Changes of static and dynamic spine alignment in patients with severe haemophilia

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Abstract

Introduction: Haemophilic arthropathy results in a restricted range of motion and pain that often affects gait. The effect of these gait changes on spinal posture has not been studied.

Aim: To evaluate whether the altered joint situation in patients with haemophilia (PwH) leads to compensatory mechanisms evident in the trunk and spine, considering static and dynamic conditions.

Methods: PwH and healthy controls (20–65 years) were examined using rasterstereography in a controlled cohort study. Analysis was performed in static and dynamic conditions in regard to gait phases. Joint status was determined using the Haemophilia Joint Health Score (HJHS).

Results: Static measurements showed no group differences in PwH (n = 40) compared to healthy controls (n = 40) except pelvic torsion (median [25%-quartile;75%-quartile]: -1.9[-3.2;9]° vs. 0.5[-1.1;1.9]°; P = .007). In contrast, under dynamic conditions PwH showed significantly higher trunk inclination and lower apex lumbar lordosis in all gait phases. Additionally, pelvic torsion was increased in mid stance and terminal swing. Considering joint status, PwH had a higher global HJHS (23.5[13.0;30.0] vs. 3.0[1.0;5.0]; P < .001). A significant moderate correlation was shown between the HJHS mobility score and spine parameters (r = .228–.588; P < .05).

Conclusion: Degenerative joint changes in PwH lead to altered spine posture during gait. A reason could be the reduced mobility in the affected joint. Changes in spinal and pelvic posture lead to higher structural burdens; therefore, clinicians should focus on posture of spinal column during gait in daily treatment.

Keywords: arthropathy, body tilt, gait, joint, rasterstereography, spine alignment, topography

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1 | INTRODUCTION

The X-linked recessive disease haemophilia is a blood coagulation disorder, characterized by recurrent bleeding predominantly in joints and soft tissue. The disease results from the lack of clotting factor VIII (haemophilia A) or IX (haemophilia B). Patients with severe haemophilia (factor VIII or IX<1%) are particularly affected by spontaneous bleedings into joints, which leads to synovitis, degenerative joint changes, and consequently to haemophilic arthropathy. The knee, ankle, and elbow joints are mostly affected.

Haemophilic arthropathy is accompanied by swelling and restricted joint range of motion (ROM). These changes are often associated with chronic pain and impact the patient’s gait pattern. Therefore, patients with haemophilia (PwH), suffering from joint changes showed in different studies a lower ROM during the gait cycle in the knee compared to healthy controls; however, the sample sizes were relatively small. Joint pain, restricted joint mobility, and the associated gait changes may negatively influence physical performance and quality of life.

From the biomechanical perspective, the joints of the lower extremities serve as a basis for creating stability in the spine. Hence, changed gait patterns in PwH due to joint changes may have far-reaching consequences on the three-dimensional sagittal balance of the spine and pelvis. For this reason, it is necessary to determine possible deviations in spinal posture. This evaluation should also take into account the sensation of pain.

In Germany, low back pain has a lifetime prevalence of 80%, representing a common phenomenon. In addition to arthropathies, aging PwH suffer more often from age-related diseases, such as degenerative changes or general orthopaedic diseases. Back pain is the third most frequent source of pain in PwH, after the ankle and knee joints. A previous study (n = 40) showed that 40% of PwH indicated back pain was more limiting than haemophilic restrictions. Increased back pain has also been detected in patients with gonarthrosis relative to the general population. In these patients, gait change was found to affect the occurrence of back pain and to worsen back pain. In static conditions, correlations have been shown between the affected knee joints and an altered spinal posture in patients with osteoarthritis. Patients with gonarthrosis showed increased flexion in the knee and hip joint, which led to an increased inclination of the spine. However, similar effects have not been investigated in PwH so far.

The present study aimed to provide initial indications of whether compensation mechanisms exist in the spinal column and pelvis due to gait changes in adult PwH and to what extent this might influence by pain and movement restriction. Changes in spinal posture could be the reason for the increased back pain prevalence in PwH mentioned above.

Based on the shown results in patients with gonarthrosis and previous studies at PwH, it is expected that compensation occurs in PwH in both static and dynamic conditions. Therefore, this study investigates abnormalities in inclination and imbalance as well as the position of the spine, trunk and pelvis. The spinal analysis of PwH could generate new findings of functional effects and consequences for clinical use, like more specific diagnostics or an increased focus on the treatment of the spine.

2 | METHODS

2.1 | Participants

This prospective study included 40 adult patients with severe haemophilia A (n = 35) or B (n = 5), as well as 40 healthy controls without diagnosed orthopaedic impairment. Anthropometric data are shown in Table 1. As a controlled cross-sectional study, participants (20–65 years old) were examined in the University Hospital Bonn. Potential participants were excluded from the study if they had previous spine surgeries, spine diseases such as Scheuermann’s disease, or an inability to walk without a walking aid. PwH were additionally excluded for the following reasons: Positive for FVIII or FIX inhibitor, bleeding events in the previous 2 weeks, previous surgeries such as synovectomy within the previous 6 months or other bleeding diseases.

The Ethics Committee at the University of Bonn approved the study (329/19). Written informed consent was obtained from each participant after they were informed about the study protocol according to the declaration of Helsinki.

Subsequently, a pre-assessment was carried out. All participants received a joint examination at the same time of day. Information about subjective pain conditions and previous factor substitution were collected via anamnesis and German pain questionnaire. Afterwards, the rasterstereography was carried out statically and dynamically on a treadmill by the same experienced investigator.

2.2 | Rasterstereography

Rasterstereography is an indirect light-optical measuring method that performs surface measurement using the principle of triangulation. It generates a three-dimensional image of the spine in a stance position as well as during movement by using a projected light grid on the skin surface and optical sensors. The measurement was performed with the DIERS 4Dmotion®Lab and the DiCam v3.11 software (DIERS International GmbH, Schlangenbad, Germany).

The measurement system can carry out a rasterstereography, depending on the gait phases. It allows an examination of the spine position in stance and in motion in different gait phases with the same reliability as the Vicon system (Vicon Motion Systems Ltd UK, Oxford, England, UK). Furthermore, the system is regarded as valid and reliable.

Anatomical landmarks on the spine (vertebra prominens and pelvis) served as reference points for analysing the vertebral body and pelvic position in dynamic measurement and were attached by the same investigator. No reflective markers were set on the spine during static measurement due to the measurement accuracy. Using an integrated
pressure measuring plate in the treadmill, it was possible to analyse the spine position according to the gait phases: loading response, mid stance, pre swing, and terminal swing. Participants stood barefoot in their habitual posture facing a black background with their unclothed back to the camera. The following endpoints were collected within the framework of the rasterstereography: pelvis torsion, apex lumbar lordosis, trunk imbalance, trunk inclination, pelvis tilt, kyphotic angle, lordotic angle (parameter explanation is shown in Figure 1). The analysis only considered the end of a gait phase. Measurement duration was 5s while standing and in the motion phase.22

Participants were first instructed to stand on the treadmill. Next, participants were asked to walk at a speed of 3 km/h. A speed over 2 km/h was necessary to accurately identify the spine and footpoints.25 A walking speed of 3 km/h is feasible for both PwH and controls.22,26 5 min were provided for movement habituation.27,28 In dynamic conditions, the average of three gait cycles was used for analysis. All measurements were subsequently checked manually for measurement errors.

2.3 Orthopaedic joint situation – Haemophilia Joint Health Score

The clinical joint situation was examined in all subjects (PwH and controls) using the Haemophilia Joint Health Score (HJHS) version 2.1, which assesses swelling, muscle atrophy, crepitus of motion, axial deformity, joint pain, strength, ROM and gait. Higher scores imply an increased deficit in the functional and structural joint status as a sign of more pronounced haemophilic arthropathy, with a maximum possible score of 120 points in the joint situation and a maximum of four points in global gait.29 The HJHS was developed for children; however, it has also been validated for teenagers and adults.30 The average acute pain over the last 2 weeks was determined using the visual analogue scale (VAS) from 0 no pain to 10, the worst pain imaginable, for the ankle, knee and elbow joints, to evaluate the pain intensity. The sum of the VAS scores from each joint gives the total score from 0 (no pain) to 60 (the strongest imaginable pain in all joints).
2.4 Statistical analysis

Statistical evaluation was performed to compare the measured spine parameters of the treadmill analysis while standing and in motion. The calculations were performed using IBM® Statistical Package for the Social Sciences 25 software (Armonk, NY, USA) for Windows. Individual gait phases were compared to evaluate the dynamic measurement. For this purpose, an intergroup comparison was carried out in which the mean values of the spine parameters and orthopaedic joint status were compared between the PwH and control groups. For a uniform format, all data were calculated using non-parametric test procedures. Intergroup differences were evaluated by the Mann–Whitney U test. Correlations between the HJHS and VAS (global and sub scores) as well as spine parameters were determined Spearman’s rank correlation.

A significance level of \( P = .05 \) (95% confidence interval) was established. The required sample size was calculated with GPower 3.1 based on an effect size \( f^2 = .665 \), 90% power (based on preliminary investigations with an average mean difference of 7.4±0.3 degrees in trunk inclination), and an alpha error probability of .05. Therefore, 40 persons were included in each cohort.

3 RESULTS

In cohorts of 40 PwH and 40 healthy controls, a static and dynamic rasterstereography in dependence of the gait phases were performed. No significant differences in age and weight were found between the groups. Height and body mass index showed significant differences between the groups (Table 1). Regarding the joint examination results, PwH showed a significantly worse joint situation than healthy controls in total HJHS score \( (P<.001) \). HJHS group differences were displayed in all examined joints and in the clinical investigation of the gait (see Table 2). A significant group difference was found in the total VAS score \( (P<.001) \). Three of six VAS sub-variables (left/right elbow and right knee) showed no significant group differences (Table 2).

During the static measurement, only pelvic torsion showed a statistically significant \( (P = .007) \) group difference (Table 3).

Depending on the gait phases in dynamic measurement (starting with the left leg), significant group differences occurred for apex lumbar lordosis, pelvis tilt, pelvic torsion and trunk inclination, as shown in Table 4. In PwH, the apex lumbar lordosis showed a significantly lower deviation compared to healthy controls during all gait phases. A significantly higher trunk inclination was also observed in PwH. Figure 2 shows the changed spinal posture in the different gait phases. Because the gait phases depend on the respective leg side’s start, both leg sides were measured. The right leg gait phases (data not shown) showed no significant differences compared to the left leg gait phases in Table 4 and Figure 2.

Significant \( (P<.01) \) moderate correlations between trunk inclination \( (r = .303-.462) \) and total HJHS were found in all gait phases. The apex lumbar lordosis also correlated significantly \( (P<.001;r = .382-.466) \) with the HJHS. In mid stance, a significant correlation between the HJHS and pelvic torsion was found \( (P<.001;r = -.588) \). The mobility score of HJHS correlates significantly \( (P<.05) \) with trunk inclination \( (r = .261-.399) \) and apex lumbar lordosis \( (r = .343-.401) \). A significant correlation with pelvic torsion was seen in mid stance and terminal swing \( (P<.01;r = -.519-.308) \). The other parameters and gait phases showed no significant correlations. The strength score, which determined by HJHS, did not correlate with the spine parameters. The exception was trunk inclination with a correlation of \( r = .283 \) \((P<.05) \) in loading response and terminal swing \( (P<.001;r = .405) \) and pelvic torso in mid stance and terminal swing \( (P<.01;r = -.634-.309) \).

In contrast to the HJHS, no significant correlations were found between the sum of the VAS and trunk inclination, apex lumbar lordosis, trunk imbalance, pelvis tilt, kyphotic angle, lordotic angle and pelvic torsion with the exception of pelvic torsion in mid stance \( (P<.001;r = -.418) \) and terminal swing \( (P = .029;r = .244) \).
TABLE 2  Haemophilia Joint Health Score (HJHS) and visual analogue scale (VAS) in patients with haemophilia (PwH) and non-haemophilic control subjects (Con)

| Variables (range HJHS) | Variables (range VAS) |
|------------------------|------------------------|
| Ankle right (0–20)     | Ankle right (0–10)     |
| 5.0 [3.0;6.0] (0–12)   | .0 [0.2;0.0] (0–9)     |
| PwH (n = 40)           | Con (n = 40)           |
| 1.0 [0.0;2.0] (0–4)    | .0 [0.0;0.0] (0)       |
| <.001*                 | .15                    |
| Ankle left (0–20)      | Ankle left (0–10)      |
| 4.0 [2.0;7.0] (1–13)   | .0 [0.0;2.0] (0–3)     |
| PwH (n = 40)           | Con (n = 40)           |
| 1.0 [0.0;2.0] (0–3)    | .0 [0.0;0.0] (0–4)     |
| <.001*                 | .02                    |
| Knee right (0–20)      | Knee right (0–10)      |
| 2.0 [1.0;5.0] (0–12)   | .0 [0.0;1.0] (0–4)     |
| PwH (n = 40)           | Con (n = 40)           |
| 1.0 [0.0;0.0] (0–4)    | .0 [0.0;0.0] (0–4)     |
| <.001*                 | .15                    |
| Knee left (0–20)       | Knee left (0–10)       |
| 2.0 [1.0;4.0] (0–10)   | .0 [0.0;0.0] (0–2)     |
| PwH (n = 40)           | Con (n = 40)           |
| 1.0 [0.0;0.0] (0–2)    | .0 [0.0;0.0] (0–2)     |
| <.001*                 | .01                   |
| Elbow right (0–20)     | Elbow right (0–10)     |
| 2.0 [0.0;4.0] (0–7)    | .0 [0.0;0.0] (0–1)     |
| PwH (n = 40)           | Con (n = 40)           |
| 2.2 [5.0;4.0] (-3.6–11.9) | 1.6 [1.3;2.0] (-4.2–6.8) |
| <.001*                 | .28                    |
| Elbow left (0–20)      | Elbow left (0–10)      |
| 1.0 [3.0;8.0] (0–9)    | .0 [0.0;0.0] (0–1)     |
| PwH (n = 40)           | Con (n = 40)           |
| 1.0 [0.0;0.0] (0–1)    | .0 [0.0;0.0] (0–4)     |
| <.001*                 | .14                    |
| Gait Score (0–4)       | Total Score (0–60)     |
| 3.5 [2.3;4.0] (0–4)    | 3.0 [0.0;6.0] (0–14)   |
| PwH (n = 40)           | Con (n = 40)           |
| 2.2 [5.0;4.0] (-3.6–11.9) | 1.6 [1.3;2.0] (-4.2–6.8) |
| <.001*                 | .01                    |
| Total Score (0–124)    | Data shown as score points and presented as median [P25;P75] (min–max). HJHS (total score = the sum of the joint and the gait scores: 0–124) VAS (total score = the sum of the joint scores: 0–60). Mann–Whitney U test.
| 23.5 [13.0;30.0] (4–51) | 3.0 [0.0;6.0] (0–14)   |
| Con (n = 40)           | .001*                  |

TABLE 3  Group differences in static spine parameters between n = 40 patients with haemophilia (PwH) and n = 40 non-haemophilic controls (Con)

| Variables | Group | Static measurement – 4D average | P-value |
|-----------|-------|---------------------------------|---------|
| Trunk imbalance VP-DM (*) | PwH | .2 [-.6; .7] (-4.2–3.1) | .360 |
|           | Con  | .3 [-1.0; .7] (-2.5–3.2)      |         |
| Trunk inclination VP-DM (*) | PwH | 2.2 [5.0;4.0] (-3.6–11.9) | .283 |
|           | Con  | 1.6 [1.3;2.0] (-4.2–6.8)      |         |
| Pelvis tilt DL-DR (*) | PwH | -1.1 [-5.1; 3.7] (-11.1–11.0) | .519 |
|           | Con  | -2 [-3.2;2.3] (-6.4–7.5)      |         |
| Pelvic torsion DL-DR (*) | PwH | -1.9 [-3.2; 9] (-9.0–5.2) | .007* |
|           | Con  | .5 [-1.1; 1.9] (-7.0–3.9)     |         |
| Kyphotic angle VP-T12 (*) | PwH | 47.7 [42.3;53.0] (34.4–59.2) | .336 |
|           | Con  | 46.8 [41.1;50.5] (30.7–60.3)  |         |
| Lordotic angle T12-DM (*) | PwH | 29.7 [22.6;37.1] (9.7–51.1) | .923 |
|           | Con  | 28.8 [25.6;34.2] (8.9–44.9)   |         |
| Apex lumbar lordosis (mm) | PwH | -411 [-436; -384] (-490– -318) | .256 |
|           | Con  | -417 [-436; -408] (-475– -376) |         |

Measurement was performed in movement with a rasterstereography. DL/DR = left/right lumbar dimple. T12 = twelfth thoracic vertebra. Data presented as median [25%-quartile;75%-quartile] (min–max). Mann–Whitney U test. Abbreviations: VP, vertebra prominens; DM, midpoint between lumbar dimples.

DISCUSSION AND CONCLUSION

Our results demonstrate an influence of joint changes on spine alignment in dynamic conditions. A change in trunk inclination, apex lumbar lordosis and pelvic torsion could be identified as the compensatory mechanism. The joint movement restriction in the major affected joints might be an influencing factor for compensatory mechanisms in the spinal column. Interestingly, there was no difference in the spine during static measurements despite joint changes (except pelvic torsion), while in dynamic conditions, a significant difference was shown. Thus,
TABLE 4 Group differences in dynamic spine parameters starting with the left leg between \( n = 40 \) patients with haemophilia (PwH) and \( n = 40 \) non-haemophilic controls (Con)

| Variables                  | Group            | Loading response | Mid Stance       | Pre swing        | Terminal swing  |
|----------------------------|------------------|------------------|-------------------|------------------|-----------------|
| Trunk imbalance VP-DM (°)  | PwH              | -7[2.5;0] (-3.6–1.5) | -4[1.4;5] (-4.7–2.3) | 1.9[8.5;12.0] (-3.9–3.6) | -1[1.1;8] (-2.6–2.5) |
|                           | Con              | -4[1.2;2] (-3.1–2.6) | -4[1.2;2] (-3.1–2.6) | -4[7.2;6.7] (-2.0–2.2) | -0[7.7] (-2.0–2.2) |
| Trunk inclination VP-DM (°) | PwH              | 6.5[4.6;8] (-6–15.8) | 6.8[4.9;8.2] (1.7–15.5)*** | 6.1[4.3;7.6] (1.5–15.7) | 7.0[5.2;8.2] (2.1–16.1)*** |
|                           | Con              | 5.1[2.8;7.1] (-4.2–10.0) | 5.1[2.8;7.1] (-4–10.0)** | 5.1[3.0;6.4] (-8–12.3)** | 5.1[3.0;6.4] (-8–12.3)** |
| Pelvis tilt DL-DR (°)      | PwH              | -6[3.5;1.7] (-9.8–7.2) | -1[3.9;1.6] (-10.6–5.5) | .4[-1.8;2.9] (-7.4–7.4) | 1.0[-2.3;3.2] (-7.8–6.2) |
|                           | Con              | -2[2.5;1.5] (-7.0–9.7) | -2[2.5;1.5] (-7.0–9.7) | 1.9[3.2;9] (-3.7–10.9) | 1.9[3.2;9] (-3.7–10.9) |
| Pelvic torsion DL-DR (°)   | PwH              | .2[-1.9;2.8] (-6.9–5.6) | -3.8[-6.1;2.5] (-12.4–6.5)*** | -1.2[-3.1;1.2] (-6.6–2.9) | 3.0[-5.5;4.4] (7.1–8.4)*** |
|                           | Con              | 1.4[-3.2;8] (-4.1–7.2) | 1.4[-3.2;8] (-4.1–7.2)*** | -8[-2.6;1.0] (-4.8–4.6) | -8[-2.6;1.0] (-4.8–4.6)*** |
| Kyphotic angle VP-T12 (°)  | PwH              | 47.3[41.8;52.5] (30.0–61.7) | 47.1[42.7;52.2] (27.6–61.3) | 47.4[43.2;52.3] (28.6–61.0) | 47.2[42.1;52.5] (28.9–59.2) |
|                           | Con              | 24.2[18.0;30.7] (31.7–60.2) | 45.5[41.7;48.6] (31.7–60.2) | 45.3[41.3;48.8] (31.2–61.1) | 45.3[41.3;48.8] (31.2–61.1) |
| Lordotic angle T12-DM (°)  | PwH              | 25.7[18.5;32.5] (7.3–44.5) | 25.3[19.1;32.2] (2.7–43.4) | 26.5[18.9;31.8] (8.1–42.0) | 25.9[19.4;32.4] (7.3–43.6) |
|                           | Con              | 24.2 (-9.4–24.2) | 24.2[18.0;30.7] (-9–42.4) | 24.3[17.8;30.4] (-1.4–42.0) | 24.3[17.9;30.4] (-1.4–42.0) |
| Apex lumbar lordosis (mm)  | PwH              | -394[-422;371] (-499–310)** | -397[-420;372] (-494–311)** | -399[-425;373] (-498–315)** | -392[-418;370] (-486–306)** |
|                           | Con              | -418[-437;401] (-491–358)** | -418[-437;401] (-491–358)** | -418[-419;406] (-477–358)** | -418[-438;406] (-477–358)** |

Measurement was performed in motion with a rasterstereography supported by a pressure measuring plate. DL/DR = left/right lumbar dimple. T12 = twelfth thoracic vertebra. Data presented as median[25%-quartile;75%-quartile] (min–max). Mann–Whitney U test.

Abbreviations: VP, vertebra prominens; DM, midpoint between lumbar dimples.

*P≤.05; **P≤.01; ***P≤.001.

FIGURE 2 Model to show the compensation mechanisms in the spinal column of patients with haemophilia (PwH) in comparison to the healthy controls (Con) under dynamic conditions. PwH show a decreased apex lumbar lordosis and increased trunk inclination in all gait phases. Pelvic torsion is also increased in mid stance (left torsion) and terminal swing (right torsion). The figure shows the gait cycle starting with the left leg.

The dynamic measurement showed different results than static diagnostics. However, clinical examination of the spine is usually performed statically. Similar results were shown in patients with degenerative lumbar kyphoscoliosis. The differences in spine changes only became apparent in dynamic measurements, which emphasizes the need to carry out dynamic measurements.

Research indicated a negative correlation between sagittal trunk inclination and physical performance as well as coordination in healthy
people.\textsuperscript{33} The instability was already evident from the foot position in stance; Kurz et al. showed an increased load distribution on the forefoot in PwH using pedobarography.\textsuperscript{34} Besides, the joint status influences the risk of falls in PwH.\textsuperscript{35} Furthermore, persons with an increased risk of falling also showed a higher sagittal trunk inclination as a potential compensation mechanism to achieve a higher balance than before.\textsuperscript{33} Increased flexion in the trunk creates better stability by lowering the body’s centre of gravity. Thoracic and cervical vertebral flexion is one option to stabilize the inclined body and is supported by our data (unpublished). A higher flexion in the cervicothoracic region could explain the significantly reduced apex lumbar lordosis in PwH, in addition to the increased trunk inclination. The higher pelvic torsion, as shown in Figure 2, is a further indication of reduced stability. PwH showed a higher torsional movement in gait phases that require higher stability (see min-max values in Table 4). In mid stance and terminal swing, PwH had a significantly higher torsion in the direction of the leg with the highest load (Figure 2). Higher torsion in the pelvis could result in problems in the iliosacral joint due to a higher load. Granata et al. showed a higher load and compression in the spine given a higher flexion of the vertebral bodies.\textsuperscript{36} Therefore, the goal should be to avoid increased flexion in the spine, especially when lifting additional loads.

The change in posture also influences the sagittal balance, which describes a physiological and energetically economical alignment of the spinal column.\textsuperscript{32} In a healthy population, the natural aging process causes a change in the sagittal balance due to reduced mobility and increasing compensation mechanisms. The compensation mechanisms also lower the body’s centre of gravity to achieve better gait stability.\textsuperscript{32} This process is also present in younger PwH due to poorer joint situations. However, the gait changes in PwH and the non-haemophilic aging population do not necessarily foster the same compensation mechanisms. Nevertheless, PwH are affected earlier by postural changes in the spine compared to patients with osteoarthritis, suggesting a more prolonged temporal impact on the spine.

In contrast to other studies, correlations between the clinical joint examination and gait analysis parameters could be established.\textsuperscript{11} The cause of higher trunk inclination, pelvic torsion and lower apex lumbar lordosis in our study was primarily seen in weak joint mobility rather than acute pain due to a lack of correlation between spinal parameters and VAS. Therefore, we assumed that spinal posture was mainly dependent on joint mobility. The higher sagittal trunk inclination may increase energy consumption during gait due to higher muscle activation in trunk extensors and hip extensors in PwH. In addition, this modified posture might lead to an increased impact on the hip joint. Postural changes in the spine might cause back pain, which is the third most common source of pain in PwH.\textsuperscript{16}

Although muscle strength was not determined, correlations to spinal parameters could only partially be established by using HJHS strength values. The correlation could derive from arthropathies affecting the musculus quadriceps, which is common in PwH.\textsuperscript{37} Strength in this muscle is necessary to stabilize the knee joint. Thus, further treatments should strengthen muscular structures that have a stabilizing function, such as the quadriceps muscle and the trunk. An other goal should be to improve the ROM in the affected joints to reduce abnormal postures in the pelvis and spine. In this case, targeted physiotherapy and sports therapy, as well as exercises in balance and motion, could be treatment options. In patients with gonarthrosis, these actions have improved balance and reduced the risk of falls.\textsuperscript{38}

5 Conclusion

In conclusion, the results showed no group differences in static spine parameters but an increased trunk inclination and decreased apex lumbar lordosis in all gait phases during dynamic conditions. Furthermore, PwH showed an increased pelvic torsion in mid stance and terminal swing. This has the consequence that the compensation in musculoskeletal system must be considered for the orthopaedic treatment of PwH. To understand better the spine and gait compensation mechanisms in PwH, further investigations of the sagittal trunk inclination, foot pressure and the joint axes are necessary. Furthermore, the long-term clinical relevance of the findings and differentiation regarding the target joint should be clarified in following studies.

5.1 Limitations

The gait pattern is subject to intrapatient variability. When evaluating specific gait parameters, it is important to study a homogenous study group (e.g., excluding patients with spine diseases, surgeries in the last 6 months), yet gait patterns are subject to variability resulting from, for example, different bilateral joint restrictions. Hence, a certain degree of variability in the study subjects cannot be excluded. In attempting to assign individual gaits to a group, inaccuracies may occur. For this reason, longitudinal section measurements are necessary to evaluate intrapatient changes for future studies. Furthermore, the use of pain medication was not an exclusion criterion, so that the results of pain perception can only be interpreted in a limited way. The HJHS strength score cannot represent the actual strength of the test persons but can only give a tendency for a reduction in strength. Therefore, for a correct correlation between the strength and the spinal parameter this must be validated with strength-specific methods. Finally, the rasterstereography was performed on a treadmill at a standardized velocity of 3km/h to reduce variations. This could lead to changes in the gait pattern at different body sizes and influence the posture. Although the treadmill allows a higher degree of standardization, gait and spinal posture changes are only partially comparable to overground walking. A transfer to everyday movements is only possible under consideration of the treadmill effect.\textsuperscript{39}

Acknowledgments

We want to thank Natascha Marquardt, Silvia Horneff and Claudia Klein for their support in the recruitment process. This study was financially supported by Swedish Orphan Biovitrum GmbH. S. Krüger has received honoraria and travel support from Shire/Takeda and Swedish Orphan Biovitrum. S. Krüger was an employee at the Department of
Sports Medicine at the time of the study and when the manuscript was written but is now employed by Takeda. The other authors stated that they had no interests, which might be perceived as posing a conflict or bias.

Open access funding enabled and organized by Projekt DEAL.

AUTHOR CONTRIBUTION
Jamil Hmidaa, Thomas Hilberg and Andreas C.Strauss performed chart review, data collection and wrote the paper. Steffen Krüger, Tom R. Jansen, and Georg GOLD Mann performed chart review and collection of clinical data; Johannes Oldenburg and Dieter C. Wirtz analysed results and edited the manuscript.

DATA AVAILABILITY STATEMENT
The data that support the findings of this study are available from the corresponding author, JH, upon reasonable request.

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**How to cite this article:** Hmida J, Hilberg T, Krüger S, et al. Changes of static and dynamic spine alignment in patients with severe haemophilia. *Haemophilia*. 2021;27:e721–e729. https://doi.org/10.1111/hae.14406