Benefits, challenges and potential utility of a gait database for diabetes patients

Gait analysis is a useful tool in understanding movement impairments, which impacts upon patient wellbeing. The use of gait analysis in patients with diabetes has led to improvements in healthcare including the treatment and prevention of ulceration and development of targeted exercise interventions. The current convention when analysing gait is to address specific complications of diabetes, controlling for potential influencing conditions within a study sample to understand the effects of the few specific complications chosen for analysis. Databases allow for the storage of data in a structured format, allowing easy access to large quantities of data in a consistent, comparable manner. A database of gait analyses of patients with diabetes has the potential to include far greater sample sizes for statistical analyses, allowing multiple influencing factors to be assessed simultaneously, and relationships identified between multiple influencing factors. However, a database of this type would encounter ethical and methodological challenges in its implementation, which are discussed. This paper introduces some of the potential benefits, challenges and utility of a gait database for diabetes patients. We highlight that, whereas the creation of a database within this clinical population would be a complex process both ethically and practically, huge potential benefits could be gained, overcoming some of the limitations faced by traditional isolated gait analysis studies.

Introduction

The global diabetes prevalence is high and within the UK it is estimated to be 6.4% (1) but has been increasing annually (2), with 5,314 deaths reported as attributable to diabetes in 2014 (1). However, the complications of diabetes (e.g. neuropathies, cardiovascular disease, etc.) also have far reaching impacts on patients' quality of life (Egede & Ellis, 2010). There is, therefore, a need to improve understanding and treatment of these complications.

Mobility is a vital part of quality of life and patients with diabetes are frequently reported to be less active than non-diabetic controls (3,4). Inactivity is unwelcome given the vast benefits of exercise to both glycaemic control (5) and general health (6). The effects of inactivity become increasingly damaging with increasing age, with over 20% of patients with diabetes over 60 years old in the U.S. unable to perform everyday tasks including climbing stairs or housework (7).

The importance of mobility is reflected by decades of research providing a wealth of clinical information and improvements in patient care. Advances resulting from gait analyses have included: identification of areas of high foot pressures indicating ulceration risk (8), personalised orthotic treatments, and targeted exercise interventions to improve mobility (9).

What is gait analysis?

Gait analysis is the assessment of how people walk and negotiate their environment, providing insight to how an individual or group of people are functioning during a given activity. Gait analysis has applications in both identification of movement-related problems as well as enabling condition or individual specific comparisons to be drawn for tailored treatment to improve movement during a given task. The greatest strength of gait analysis clinically is the ability to identify movement impairments and the potential underlying physiological mechanisms typically using non-invasive techniques. However, this relies on understanding what is considered to be 'normal' gait to identify any deviations from this 'norm'. *An individual's gait is influenced by numerous physiological elements including the musculoskeletal, vestibular and nervous systems, as well as psychological implications upon control of movement. Therefore, any condition/factor that impacts on these elements has implications for how an individual performs a given activity.* Identification of gait strategies within both healthy individuals and patients with diabetes is therefore critical to the identification of differences between the populations, as well as individual differences within a single patient, which allows for personalised diagnoses and care. Gait can be highly individual with variance existing across any group/population, with exclusion criteria helping to more clearly define populations. This typical experimental design controls for the influence of potential confounding variables, but on the other hand limits the ability to assess multiple complications simultaneously.

What is a database?

Databases are common for collating large quantities of data. Most research studies will store patient information and research data within databases to clearly and robustly separate out variables and allow individual components of a large dataset to be easily compared. Within modern culture and increasing global interconnectivity, large collaborative databases are becoming more common. A collaborative database allows multiple individuals or organisations to contribute data/information, which is stored in a consistent manner and allows members to then ask questions of that database. The aim of this paper is to discuss the potential benefits, challenges and utility of a gait database for diabetes patients.

The value of gait analyses of patients with diabetes

Gait in patients with diabetes is a highly researched area of interest: a search of Elsevier at the time of writing yields over 12,000 articles relevant to diabetes and gait, with the annual publication rate rising steadily over the past two decades from 165 in 1998 to 924 new publications in 2015. Much of this research has focussed on aspects of great importance most notably falls and foot ulceration. Both of these issues which are of particular risk to patients with diabetes (10–12), present challenges to health and quality of life and are associated with the mechanisms of walking . Falling is directly related to an individual's ability to maintain an upright posture during standing and walking and foot ulceration is largely contributed to by the daily mechanical loading applied to the foot. Therefore, it is crucial to understand the mechanisms behind these issues and develop treatments to reduce their incidence.

Foot ulceration: prevention and treatment

Diabetic foot ulceration is particularly common in patients with diabetic peripheral neuropathy (DPN) (13) due to the loss of the natural protective sensory responses. With a DPN present in up to 50% of patients; DPN and related foot ulceration places a huge burden upon the population and the healthcare service. Gait analysis has provided insight to those mechanisms which increase the risk of foot ulceration, thereby facilitating preventative measures. Plantar pressure measurement performed during gait allows for identification of high-pressure areas indicative of high-risk sites for ulceration as can be seen by comparison of three examples in Figure 1; where increased pressure can be seen under the heel and metatarsal heads in the foot of an individual with diabetes, and under the mid-foot of a patient with a rocker-bottom Charcot deformity. This allows interventional therapies to be employed to reduce pressures in the identified areas, often in the form of specialised footwear or orthoses (14,15). Other methods shown to reduce plantar pressures include: surgery to increase dorsiflexion range (16) or replace depleted soft tissue (17); as well walking with shorter step lengths (18). There is some discussion on whether vertical plantar pressures alone are a strong indicator of ulceration (19). It is generally considered that additional influences, including loading time (20) and shear forces (21), should also be considered.

Understanding fall risk in people with diabetes

Gait analysis can identify balance impairments that may explain the high risk of falls in diabetes patients and may also provide insight to the underlying physiological mechanisms responsible. Such analyses may assess kinematics (movement), kinetics (forces) and muscular activity during ambulatory activities. The influence of DPN upon these gait measures is commonly investigated, due to the associated reduction in proprioception (22) and its role in balance (23). However, gait alterations are also observed in diabetes patients without DPN (24), which result from deterioration of skeletal muscle (25,26) and visual factors (26). These sensory and muscular detriments result in patients with diabetes utilising a more conservative gait strategy: walking at a slower speed (27–30), with lower muscular demands (29,31) and a larger base of support (27,32). However, this slower walking speed is directly associated with a reduced quality of life (33,34). Patients also continue to display reduced speed-of-strength-development (35), toe-clearance (36) and greater gait variability (30,37); all of which are associated with an increased risk of falling (37,38).

Design and validation of targeted interventions

Identification of gait impairments has led to therapeutic exercise interventions for diabetes patients. Exercise has been shown to improve many aspects of gait on level and uneven ground (9), as well as during stair negotiation (39). This highlights the importance of the use of exercise as a treatment for patients with diabetes, as it is well known for the beneficial impact it has upon both glycaemic control (40,41) as well as improving general cardiovascular health.

Participant populations in typical studies

Whilst gait analyses from various isolated studies have contributed greatly to understanding gait impairment in diabetes and the implementation of appropriate interventions, there are limitations introduced by how these are utilised. The manner in which a patient with diabetes is affected by the disease is highly individual: sensory, vascular and muscular complications are all common. However, a single patient may develop all or none of these complications; this means that when comparing this population to individuals without diabetes, care must be taken in interpreting the cause of any potential alterations. A typical gait study will assess somewhere between twenty and a hundred individuals, divided into sub-groups, two recent reviews of gait literature regarding diabetes found average study sizes of n=48 (42) and n=52 (43). These study populations are sub-divided most commonly into people with and without diabetes (with or without additional complications), giving an average group size within the studies reported of n=21-25 (42,43). Within the U.K. there are in excess of three million patients diagnosed with diabetes (1,2); therefore a typical gait study assesses a sample <0.00003% of the population, a sample level that is common amongst studies that require voluntary human participation and interaction.

The limitations of restricted sample sizes

As a result of the typical sample sizes seen within gait analyses the scope of an individual study is often narrow by necessity; strict exclusion criteria are applied to control for potential confounding conditions; thus allowing focused conclusions to be made from each study regarding a specific aspect of how diabetes affects gait. What few gait studies have been able to do however, is simultaneously separate out the different effects of multiple complications present within the population. Meta analyses allow findings to be compared between studies, and trends to be identified across studies and attributed to individual complications of the disease. However, the utility of these reviews is limited by the variation of parameters reported within each study, the level of detail provided for each parameter and the variation in methodologies between individual studies. This can cause differences to be noted between studies, that whilst similar may have resulted from populations with slightly different characteristics, due to variations in the inclusion criteria. For example: Sawacha *et al.* (44) showed increased anteroposterior ground reaction forces in patients with DPN; however Katoulis *et al.* (45) showed no difference in this variable for patients with DPN, unless the patients also had a history of previous ulcers. This sub grouping utilised by Katoulis *et al.* (45) demonstrated a difference in the fundamental mechanics of walking in patients who have previously had an ulcer. However, the findings appeared to disagree with those presented by Sawacha *et al.* (44), whom did not differentiate between patients with and without a history of ulcers. Including more sub-groups, however, requires additional recruitment, data collection and increased complexity of the comparisons to be performed. However, this example demonstrates the need to account for multiple variables in order to identify accurately the causes of any observed differences within a sample population.

Databases: expanding your data pool

A potential method to address the difficulty in collecting large quantities of data is that of a database. Current methodologies allow data to be collected for individual studies, recruiting a set of patients to assess a specific question, or series of questions. At the end of this process the data are discarded or stored according to the ethical requirements of the study. Following this traditional research approach, gait studies need to recruit new participants every time a new hypothesis requires testing. However, multiple studies may assess many of the same variables. Sawacha *et al.* (46) and Brown *et* *al.* (31) each assessed walking along level ground; the foci of each study was different, and the exact methodologies differed, however, both studies recorded kinematic and kinetic data and the studies assessed 67 and 80 participants respectively. The collaborative nature possible with databases, would share the burden of data collection between studies, allowing analyses to be performed with a far greater sample population forming a closer representation of the overall population. These future analyses could allow examination of an increased number of covariates (which would otherwise have required controlling), including those whose influences may be too subtle for statistical analyses to identify interactions within current study sample sizes. Additionally a long-term database system could create the potential for longitudinal studies to be performed with greater ease, allowing for the development of the many alterations to gait patterns in patients with diabetes to be further understood, or for alterations within a single patient to be identified and flagged for potential intervention.

Understanding of the subtleties of gait within the population may increase the diagnostic capabilities of gait analyses. Currently, plantar pressure analysis is one of the more clinically applied methods of gait analysis, used to identify specific areas on the plantar surface of the foot likely to ulcerate. Other techniques, such as a timed up-and-go test (47), a simple assessment that can be indicative of high fall risk (48), provide flags for specific risk factors within an individual patient. By increasing the number of complications considered during a single gait activity, there could be potential for using more in-depth gait analysis to identify the presence of multiple possible complications through non-invasive testing. Given the progression of technologies used for gait analysis, including the development of marker-free systems (49–51), this could become a valuable diagnostic tool in the future, assuming adequate understanding of the influence of diabetes, to support its use.

Creating a useful gait database

Ethical considerations

When attempting to develop a database of this kind unfortunately multiple challenges present. Ethical considerations of such a database need to firstly be considered. To provide adequate privacy to patients, shared information should be anonymous; however, to allow for longitudinal analysis, or prevent replication of data, it must be possible to check if a patient has contributed to the database in the past. This could be overcome by recording participation within a patient's confidential notes, not included within the shared dataset. Especially given current developments of gait analyses as a biometric ID system (52), any database would require clearly defined limits of use, and protection to avoid abuse that could lead to breaches of personal information between database operators and patients.

Limits of use would need to be strictly defined to provide contributing individuals with adequate informed consent. The most optimal use of a gait database would be long term, and not all hypotheses may be predictable at the onset or before consent is given. Therefore, the database would require a clearly outlined scope of use that allows the capacity for different analysis techniques to develop. This would be a crucial stage of development, as a broad scope and continuously developing aims complicates the issue of a patient giving properly informed consent; whilst also protecting them from unforeseen potentials to abuse the data. It is likely a regulatory body would be required to assess all future uses of the database to ensure the scope of consent was not breached. The complexity of these issues increases with the size of the database and the number of contributing organisations. If a database comprised of collaborators from multiple nationalities for instance, then understanding of the ethical governances, as well as monitoring their enforcement and the use of database would require a regulatory body capable of monitoring all users and accounting for variations in national ethical standards. If restricted to a single organisation (e.g. a single research institute or hospital) however, the potential number of vulnerabilities and ethical considerations would be limited in comparison.

The importance of consistent report parameters

To enable coherent searches and comparisons, a database requires a consistent organisation and structure for the data stored within it. Gait analysis can generate a wide range of parameters, of which temporal-spatial parameters, joint kinematics and kinetics, ground reaction forces, plantar pressures and electromyography are some of the most frequently reported. However, the manner in which these are reported varies greatly; for example when assessing plantar pressures different studies have separated the foot into different regions of interest (53), or considered the foot as a whole (19). This type of variation exists in nearly every type of reported gait variable; if a database system was to be utilised, it would require a stringent definition of how each and every variable should be presented. One solution would be to include raw data rather than specific measures. Ground reaction forces for instance vary throughout the stance phase, and are generally measured throughout and only afterward are analysed to generate the desired measure (e.g. peak force). By storing raw data in a database, this would not only reduce the amount of work required prior to adding a patient's results to the database, but would also provide the greatest flexibility for analysis, allowing desired variables to be calculated on demand, rather than restricting investigators to a pre-defined aspect of that variable. This would also ensure variables would be calculated in the same manner for data that could potentially come from multiple organisations who would otherwise perform calculations in different manner to another contributor.

As discussed above, with the use of a database, multiple covariates may be considered simultaneously and reliable reporting of influential factors could be produced. This would, however, require detailed recording of any potentially influential variable, which if traditionally excluded for, would not be typically reported by an isolated gait study. This would result in a greater workload when assessing a patient compared to a traditional and targeted analysis, and potentially create gaps in datasets if some contributing parties to the database did not have the capabilities to perform every test.

Ensuring comparability

Opportunities for errors between datasets also exist: methodological, environmental and instrumental. This is particularly pertinent if again considering a database with multiple contributing organisations. The technologies utilised for gait analysis vary greatly, and a single variable can be assessed by a variety of techniques. Gait kinematics, for instance, are generally measured by optoelectronic camera systems; these exist with active and passive marker technologies, are sold by multiple companies, or could also be measured by standard video cameras, accelerometers or goniometers. Figure 2 shows an example of a passive marker technology in use with a motion analysis system - reflective markers placed upon the skin are detected by multiple cameras within the gait laboratory to calculate precise 3D co-ordinates of the marker positions. From this data a number of gait parameters can be determined. Each different variation of equipment will exist with a different range of instrumental error, as well as different limitations upon its use (e.g. video systems require a staged area, whereas accelerometers could be worn in an unprepared environment). This introduces issues when comparing data from different laboratories, collected using varying equipment. A useful database would require specific equipment to be utilised in order to maximise comparability, a potential for multiple variations of equipment could be designed into the database, but would have to be considered properly within any analysis.

Apart from the equipment variations between studies, gait analysis utilises a huge range of specific methodologies and environments. One laboratory may have a 10m level walkway, whilst another has a 50m walkway or a treadmill. If the entire walkway was to be used during gait analysis, the results from each laboratory would be influenced differently by factors including fatigue, acceleration/deceleration times. For example, a treadmill may enable acceleration/deceleration times to be eliminated by not recording the start and finish, whereas a short walkway may not provide sufficient space. The short walkway however may have less impact upon fatigue due to ease of taking breaks after each walking trial. A treadmill also provides easy standardisation of walking speed across participant, however, if a study is interested in a person's self-selected walking speed this becomes very difficult to implement on a treadmill.

Other variations of more challenging activities could include: different types of 'irregular surface', different dimensioned staircases, etc. Even when considering data from a single laboratory, methodologies may vary, for example: two different studies of gait, using the same equipment, looking at the same kinematic variables, could potentially utilise different kinematic marker sets (e.g. a study utilising a piece of equipment that would interfere with a specific marker set, it would alter the marker-set to accommodate the need for both types of data as demonstrated by comparison of the two exemplar marker sets shown in Figure 3). Without a definitive 'gold standard' kinematic marker sets are designed for specific purposes, and each have individual benefits and limitations based on marker positions upon the body, calculations utilised to generate kinematics and kinetics, etc. Guidelines would be required therefore for how all data were collected as well as considering what equipment was utilised in order for it to be suitable for inclusion in the database.

Conclusion

We have presented a brief overview of the importance of gait analyses within the population of patients with diabetes and some of the potential benefits, challenges and the utility of a gait database. Mobility is critical to quality of life, and people with diabetes face numerous challenges to the physiological systems responsible for the control and application of movement. Current gait studies have provided useful insights into how diabetes influences movement for a range of activities experienced during daily life, and has allowed the development of diagnostic techniques and interventional therapies to address ulceration and fall risk as well as improving mobility. However, *due to the large variety of complications that may be present alongside diabetes, it can be difficult to determine the causal factor within small studies.*

A gait database would allow for more extensive investigations to be performed by expanding the potential study population size and enabling multiple influencing factors to be simultaneously analysed. We have discussed some of the numerous considerations that would require addressing in order to create a collaborative gait database and whilst these would require appropriate consideration, the possibility of creating a database is real. Within this paper however, we have not had the scope to discuss each consideration in full; what is clear however, is that a gait database within a single organisation would provide immense simplification for the issues of managing and standardising the data contributing to a database. Therefore, whilst a gait database would have considerable benefits, the complexity of creating such a database makes it more suitable for consideration within a single organisation such as a hospital or university.

Figures

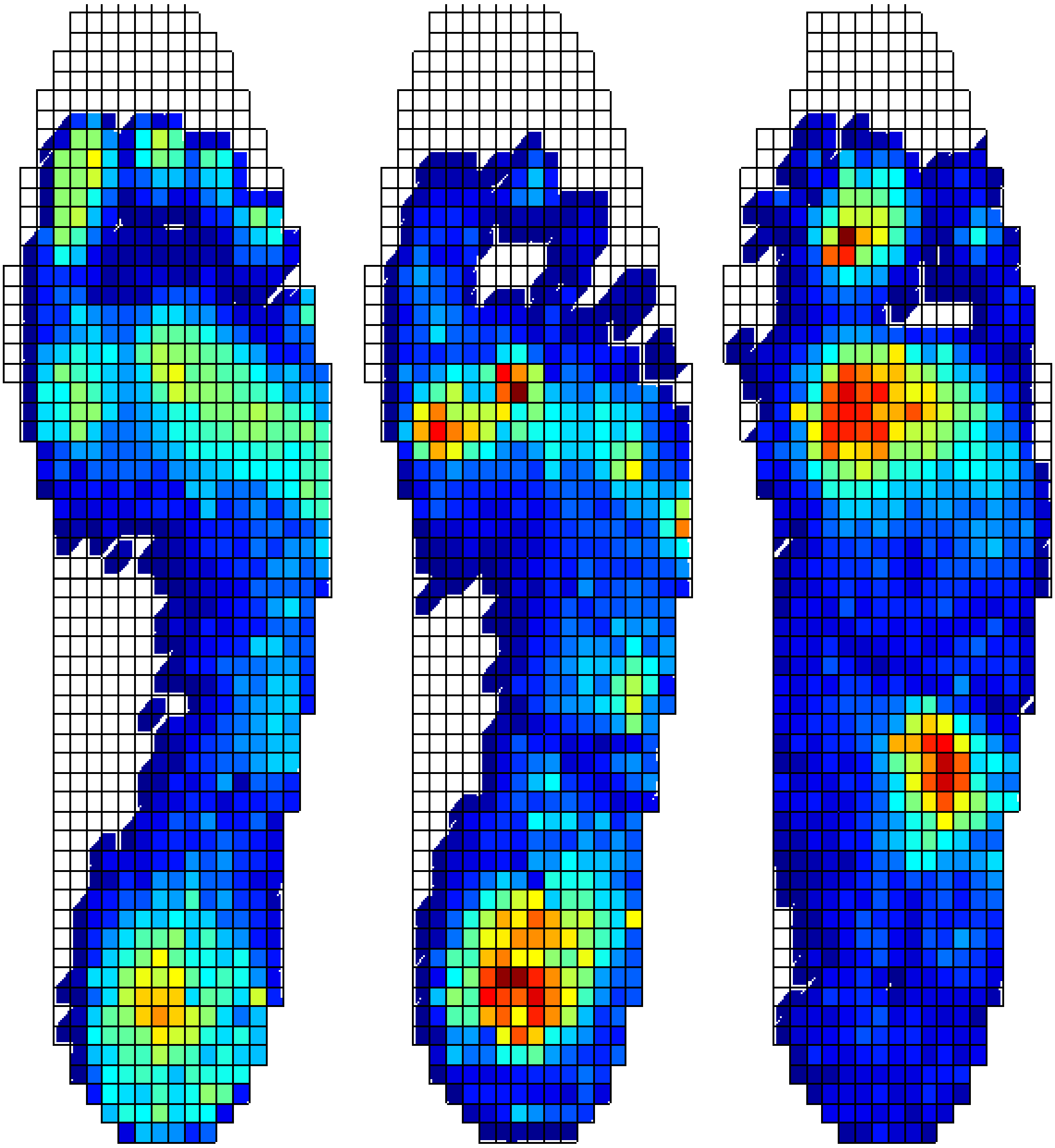

Figure 1 - Example images of plantar pressures during walking for a healthy foot (left), a foot with heightened pressures underneath the heel and metatarsal heads (centre) and a foot with a rocker-bottom Charcot deformity (right), characterised by heightened pressure underneath the mid-foot underneath the deformity and reduced pressure at the heel. Levels of pressure are indicated by dark blue for low pressure, lightening shades indicate heightening pressure, with dark red indicating the highest levels of pressure.

Figure 2 – Example of a participant undertaking gait analysis stepping over a simulated obstacle, using an optoelectronic camera system and passive reflective markers. Also shown are wireless electromyography receivers (black boxes) and force platforms embedded in the walkway. Due to the highly reflective nature of the passive reflective markers they appear to glow brightly when lights such as a camera flash hits them.

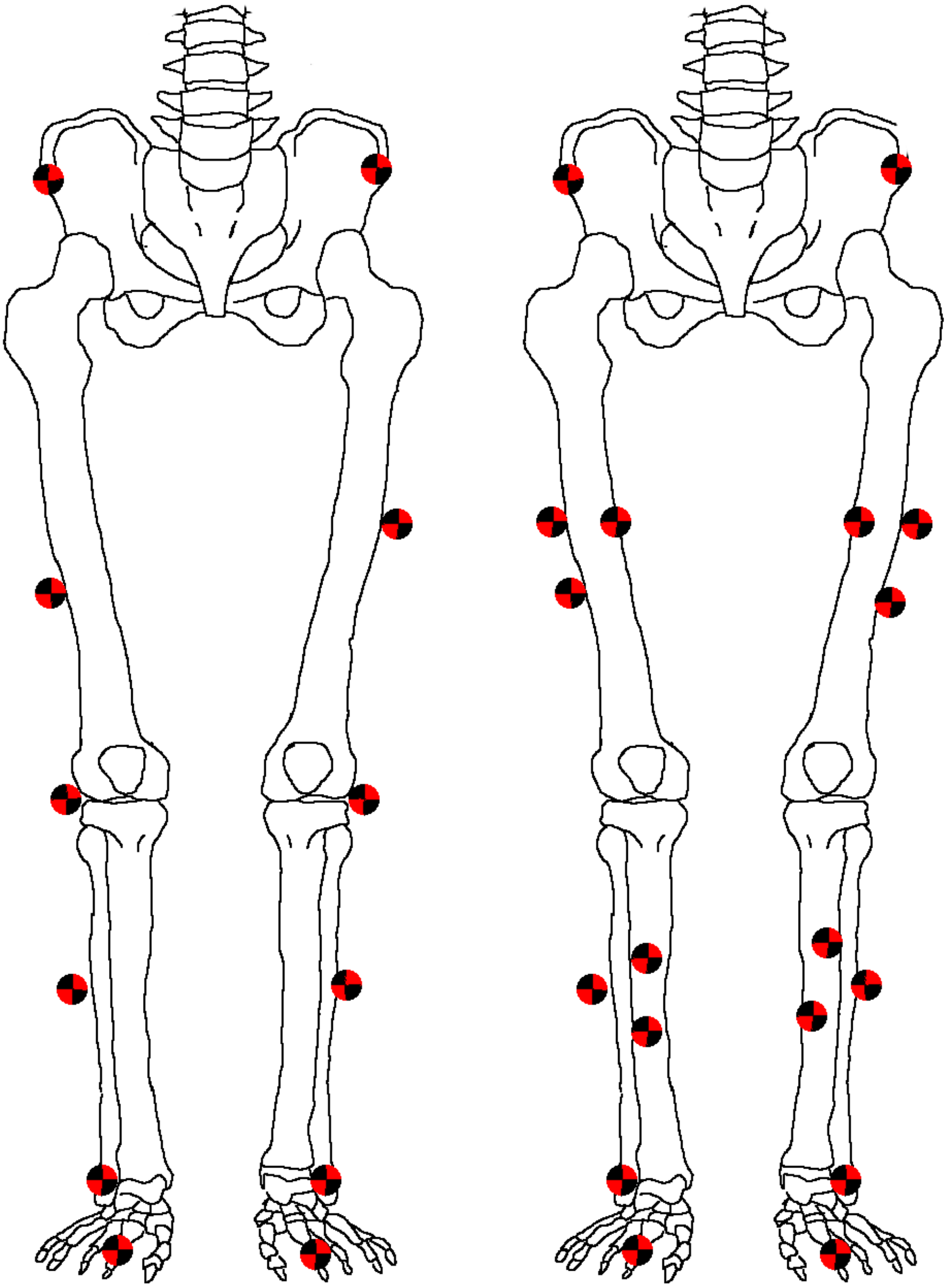

Figure 3 – Anterior views of 2 example marker-sets that may be utilised by video based 3D gait analyses. A Helen-Hayes marker-set (left) is a commonly used clinical marker-set with the minimal number of markers for 3D kinematics. An alternative marker-set (right) shows how a marker-set may be altered if the knee is obscured and no markers can be placed on them (e.g. when a knee brace is in use). This alternative marker-set employs different calculations to track the knee joint than the Helen-Hayes model; utilising relative positions of the shank and thigh segments tracked independently by the three markers upon each, rather than utilising a shared marker placed upon the joint as is found in the Helen-Hayes marker set. This difference in methodologies results in different levels of systematic error between marker-sets for the same kinematic measure.

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