spectrum, particularly in earlier stages with less structural damage [6]. Aligning with this, the Assessment of SpondyloArthritis international Society (ASAS) recently revised the axSpA core set, and removed spinal mobility from the mandatory outcome measures collected in therapeutic studies of axSpA [7].

At the time of its development, the validation of BASMI did not include a formal assessment of mobility in healthy individuals, leaving no benchmark for what constitutes a “normal” score. This gap was later addressed in the MOBILITY study, [8] which showed that BASMI scores are significantly influenced by age, height, and sex. Among healthy individuals, the mean value was 1.5 (range 0.2–4.7) on the 0–10 scale, while no participant reached the theoretical minimum of zero of the score. Based on the MOBILITY data, age-specific percentile-based reference limits (e.g., 50th percentile of the LSF for a given age), adjusted for height, are now available. A previous study from the United Kingdom reported similar findings, with only 1.2 % (2/168) of healthy individuals reaching a BASMI score of zero [9].

The MOBILITY study further highlighted that BASMI can over- or underestimate spinal mobility, particularly in older adults or in individuals who are significantly shorter or taller than average, potentially distorting the clinical assessment of mobility restriction severity. The mobility assessment would be more accurate if the score truly reflected restriction caused by the disease, rather than by anatomical (e.g. impact of skull conformation on TTW) or physiological variations (e.g. age). Since the existing BASMI components do not account for these physiological differences, and concerns were raised about the anchors, which were arbitrarily defined, we aimed to overcome this by (i) adjusting the mobility score for biases introduced by age, height, and sex, and (ii) redefining measurement anchors and ranges so that the scores reflect mobility limitations beyond what is expected in non-axSpA individuals to provide a more valid (less confounded) reflection of spinal mobility. Our aim was to develop a corrected axial spondyloarthritis spinal mobility index (CASMI) that is better suited to capturing the true impact of the disease.

The objectives of this study were to perform the initial steps towards the development of a CASMI, assess whether various potential versions are uninfluenced by age and height in healthy individuals, and compare its construct validity with that of BASMI in patients with axSpA.

Methods

The overall approach taken was to adjust each BASMI component to enhance the resulting score, so that it reflects the (expected) deviation from the normal value expected for a given individual.

Populations

For the development of CASMI, data from two cohorts were used:

a). The MOBILITY study was designed to examine the influence of age, height, and sex on spinal mobility in healthy, non-axSpA individuals from the Netherlands and Portugal. Percentile curves were generated to illustrate the normal variation in mobility by the confounding variables and enhance application in clinical practice. A total of 393 participants were included; 211 (54 %) were male, with a mean age of 44 years (standard deviation (SD) 14, range 20–69) and a mean height of 175 (12 (range 146–209) cm.(9) Participants were purposely stratified to achieve equal representation across age, sex, and height categories.
b). A long-standing r-axSpA cohort from Ireland, including 40 participants, of whom 25 (63 %) were male, with a mean age of 48 years (range 27–76), and a mean symptom duration of 23.6 years (range 3–52) [10–12]

Subsequently, to assess the performance of the CASMI and start its validation process, namely by assessing the construct validity in axSpA, another cohort of patients with long-standing axSpA, the Outcome in Ankylosing Spondylitis International Study (OASIS) with patients from the Netherlands, Belgium and France, was used [13] Of the 216 patients included at baseline, 154 (77 %) were male, with a mean age of 44 (13, range 19–77) years, and a mean symptom duration of 20.5 (11.7, range 0.3- 54) years. The mean modified Stoke Ankylosing Spondylitis Spine Score (mSASSS) at baseline was 11.6 (16.2) [14].

CASMI development

The development of CASMI and its components involved a three-step correction of the BASMI anchors, followed by scaling of each raw measurement to a 0–10 scale and the calculation of the overall score(s).

Step 1- Definition of base anchors (denoted as S in Table 1)

Fixed base anchors were first defined using population percentiles: the normal anchor (score=0) was set at the 50th percentile of non-axSpA individuals (in separate analyses, the 75th percentile was used instead of the 50th percentile), [8] while the severe anchor (score=10) was set at the 95th percentile of patients with long-standing r-axSpA [10–12].

Step 2 – Individual adjustment

These base anchors were then individualized for each patient according to age, sex and height, by applying the regression coefficients derived from the MOBILITY study, which quantify the natural effect of age, sex, and height on spinal mobility. This allowed each patient’s score to be calibrated against expected normal and severe values for a person of the same demographic profile.

As TTW was not significantly influenced by age, sex, or height, only its anchors were corrected: the normal anchor (score=0) was reset from 8 cm (original BASMI) to 11 cm, corresponding to the mean TTW in non-axSpA individuals with OTW=zero [8] Additionally, an Occiput-to-wall (OTW) score was considered by using as the normal limit (score=0) the value 0 cm, and 15 cm as the maximum value (score=10), with the latter derived from the 95th percentile of the OASIS cohort (as comparable data were not available in the Irish cohort).

Step 3-Rescaling and CASMI calculation

Each observed (raw) measurement was then positioned proportionally between the individualized anchors and expressed as a 0–10 score.

CASMI versions corrected using the MOBILITY regression coefficients were labelled _M (i.e. CASMI_M) and calculated by averaging the adjusted BASMI components.

Each of the two CASMI_M versions was additionally labelled according to the percentile used for the base normal anchor (i.e.

CASMI_M50 for the MOBILITY 50th percentile; CASMI_M75 for the 75th). By applying this correction, we expected at least 50 % (_M50) or 75 % (_M75) of subjects to score zero on the corrected scores (LSF, Schober's test, IMD, and cervical rotation), reflecting that the chosen percentile anchors correspond to the expected distribution of normal performance.

Additional CASMI versions

A trigonometric method was also employed to derive a third version of CASMI (CASMI_T50), adjusting primarily for height by incorporating data on the angles formed by the natural spine and hip ranges of motion (Supplementary Text S1).

A fourth CASMI version was computed by replacing the TTW by OTW, which is considered a more valid measure and for which we know the normal score, i.e. score of 0, resulting in a new CASMI_M50 version called CASMI_OTW.

Since the BASMI is also composed of a score assessing hip mobility, we decided to also calculate a pure spinal mobility assessment score, by excluding the IMD from the CASMI_OTW, which was the fifth CASMI version and labelled as CASMI-4-OTW.

Table 1 presents the formulae for the five components of BASMI, as well as the formulae for the corrected CASMI components. A more detailed explanation of the full formulae used for the five different CASMI versions (CASMI_M50, CASMI_M75, CASMI_T50, CASMI_OTW, and CASMI-4-OTW) can be found in the Supplementary text S1 and Supplementary Table S1. Throughout the manuscript, the term CASMI refers to the CASMI_M50 version unless otherwise specified.

CASMI performance and validation

The performance of CASMI (five versions) was evaluated using two populations: non-axSpA individuals from the MOBILITY study and patients with axSpA from the OASIS cohort. Comparisons were made between BASMI and CASMI (and their individual components) in terms of mean values, floor and ceiling effects. To better visualize the distribution of both indices, density plots were generated.

Additionally, to compare the individual absolute difference between each of the BASMI and CASMI versions (and particularly between the different versions of each component), we calculated the absolute difference between the BASMI and CASMI scores in the axSpA cohort (OASIS). These differences were then categorized as <0.5, between 0.5 and <1.5, and ≥1.5.

The influence of age and height was assessed by comparing correlations (Spearman coefficients) of BASMI and CASMI scores with these variables in MOBILITY and OASIS. It was hypothesized that correlations between CASMI (and its components, except for TTW) and age or height would be reduced by at least 10 % (0.1 units) compared to BASMI (a threshold arbitrarily chosen as indicative of a meaningful difference), thereby bringing coefficients closer to zero and reflecting reduced influence of these confounding variables.

Construct validity was examined in the OASIS cohort by correlating BASMI and CASMI scores with disease-related outcomes: Bath Ankylosing Spondylitis Functional Index (BASFI), Axial Spondyloarthritis Disease Activity Score (ASDAS), Bath Ankylosing Spondylitis Disease Activity Index (BASDAI), mSASSS, and the number of syndesmophytes. For all these instruments, higher values represent worse outcomes. It was hypothesized that correlations with these measures would remain similar for BASMI and CASMI, since the external measures were expected to be less independent of demographic correction.

Lastly, discrimination between known-groups was evaluated for BASMI and CASMI (and components) versions by contrasting groups based on: i) **BASFI:** low vs high functional impairment using thresholds BASFI ≤3 vs ≥6; ii) **mSASSS:** low vs high structural spinal using the threshold of mSASSS ≤1 vs >10; iii) **Number of syndesmophytes:** using the threshold of 0 vs >10 (cutoff chosen to still keep approximately 20 % of patients in this group). To compare the known-groups being contrasted, the standardized mean difference (SMD) was calculated, defined as the difference between group means divided by the pooled standard deviation (SD). A higher absolute SMD indicates better discrimination between known groups, with values above 0.8 considered 'good' [13–17]

Table 1
Equations for the conversion of the raw assessments (A) into scores (S) for the five components of the BASMI and CASMI, including applied adjustment.

Instruments		S=0 (Normal Limit)[#] if:	S between 0–10:	S=10 (Severe limit)[#] if:	Age	Sex	Height
Lateral spinal flexion (cm)	BASMI	A≥21.1	S = (21.1-A)/ 2.1	A≤0.1			
	CASMI	≥22.1-adjustments[±]	S = (Normal limit-A)/(Normal limit – Severe limit)/10)	≤2.25-adjustments	✓		✓
Tragus-to-wall distance (cm)	BASMI	A≤8	S = (A-8)/3	A≥38			
	CASMI	A≤11	S = (A-11)/1.5	A≥26			
Occiput-to-wall distance (cm)	CASMI	A≤0	S = (A-0)/1.5	A≥15			
Schober's test (cm)	BASMI	A≥7.4	S = (7.4-A)/0.7	A≤0.4			
	CASMI	≥5.2-adjustments	S = (Normal limit-A)/(Normal limit – Severe limit)/10)	≤0.2-adjustments	✓		
Intermalleolar distance (cm)	BASMI	A≥124.5	S = (124.5-A)/10	A≤24.5			
	CASMI	≥119-adjustments	S = (Normal limit-A)/(Normal limit – Severe limit)/10)	≤29.5-adjustments	✓	✓	✓
Cervical rotation angle (°)	BASMI	A≥89.3	S = (89.3-A)/8.5	A≤4.3			
	CASMI	≥81±1.92 [*]-adjustments	S = (Normal limit-A)/(Normal limit – Severe limit)/10)	≤11.5±0.27[**]-adjustments	✓	✓	

[#] Normal and severe limits were calculated based on appropriate adjustments for age, sex, or height.

Age, sex and height correction factors were derived from the regression coefficients obtained in the MOBILITY study.

[*] If male sex "+1.92", if female sex "-1.92"

[**] If male sex "+0.27", if female sex "-0.27"

A, assessment (of the individual spinal mobility measure); S, score; BASMI, Bath Ankylosing Spondylitis Metrology Index; CASMI, Corrected Ankylosing Spondylitis Metrology Index.

[±] Details on all adjustments are found in Supplementary Table S1. Example of the adjustments made for Lateral spinal flexion for a 20-year old patient with a height of 170cm:

i. *Normal Limit (basal anchor based on the 50th percentile form the MOBILITY study)* 22.1 – 0.15*(Age-20) – 0.03*(170-height) if age ≥20 22.1 – 0.03*(170-height) if age <20

ii. *Severe Limit (basal anchor based on the 95th percentile of the r-axSpA cohort)* 2.25 –0.015*(Age-20) – 0.003*(170-height) if age ≥20 2.25 – 0.003*(170-height) if age <20

Results

Correction of BASMI: the CASMI development

Applying correction factors for age, sex, and height to the BASMI, as well as modifying or removing certain components, led to the development of five distinct CASMI versions. Overall, CASMI yielded lower mean scores than BASMI in both non-axSpA individuals (0.6 [SD 0.6] vs 1.8 [0.7]) and patients with axSpA (3.2 [2.0] vs 3.8 [1.6]). The score range was also lower, with CASMI values going from 0–3.4 compared to 0.2–4.7 for BASMI, in the non-axSpA individuals, but higher in patients with axSpA (0.1–9.1 vs 0.9–8.4) (Table 2, Table 3). To illustrate the impact of these corrections, we provide two contrasting examples. Both patients had the same BASMI scores but differed in their sociodemographic profiles. The first, a 70-year-old woman with a height of 163 cm, had a BASMI of 2.66 that decreased to a CASMI of 0.42 after correction. The second, a 31-year-old man with a height of 188 cm, had a BASMI of 2.64, which corrected to a CASMI of 2.26.

CASMI performance in non-axSpA individuals (MOBILITY) and validation in axSpA cohort (OASIS)

Distribution, floor and ceiling effect

Analyses in the non-axSpA (MOBILITY) and axSpA (OASIS) cohorts confirmed this overall reduction in the CASMI scores compared to BASMI. Minimum CASMI component values remained close to zero, but floor effects increased, reflecting a higher proportion of individuals classified within the normal range. In non-axSpA individuals (MOBILITY), the floor effect rose from 33 % to 60 % for LSF, from 3 % to 50 % for Schober's test, from 19 % to 32 % for IMD, and from 7 % to 50 % for CR (Table 2). By contrast, increases in the floor effect for the five overall CASMI scores were minimal (from 0 % to 3 % for CASMI_M50, increasing to 15 % with CASMI_4_OTW). For TTW, 56 % of participants achieved a normal score compared to 0 % in the original BASMI version, thereby eliminating the false floor effect (Table 2).

In patients with axSpA (OASIS), the floor effect increased for the individual components but remained at 0 % for both BASMI and CASMI composite scores. For example, in the TTW score, the original floor effect was 0.5 %, which increased to 26 % in the corrected TTW version. Notably, the OTW score showed a floor effect of 50 %. Regarding the maximum values, higher scores were observed across all corrected components and CASMI compared to BASMI. However, the ceiling effect increased only slightly in the individual components (except for Schober's test), while it remained at 0 % for the CASMI scores (Table 3).

Regarding the use of the 75th percentile of MOBILITY as the normal anchor, results were also generally consistent with those obtained using the 50th percentile. The main difference was observed for IMD, where the floor effect decreased from 32 % (IMD_M50) to 16 % (IMD_M75) in MOBILITY and from 27 % to 16 % in OASIS. In OASIS, a minimal ceiling effect (1–3 %) also appeared in all components except IMD (data not shown).

Density plots further illustrated the distributional shifts. In non-axSpA individuals (MOBILITY, Fig. 1a), the CASMI distribution peaked to the left of BASMI, reflecting systematically lower scores. Fig. 1b highlights the CASMI-4-OTW version (excluding IMD and replacing TTW with OTW), which showed a markedly higher floor effect. Similarly, in patients with axSpA (OASIS cohort, Fig. 1c), the CASMI distribution is also shifted to the left (mean scores) of the BASMI, although to a lesser extent, again indicating on average lower scores. While the overall skewness remains relatively similar between the two scores, CASMI shows a wider spread at both extremes, with a larger number of individuals scoring at the lower end. Fig. 1d, including the CASMI-4-OTW, shows lower scores in general, as depicted by the peak of the curve, but with higher minimum and maximum values compared to the full corrected version in Fig. 1c.

On a patient level, as shown in Supplementary Figure S2, larger

Table 2
Descriptive data and construct of the BASMI/CASMI and their components in healthy subjects (MOBILITY study, n=393).

Instrument	Scale characteristics					Correlations	
	Mean (SD) score (0–10)	Minimum score (0–10)	Floor effect n (%)	Maximum score (0–10)	Ceiling effect n (%)	Age (Rho)	Height (Rho)
Lateral spinal flexion score	**1.2 (1.3)**	**0**	**131 (33)**	**6.2**	**0 (0)**	**0.553**	**-0.119**
Lateral spinal flexion_M50 score	0.6 (1.0)	0	234 (60)	5.6	0 (0)	0.024	0.008
Tragus to wall score	**1.1 (0.4)**	**0.3**	**0 (0)**	**3.8**	**0 (0)**	**0.161**	**0.480**
Tragus to wall_M score	0.3 (0.7)	0	219 (56)	5.7	0 (0)	0.158	0.415
Occiput to wall score	0.2 (0.7)	0	366 (93)	5.3	0 (0)	0.305	0.152
Schober's test score	**3.4 (1.4)**	**0**	**11 (3)**	**7.4**	**0 (0)**	**0.141**	**-0.011**
Schober's test_M50 score	0.8 (1.1)	0	196 (50)	5.7	0 (0)	0.020	-0.021
Intermalleolar distance	**1.4 (1.2)**	**0**	**73 (19)**	**6.4**	**0 (0)**	**0.340**	**-0.385**
Intermalleolar distance_M50 score	0.9 (1.0)	0	125 (32)	5.1	0 (0)	0.156	0.058
Cervical rotation score	**1.9 (1.2)**	**0**	**26 (7)**	**6.1**	**0 (0)**	**0.446**	**-0.147**
Cervical rotation_M50 score	0.5 (0.8)	0	195 (50)	4.8	0 (0)	0.003	-0.051
BASMI	**1.8 (0.7)**	**0.2**	**0 (0)**	**4.7**	**0 (0)**	**0.574**	**-0.200**
CASMI_M50	0.6 (0.6)	0	12 (3)	3.4	0 (0)	0.129	0.083
CASMI_M75	1.1 (0.7)	0	1 (0)	4.7	0 (0)	0.120	0.065
CASMI_T50	0.8 (0.6)	0	9 (2)	3.6	0 (0)	0.109	0.244
CASMI_OTW	0.6 (0.6)	0	22 (6)	3.8	0 (0)	0.122	0.036
CASMI_4_OTW	0.5 (0.6)	0	59 (15)	4.3	0 (0)	0.070	0.039

BASMI, Bath Ankylosing Spondylitis Metrology Index; CASMI, Corrected Ankylosing Spondylitis Metrology Index; OTW: Occiput to wall.
The normal limit (anchor zero) for the BASMI components was defined based on their established minimal values, while for the CASMI components, it was set using the 50th (or 75th) percentile of BASMI values from the MOBILITY study. The severe limit (anchor 10) for the BASMI components was defined based on their established maximum values, while for the CASMI components, it was set using the worst values (percentile 95th) from a longstanding established r-axSpA cohort.
M: MOBILITY coefficient-based adjustment formula (except for tragus to wall, where the normal limit was based on the mean value from the MOBILITY study in non-axSpA individuals, and the occiput to wall where the highest limit was based on the 95th percentile of the OASIS cohort).The number 50 or 75 represents the percentile used for the normal limit.
T: Trigonometric-based adjustment formula.
In bold BASMI (components) values.
Cells are colored green when the CASMI (components) showed, compared to BASMI (components) a lower correlation with age or height (i.e., improves) by more than 10 % (>0.1), and red when the correlation was higher (by at least 10 % i.e., worsens) when compared to BASMI (components).

Table 3
escriptive data and construct of the BASMI/CASMI and their components in patients with axSpA (OASIS, cohort n=216).

Instruments	Scale characteristics					Correlations						
	Mean (sd) score value (0–10)	Min score value (0–10)	Floor effect n (%)	Max score value (0–10)	Ceiling effect n (%)	Age (Rho)	Height (Rho)	BASFI (Rho)	BASDAI (Rho)	ASDAS (Rho)	mSASSS (Rho)	Syndesmophytes (Rho)
Lateral spinal flexion score	**5.5 (2.6)**	**0**	**6 (3)**	**9.7**	**0 (0)**	**0.372**	**-0.307**	**0.484**	**0.158**	**0.184**	**0.440**	**0.338**
Lateral spinal flexion_M50 score	5.5 (3.1)	0	14 (7)	10	6 (3)	0.230	-0.251	0.457	0.148	0.199	0.376	0.280
Tragus to wall score	**2.1 (1.6)**	**0**	**1 (0.5)**	**8.8**	**0 (0)**	**0.361**	**-0.067**	**0.339**	**-0.007**	**0.135**	**0.543**	**0.446**
Tragus to wall_M score	2.2 (2.8)	0	55 (26)	10	7 (3)	0.376	-0.082	0.358	0.001	0.138	0.549	0.446
Occiput to wall score	2.4 (3.2)	0	107 (50)	10	13 (6)	0.441	-0.015	0.390	0.059	0.140	0.571	0.440
Schober's test score	**6.5 (2.0)**	**0**	**0 (0)**	**10**	**10 (5)**	**0.183**	**-0.164**	**0.425**	**0.116**	**0.199**	**0.435**	**0.342**
Schober's test_M50 score	4.5 (2.9)	0	9 (4.2)	10	3 (1)	0.137	-0.120	0.381	0.124	0.192	0.392	0.304
Intermalleolar distance	**2.1 (1.9)**	**0**	**41 (19)**	**8.6**	**0 (0)**	**0.403**	**-0.537**	**0.459**	**0.222**	**0.203**	**0.342**	**0.230**
Intermalleolar distance_M50 score	1.6 (1.8)	0	56 (27)	8.58	0 (0)	0.189	-0.319	0.418	0.210	0.216	0.270	0.250
Cervical rotation score	**3.0 (2.6)**	**0**	**27 (12)**	**10**	**2 (1)**	**0.373**	**-0.357**	**0.492**	**0.211**	**0.296**	**0.425**	**0.394**
Cervical rotation_M50 score	2.1 (2.8)	0	83 (38)	10	5 (2)	0.147	-0.229	0.425	0.156	0.301	0.337	0.336
BASMI	**3.8 (1.6)**	**0.9**	**0 (0)**	**8.4**	**0 (0)**	**0.450**	**-0.356**	**0.594**	**0.212**	**0.273**	**0.584**	**0.473**
CASMI_M50	3.2 (2.0)	0.1	0 (0)	9.1	0 (0)	0.301	-0.242	0.585	0.169	0.298	0.552	0.450
CASMI_M75	3.6 (1.9)	0.5	0 (0)	9.1	0 (0)	0.289	-0.294	0.594	0.171	0.298	0.557	0.457
CASMI_T50	3.2 (2.0)	0.1	0 (0)	9.0	0 (0)	0.294	-0.204	0.549	0.180	0.272	0.542	0.431
CASMI_OTW	3.2 (2.1)	0.1	0 (0)	8.9	0 (0)	0.333	-0.244	0.581	0.200	0.279	0.563	0.441
CASMI_4_OTW	3.6 (2.3)	0.1	0 (0)	9.9	0 (0)	0.324	-0.228	0.554	0.175	0.260	0.571	0.444

Missing data for LSF=11; IMD=2; LF=1; BASMI/CASMI=11.
BASMI, Bath Ankylosing Spondylitis Metrology Index; CASMI, Corrected Ankylosing Spondylitis Metrology Index; OTW: Occiput to wall.
The normal limit (anchor zero) for the BASMI components was defined based on their established minimal values, while for the CASMI components, it was set using the 50th (or 75th) percentile of BASMI values from the MOBILITY study. The severe limit (anchor 10) for the BASMI components was defined based on their established maximum values, while for the CASMI components, it was set using the worst values (percentile 95th) from a longstanding established r-axSpA cohort.
M: MOBILITY coefficient-based adjustment formula (except for tragus to wall, where the normal limit was based on the mean value from the MOBILITY study, and the occiput to wall where the highest limit was based on the 95th percentile of the OASIS cohort). The number 50 or 75 represents the percentile used for the normal limit.
T: Trigonometric-based adjustment formula.
In bold BASMI (components) values.
Cells are colored green when the CASMI (components) showed, compared to BASMI (components) a lower correlation with age or height (i.e., improves) by more than 10 % (>0.1), and red when the correlation was higher (by at least 10 % i.e., worsens) when compared to BASMI (components).

absolute differences between BASMI and CASMI in axSpA patients (OASIS) were most evident in the individual components, particularly in the 50th percentile versions. The largest discrepancy was observed in Schober's test, where 68 % of patients showed differences ≥1.5 points. Overall, the CASMI 50th percentile versions showed that 66–73 % of the differences with BASMI fell between 0.5 and 1.5 points, while in the CASMI_M75, more than half of the differences were <0.5 points.

Correlation with age and height (and disease related variables)

In non-axSpA individuals (MOBILITY), the hypothesized reduction in correlations with age and height was confirmed. Age effects were eliminated in all corrected versions (with rho values close to 0, and none exceeding 0.2), except the TTW, where no age adjustment had been applied, and no meaningful change was observed (Table 2). Regarding height, CASMI components generally showed lower correlation compared with BASMI, particularly for IMD, where a marked decrease was observed (from 0.38 to 0.06). The only exception was Schober's test, where a non-significant increase in the correlation with height was found.

In the axSpA cohort (OASIS) (Table 3), a similar improvement was observed for correlations with age, with gains in all components except TTW and Schober's test. Correlations with height improved significantly only for the IMD component and for the total CASMI scores, except for CASMI_M75.

Results using the trigonometric version (CASMI_T50) were largely consistent, except for an overcorrection for height observed in the non-axSpA (MOBILITY) population. Specifically, the correlation between LSF and height increased from -0.12 for the original LSF component score to 0.35 for the LSF_T50, resulting in the absence of the desired decrease in the overall correlation for the overall CASMI_T50 (from -0.20 in BASMI to 0.24 in CASMI_T50) (data not shown).

Conversely, in the axSpA cohort (OASIS), the trigonometric correction performed slightly better, with a correlation between IMD and height decreasing from -0.53 to -0.24 (IMD_T50) compared to -0.32 (IMD_M50). However, this improvement did not translate into a meaningful difference (defined as >0.1) in the overall correlation reduction between the two CASMI versions, which decreased from -0.36 in BASMI to -0.20 in CASMI_T50 and -0.24 in CASMI_M50 (data not shown).

No major differences were observed across the other CASMI versions either (CASMI_OTW and CASMI_4_OTW) (Table 2, Table 3).

Discrimination between known-groups

Lastly, in discrimination between known groups, based on functional

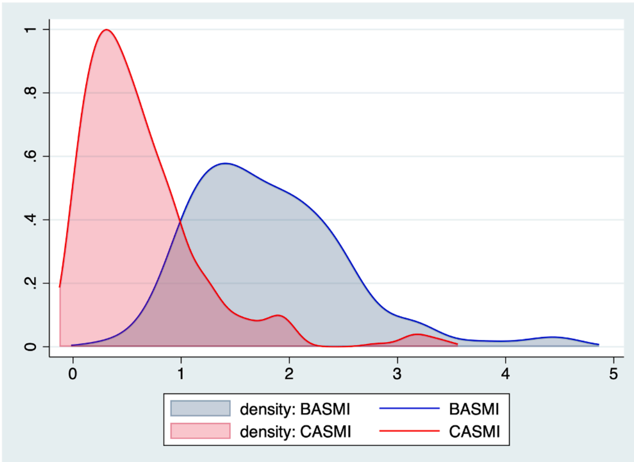

Fig. 1a. Density plots for BASMI and CASMI (CASMI_M50) in MOBILITY study. The CASMI version used (_M50) corrected mobility components using coefficients from the MOBILITY study, with the anchor=0 defined by the 50th percentile of the MOBILITY study.

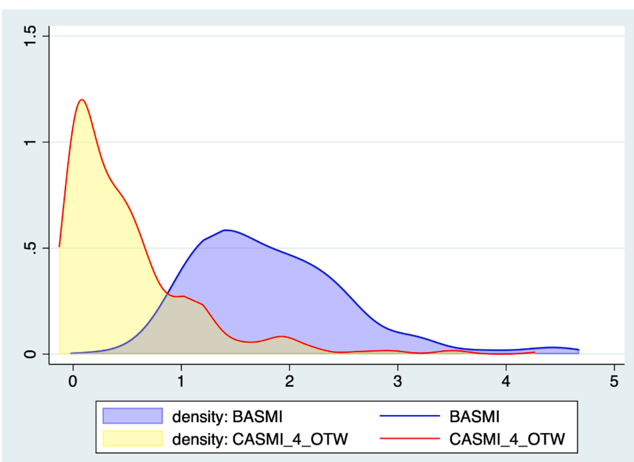

Fig. 1b. Density plots for BASMI and CASMI 4 components with occiput to wall instead of tragus to wall (CASMI_4_OTW) in MOBILITY study. The CASMI version used (_4_OTW) excludes the intermalleolar distance and replaces tragus-to-wall with occiput-to-wall.

impairment (BASFI) or spinal radiographic damage (mSASSS or the number of syndesmophytes), the SMDs for individual BASMI components, as well as for BASMI and all versions of CASMI were good, with SMD values largely exceeding 0.80 (Table 4). The only exceptions were the IMD scores and CR_M50 score, which showed just adequate discrimination between groups with low vs high mSASSS.

Discussion

In this study, a corrected and individualized version of the BASMI, the CASMI, was developed and validated to account for the physiological influence of age, sex, and height on spinal mobility. The traditional spinal mobility index, BASMI, does not consider these key demographic and anthropometric variables, which can lead to misclassification, particularly in older or shorter individuals who naturally present with (relative) lower mobility.

Previous studies had already demonstrated that age, sex, and height significantly influence spinal mobility; however, these findings were mostly limited to descriptive analyses and group comparisons [18–20] It was only with the MOBILITY study that reference intervals based on

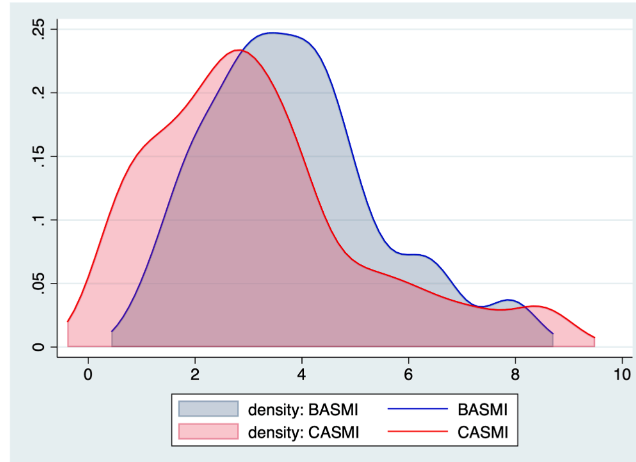

Fig. 1c. Density plots for BASMI and CASMI (CASMI_M50) in OASIS. The CASMI version used (_M50) corrected mobility components coefficients from the MOBILITY study, with the anchor=0 defined by the 50th percentile of the MOBILITY study.

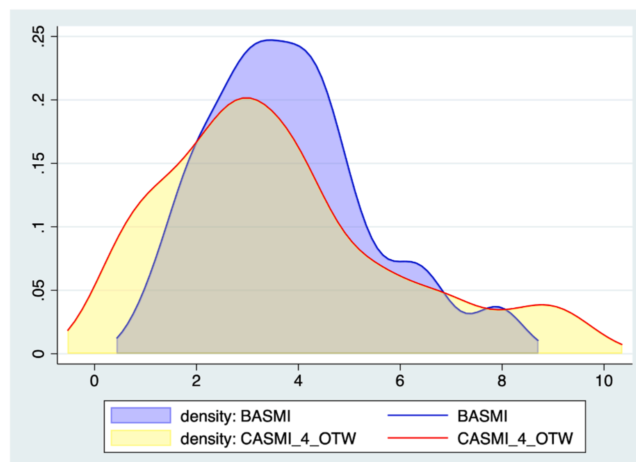

Fig. 1d. Density plots of BASMI and CASMI 4 components with occiput to wall instead of tragus to wall (CASMI_4_OTW) in OASIS. The CASMI version used (_4_OTW) excludes the intermalleolar distance and replaces tragus-to-wall with occiput-to-wall.

these variables were formally established, providing the framework for individualized correction [8] By introducing these adjustments, CASMI aims to provide a more valid representation of the pathological mobility impairment that is less influenced by age, sex and height, thereby focusing more directly on disease-related limitation, and enhancing both clinical interpretation and comparability across diverse patient populations.

In the early development of the CASMI, a trigonometric function (CASMI_T50) was modelled mainly for IMD to explore whether the observed correlation with height could be explained in geometric terms. This analysis showed that the expected trigonometric adjustment for height closely matched the coefficient obtained in the MOBILITY regression analysis. It was therefore concluded that the relationship between IMD and height reflects variation in limb length rather than in the angle of hip abduction. The trigonometric model also suggested that the height correction coefficient derived from non-axSpA individuals may overestimate the adjustment required in axSpA patients with severely limited hip abduction.

Although five different versions of the CASMI were developed and tested, no major differences were found among them. Among these, the

Table 4
BASMI and CASMI discrimination between known-groups stratified by spinal structural damage (mSASSS) in patients with axSpA (OASIS cohort).

	BASFI			mSASSS			Syndesmophytes		
	<3 Mean (sd) n =94	>6 Mean (sd) n = 31	SMD	≤1 Mean (sd) n= 53–58	>10 Mean (sd) n= 56–58	SMD	=0 Mean (sd) n = 80–86	>10 Mean (sd) n = 19–20	SMD
Lateral spinal flexion score	4.4 (2.5)	6.9 (1.9)	1.05	4.1 (2.4)	6.8 (2.0)	1.20	4.6 (2.6)	7.3 (1.6)	1.08
Lateral spinal flexion_M50 score	4.3 (2.9)	7.0 (2.5)	0.96	4.2 (2.7)	6.9 (2.7)	1.00	4.7 (2.9)	7.3 (2.2)	0.95
Tragus to wall score	1.5 (0.8)	3.5 (2.4)	1.40	1.3 (0.8)	2.8 (1.6)	1.22	1.4 (0.8)	3.5 (2.0)	1.88
Tragus to wall_M score	1.1 (1.5)	4.6 (3.8)	1.48	0.7 (1.4)	3.6 (3.0)	1.23	1.0 (1.5)	4.9 (4.6)	1.91
Occiput to wall score	0.9 (1.8)	5.4 (3.9)	1.77	0.7 (1.9)	4.1 (3.2)	1.30	1.0 (1.9)	5.6 (3.5)	2.02
Schober's test	5.7 (1.7)	8.2 (1.7)	1.47	5.5 (1.8)	7.6 (2.0)	1.11	5.7 (1.8)	8.3 (1.7)	1.53
Schober's test_M50 score	3.4 (2.4)	6.9 (2.5)	1.45	3.2 (2.5)	6.1 (2.9)	1.06	3.4 (2.4)	7.2 (2.3)	1.58
Intermalleolar distance score	1.4 (1.3)	3.9 (2.2)	1.54	1.4 (1.4)	2.7 (2.1)	0.77	1.5 (1.4)	3.3 (2.1)	1.20
Intermalleolar distance_M50 score	1.0 (1.2)	3.3 (2.4)	1.52	1.0 (1.2)	2.0 (2.2)	0.59	1.0 (1.1)	2.5 (2.5)	1.03
Cervical rotation score	1.9 (1.9)	5.7 (2.6)	1.79	1.9 (2.3)	3.9 (2.5)	0.82	2.0 (2.2)	5.2 (2.2)	1.45
Cervical rotation_M50 score	1.1 (1.9)	4.9 (3.4)	1.61	1.2 (2.4)	2.9 (2.9)	0.61	1.2 (2.3)	4.2 (3.0)	1.25
BASMI	3.0 (1.1)	5.6 (1.7)	2.03	2.8 (1.2)	4.7 (1.4)	1.46	3.0 (1.1)	5.4 (1.3)	2.09
CASMI_M50	2.2 (1.3)	5.3 (2.3)	1.94	2.0 (1.3)	4.2 (1.9)	1.35	2.2 (1.2)	5.1 (1.8)	2.13
CASMI_M75	2.6 (1.3)	5.6 (2.2)	1.97	2.4 (1.3)	4.6 (1.8)	1.36	2.7 (1.2)	5.4 (1.7)	2.13
CASMI_T50	2.2 (1.2)	5.2 (2.3)	1.94	2.0 (1.3)	4.2 (1.9)	1.35	2.2 (1.2)	5.1 (1.8)	2.16
CASMI_OTW	2.1 (1.3)	5.4 (2.3)	2.05	2.0 (1.4)	4.3 (1.9)	1.39	2.2 (1.3)	5.3 (1.8)	2.19
CASMI_M_4-OTW	2.4 (1.5)	6.0 (2.5)	1.99	2.4 (1.7)	4.9 (2.0)	1.37	2.6 (1.5)	5.9 (1.9)	2.09

SMD, Standardized Mean Difference, <0.5 Low; ≥0.5 & <0.8 Moderate (coloured in orange); ≥0.8 Good (coloured in green)
BASMI, Bath Ankylosing Spondylitis Metrology Index; CASMI, Corrected Ankylosing Spondylitis Metrology Index; OTW, occiput to wall.
The normal limit (anchor zero) for the BASMI components was defined based on their established minimal values, while for the CASMI components, it was set using the 50th (or 75th) percentile of BASMI values from the MOBILITY study. The severe limit (anchor 10) for the BASMI components was defined based on their established maximum values, while for the CASMI components, it was set using the worst values (percentile 95th) from a longstanding established r-axSpA cohort.
M: MOBILITY coefficient-based adjustment formula (except for tragus to wall, where the normal limit was based on the mean value from the MOBILITY study in non-axSpA individuals, and the occiput to wall where the highest limit was based on the 95th percentile of the OASIS cohort). The number 50 or 75 represents the percentile used for the normal limit.
T: Trigonometric-based adjustment formula.

50th percentile version (CASMI_M50) offered the best balance between correcting for non-disease variability and maintaining sensitivity to clinically relevant limitations. In this context, "normal" mobility refers to the typical mobility observed in non-axSpA individuals, adjusted for age, sex and height. Anchoring at the 50th percentile reflects the median physiological mobility within each demographic group. In contrast, using the 75th percentile would define "normal" as above-average mobility. For these reasons, the 50th percentile was considered the most appropriate reference. The trigonometric version (CASMI_T50), although also a valid option, is more complex without providing additional benefit. Therefore, the less complex CASMI_M50 is considered the preferred version to represent the CASMI concept. Additionally, since the CASMI_4_OTW version is conceptually different (excluding the non-spinal mobility measure and replacing TTW with OTW), it represents an alternative option for assessing purely spinal mobility.

The validity of the correction was evident in both the non-axSpA and axSpA populations. As expected, the influence of age and height on mobility scores was substantially reduced, particularly for lumbar and cervical measures. This correction was most beneficial for individuals whose physiological characteristics, such as advanced age or shorter stature, previously inflated their apparent level of mobility impairment. Consequently, more individuals were correctly classified as having normal mobility. Although this resulted in higher floor effects, this finding was consistent with our hypothesis that many patients are overclassified as impaired when non-disease factors are not accounted for. In this context, a higher floor effect may reflect improved specificity for pathological restriction. However, a potential trade-off with discrimination and responsiveness at the lower end of the scale cannot be excluded, particularly in patients with early disease. Further evaluation of sensitivity to change and discrimination in clinical trial settings will be necessary to determine whether the correction affects responsiveness.

Importantly, CASMI maintained comparable construct validity with disease-related outcomes (BASFI, BASDAI, ASDAS, and mSASSS), confirming that the correction does not reduce the clinical meaning of the index. The preserved discrimination between known groups indicates that CASMI remains a robust measure of disease-related limitation while minimizing confounding by demographic factors.

Similar results were observed when evaluating alternative CASMI versions that excluded the IMD or replaced the TTW with the OTW. Despite these structural modifications, the correction methodology remained robust across versions. While the removal of IMD slightly reduced the correction's impact on height-related bias in non-axSpA individuals, this effect was not replicated in axSpA. Similarly, replacing TTW with OTW did not substantially affect associations with disease activity or the distribution of scores, although, as previously noted, this version showed a higher floor effect in non-axSpA only.

Beyond their statistical performance, these adjustments have important conceptual implications. The choice between TTW and OTW has been discussed in previous literature [21], where OTW has been shown to provide a more reliable and clinically meaningful estimate of spinal kyphosis. Unlike TTW, OTW has a natural reference value of zero, which facilitates differentiation between individuals with normal thoracic posture and those with structural deformity. It is also less affected by variations in head shape or skull conformation, improving measurement consistency. Likewise, excluding the IMD refines the conceptual scope of the score by focusing exclusively on spinal mobility. Although IMD was originally included in BASMI to capture overall flexibility, it largely reflects hip abduction and pelvic rotation rather than true spinal motion, reducing its specificity for axial involvement. Removing this component allows CASMI-4-OTW to target movements anatomically confined to the spine, in alignment with the pathophysiology of axSpA and potentially improving construct specificity for both clinical and research applications.

Taken together, these findings support the methodological flexibility of CASMI; however, they also suggest that there is limited room for substantial improvement of the score beyond the current corrections. Since all the CASMI versions performed similarly and no single option emerged as clearly superior, it will be essential to further evaluate additional measurement properties, such as sensitivity to change and discrimination in clinical trials, including in early disease, in order to establish whether CASMI truly offers more advantages over BASMI, or whether one CASMI version (replacing TTW with OTW or excluding IMD) outperforms the others. This is especially important given the potential trade-off between improved specificity (given the adjustement of the anchor for normal) and responsiveness of the scale. Only after confirming that CASMI performs at least as well as BASMI in the three domains can it be recommended as a replacement in clinical practice or research settings.

Future advances in mobility assessment may therefore depend on the incorporation of more technologically advanced methods, such as sensor-based technologies [11,12] These methods, for example, those capable of measuring thoracic rotation, could improve both construct validity and discrimination, as thoracic rotation is considered a specific feature of axSpA. Furthermore, the ability to quantify movement kinetics may enhance sensitivity in patients with early disease, allowing for the detection of early functional impairments that are not captured by current clinical measures.

This study has some limitations that should be acknowledged. First, although the CASMI provides a more individualized and potentially accurate measure of spinal mobility by adjusting for age, sex, and height, its implementation in clinical practice may be limited by the fact that height is not consistently measured during routine visits. This could restrict the feasibility of calculating the corrected score in daily clinical practice. Furthermore, the correction was primarily derived from a study conducted in non-axSpA individuals from the Netherlands and Portugal, where the average height may differ from that of populations in other regions of the world, potentially limiting the generalizability of the adjusted scores. In addition, differences in body proportions and anthropometric characteristics across ethnic and geographic populations may influence the performance of the correction. Therefore, the performance of CASMI should be evaluated in non-European populations before broad international application can be assumed. Another limitation was that the severe anchor was derived from percentile cutoffs in a relatively small cohort of long-standing r-axSpA patients. Although this group was chosen to represent the upper range of structural limitation, percentile estimates in smaller samples may be less stable. Lastly, TTW and OTW anchors were derived from different cohorts due to data availability, as OTW was not available in the Irish dataset. Although this may introduce minor differences related to cohort characteristics, no substantial differences in performance were observed between CASMI versions using these anchors.

In conclusion, CASMI represents a more individualized and valid measure of spinal mobility in axSpA by correcting for the natural influences of age, sex, and height. The CASMI_M50 version appears to offer the most balanced performance. By distinguishing physiological from pathological restriction, CASMI refines our understanding of mobility impairment. However, future research should evaluate its responsiveness and clinical trial discrimination before its use for monitoring or treatment response can be recommended. Therefore, at present, CASMI should primarily be considered a research and comparative tool until its performance in longitudinal settings is fully established. As rheumatology moves toward more personalized medicine, adopting adjusted composite indices such as CASMI may represent a meaningful step forward in the more accurate evaluation of functional outcomes in patients with axSpA.

Contributors

DC, PG, EN, AB and SR participated in the conceptualization of the study. PG created the formulas for the CASMI development. DC made the data curation and formal analysis. DC, PG, EN, AB and SR performed the writing of the original draft. All authors review the manuscript critically for important intellectual content and approved the final manuscript.

Patient consent for publication

Not required.

Ethics approval

The ethics committees from all participating hospitals have approved the respective studies.

Provenance and peer review

Not commissioned; externally peer reviewed.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.semarthrit.2026.152981.

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