Functional assessment of haemophilic arthropathy with three-dimensional gait analysis

S. Lobet, C. Hermans

In patients with haemophilia, the long-term consequences of repeated haemarthrosis include joint cartilage damage and irreversible chronic arthropathy, resulting in severe impairments in locomotion. Quantifying the extent of joint damage is of paramount importance in order to prevent disease progression and compare the efficacy of treatment strategies, such as prophylaxis. Here we summarise the results of several studies establishing three-dimensional gait analysis as an innovative approach to evaluate functionally haemophilic arthropathy. This work also provides new insights into the understanding of the biomechanical consequences of haemophilic arthropathy.

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Introduction: Assessment of musculoskeletal complications of haemophilia

In patients with haemophilia (PWH), approximately 80-90% of bleeding episodes occur in the musculoskeletal (MSK) system, especially in the large synovial joints, as well as in the muscles. These recurrent haemarthroses induce progressive cartilage damage, leading to joint destruction and subsequent severe functional limitation.

With respect to haemophilia, the MSK assessment has traditionally been performed using both radiological and clinical joint scoring systems. However, clinical joint scoring may not be sensitive to detect subtle changes in joint status and radiological examination does not provide an understanding of the causes underlying these impairments.
In this paper, we explore a new approach to the functional assessment of MSK complications in PWH by means of a specialised laboratory equipment to study biomarkers of human motor performance with three-dimensional gait analysis (3DGA).

3DGA as a new tool to explore the MSK impairments in haemophilia

In 3DGA, biomechanics analysis variables are used to pinpoint which joint or muscle system is responsible for the functional defect. Contrary to radiological and clinical examinations performed in a supine position, the uniqueness of 3DGA is that it assesses the patient during the act of walking, i.e., under weight-bearing conditions. This is of the utmost importance, as pain induced by weight-bearing activities influences the functional performances of the arthropathic joints significantly.

A digital video-based motion analysis system analyzes the kinematic part of locomotion. Kinematic analysis measures the active range of motion (ROM) of a joint. While the patient is walking on a treadmill,

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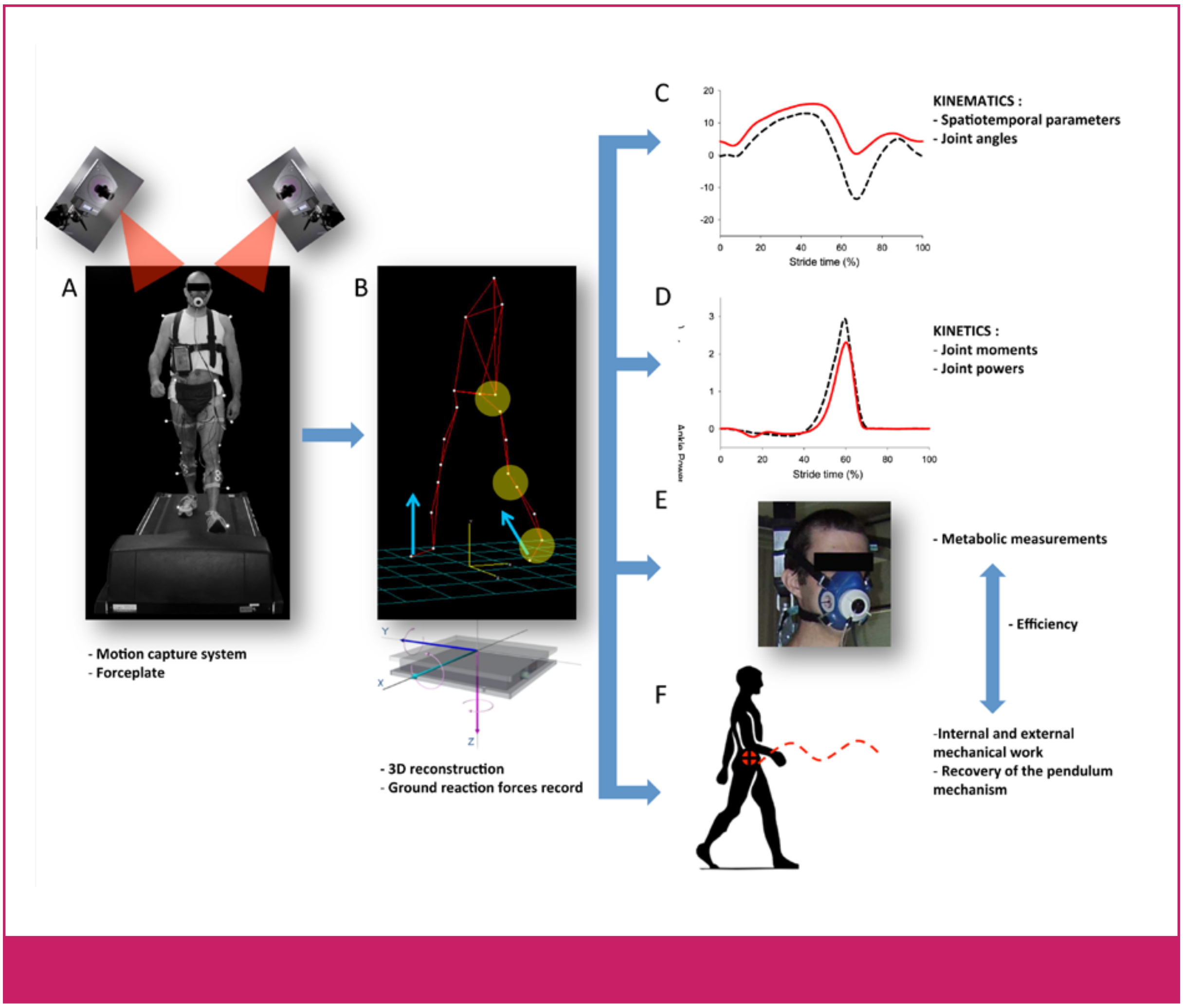

Figure 1. Infra-red light sources around each camera (A) reflect from the reflective markers reconstructed to generate the 3D trajectories (B). The images are then processed to derive the graphs of the kinematics i.e. the joint range of movement of each joint (C). A force platform located under the treadmill (B) records patient's ground reaction forces. The joint moments and powers, i.e., kinetic data (D) are calculated. Energy expenditure is measured indirectly using an ergospirometer (E). Finally, the mechanical work is calculated as the work performed to raise and accelerate the CoM (F).

infrared cameras track and record the trajectories of reflective markers positioned on the skin of the patient to define body segments *(Fig. 1A)*. It is then possible to calculate the 3D trajectory of that marker *(Fig. 1B)* and the joint angles *(Fig. 1C)*.

To obtain kinetic values, such as the moments of force and power generated or absorbed at the major joint muscles, a force platform located under the treadmill simultaneously measures the ground reaction forces (GRF) generated by the body *(Fig. 1D)*.

Classic gait analysis focuses on segmental abnormalities such as abnormal joint motion. The assessment of these segmental abnormalities is very useful in clinical practice to help in terrapeutic decisions but provide little information about the walking function. By means of mechanical work and energy costs measurements, it is possible to study the repercussions of these segmental abnormalities on locomotor function. These measurements could be more relevant to the walking patient's disability on locomotor function.

The gait laboratory at the Cliniques Universitaires Saint-Luc specifically aims to evaluate the repercussions of joint impairments on global body function by calculating more global indices of walking, such as mechanical work, i.e the energy produced by muscles to raise and accelerate the center of body

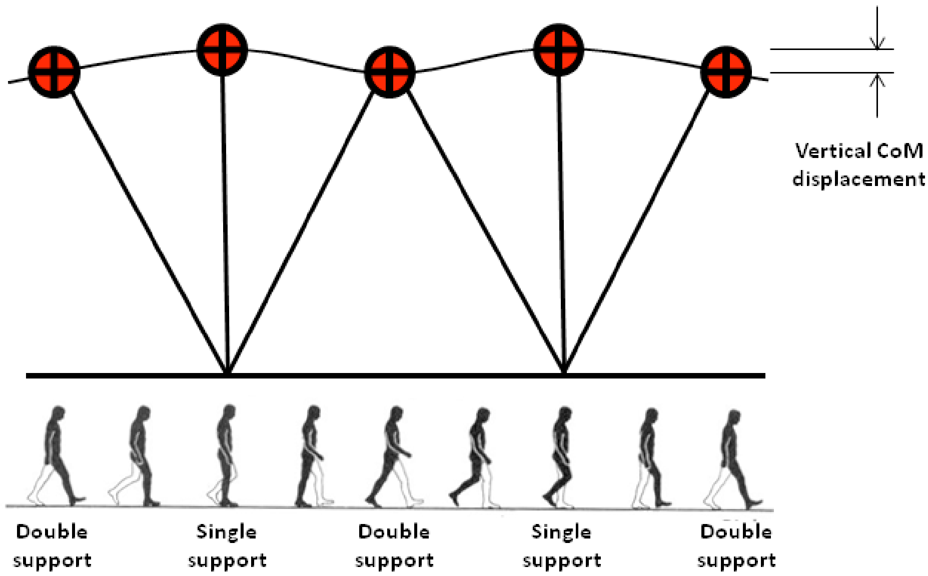

Figure 2. Inverted pendulum model of gait, showing how the center of body mass (CoM) rises during the single support and falls during the double support.

mass (CoM) *(Fig. 1F)* and metabolic measurements, i.e the chemical energy consumed by muscles. Energy expenditure is measured indirectly using an ergospirometer and is based on the rate of oxygen consumption *(Fig. 1E)*. Measurements of oxygen consumption have shown that we do indeed adjust many features of gait for economy of energy. At any particular walking speed, we spontaneously adjust our strides to the length that minimizes energy consumption at that speed.

Normal gait: why do human heads bob up and down?

After reading the introduction of this paper, you decide to take a stroll while carefully holding a full cup of boiling coffee, and here each step the coffee bobs up and spills out of your cup. People walk with a style consisting of bobbing up and down because the more economical mode of walking is an intermediate strategy in CoM displacement between extreme flatness (in the meantime you realize that you flexed unconscienciously your legs to walk smoothly) and bouncy walking.[1]

Why do we move vertically to walk straight ahead? In walking, the CoM (located approximately between the hip joints) is lifted up and down during the stride. The pathway of the CoM is a smooth, regular curve that moves with an average rise and fall of about 3-4 cm *(Fig. 2)*.[2] This vertical movement of the CoM enables individuals to save energy, because we slow down as we rise and speed up as we fall, thus passively recovering kinetic energy as gravitational potential energy and back again, as in an inverted pendulum.

Importance of preserved joint range of motion in the metabolic economy of gait

During walking, peculiar movements in the lower limb joints enable our legs to behave neither as stiff sticks nor as compliant ones.[2] These peculiar joint movements called "gait determinants" are considered paramount in human bipedalism, as they enable a smooth progression of the CoM displacement to conserve energy. For instance, if we were to walk with the legs as rigid sticks (without the foot, ankle, or knee mechanisms), the body would have to be elevated approximately 10 cm, which is

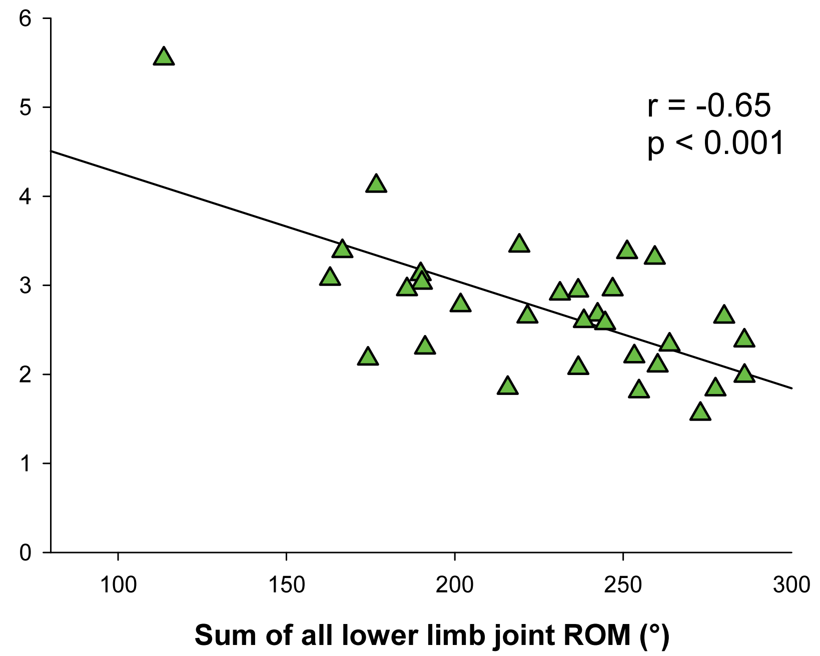

Figure 3. Net metabolic cost in 31 patients with haemophilia as function of the total ROM at ankles, knees and hips levels measured with 3DGA. The ROM of lower limb joints were calculated for both sides and then summed. r=Pearson Product Moment Correlation.

double the normal vertical displacement usually seen in normal walking. These abrupt changes in the direction of motion would require a high expenditure of energy.[2]

We used 3DGA to investigate the impact of multiple joint impairments (MJI) on the cost (demand of energy) and mechanical work (production of energy) of walking in 31 patients with haemophilia (PWH).[3] With the loss of some of the major gait determinants as a result of multiple joint arthropathy, the strategy of vertical CoM displacement reduction is compromised leading indirectly to increase in metabolic expenditure. This theory is confirmed as the metabolic cost was dramatically increased in PWH and directly correlated to the loss in joint ROM principally at the ankle level *(Fig. 3)*.[3,4]

Validation of 3DGA as an assessment tool in clinical studies

Foot deformities are common in patients with haemophilic ankle arthropathy and often responsible for discomfort when patients walk or stand for long periods. Currently, there are no validated conservative options for managing haemophilic ankle arthropathy.

3DGA was used in a clinical trial to objectively investigate the effects of custom-made orthopedic insoles and shoes in PWH with ankle arthropathy. Our study suggested that orthoses may have beneficial effects, as they provide significant pain relief and comfort improvement, with minimal side effects.[5] More specifically, insoles had limited impact on gait pattern, whereas orthopedic shoes significantly improved the propulsive function of the ankle and weight acceptance, probably due to improved comfort and reduced ankle pain.

Conclusions

Appropriate treatment of haemophilic arthropathy, whether hemostatic or orthopedic, is only possible with the availability of reliable assessment tools thus making it possible to quantify the benefits of such treatment. Musculoskeletal impairments in PWH may stem from structural and functional abnormalities, which have traditionally been evaluated radiologically or clinically. However, these examinations are performed in a non weight-

Key messages for clinical practice

- Clinicians involved in haemophilia care should be aware of developments in evaluation of biomechanical joint functions and consider 3DGA as a potential useful tool to assess haemophilic arthropathy. Integrating biomechanical research with clinical research has the potential to improve our monitoring of the early blood-induced changes in the physical status of the hemophilic joint.
- The disruption to the normal walking process by the orthopedic alterations in PWH appears to generate mechanical and metabolic changes that are closely linked to the progressive loss of mobility into the joints. It is therefore important to preserve as much as possible the joint ROM by a tailored physiotherapy program.
- Ankle arthropathy is often responsible of discomfort in PWH. As relatively cheap and safe conservative treatment, foot orthoses will likely make a substantial difference in terms of comfort and function especially for patients with limited access to replacement therapy in developing countries.

bearing supine position. Three-dimensional gait analysis can be an innovative tool to exclusively focus on the functional component of the joints during walking. Our studies showed that in PWH, the more the joint function was altered, the more metabolic energy was consumed. 3DGA analysis could highlight the effect of an orthopedic disorder in PWH during walking which can be a uself tool for clinicians.

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