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Utilizing three dimensional clinical gait analysis to optimize mobility outcomes in incomplete spinal cord damage

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ABSTRACT

Background: Three-dimensional gait analysis (3DGA) has not previously been considered by consensus panels of spinal cord experts for use in studies of patients with spinal cord damage (SCD), yet it is frequently used in other neurological populations, such as stroke and cerebral palsy.
Research question: How does 3DGA impairment based reporting guide individualised clinical decision-making in people with incomplete SCD?
Methods: Retrospective open cohort case series recruited 48 adults with incomplete SCD (traumatic or non-traumatic spinal cord dysfunction) referred to the Clinical Gait Analysis Service (CGAS), Melbourne, Australia. Three-dimensional gait data were used to identify gait impairments by the multidisciplinary clinical team. Gait patterns were classified using the plantarflexor-knee extension couple index and the Gait Profile Score (GPS). The reason for referral and the recommendations made post-3DGA were collated in decision trees to extrapolate the potential value of 3DGA in decision making for targeted intervention in this population.
Results: Participants with SCD generally walked at a reduced gait speed. When grouped by neurological level, the tetraplegia group had a significantly lower GPS, but no specific gait patterns emerged. Participants were primarily referred to the CGAS to direct clinical intervention decisions. The most frequent recommendation following 3DGA was the prescription of an ankle foot orthosis and in some cases, the recommendation was incongruent with the referrer's proposed intervention.
Significance: 3DGA can provide specific guidance in management plans for gait of patients with incomplete SCD and may help to avoid inappropriate or unnecessary interventions. This sample of patients referred to the CGAS demonstrates its clinical utility in guiding clinicians in their decision making to target individualised intervention.

1. Introduction

Walking following spinal cord damage (SCD) sustained due to trauma or non-traumatic conditions is a priority for patients and rehabilitation clinicians [1]. The main determinants of ability to regain walking after SCD include: muscle strength, coordination, proprioception, postural control [2] in addition to patient-specific factors such as spasticity, contractures, and comorbidities [2,3]. The American Spinal Cord Injury Association (ASIA) Impairment Scale (AIS) grade of injury [4] on admission is a strong predictor to subsequent walking ability [5]. In traumatic spinal cord injury [3,6] and non-traumatic spinal cord dysfunction [7], the more incomplete the SCD the more likely the patient will walk. Rehabilitation therapies directed at improving walking, such as pharmacotherapy, physiotherapy training approaches or

Abbreviations: SCD, spinal cord damage; AIS, American Spinal Cord Injury (ASIA) Impairment Scale; 3DGA, three-dimensional gait analysis; CGAS, Clinical Gait Analysis Service; CGA, clinical gait analysis; AFO, ankle foot orthosis

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Table 1
Participant demographics.

Male (n =)	Tetraplegia 19 (39.5%)	Paraplegia 18 (37.5%)	TOTAL 37 (77%)
Age (years)*	51.8 ± 12.4 [54; 26–70]	51.0 ± 16.0 [56; 19–81]	51.4 ± 14.2 [54; 19–81]
Height (m)*	1.75 ± 0.08 [1.77; 1.59–1.86]	1.73 ± 0.09 [1.74; 1.53–1.84]	1.74 ± 0.08 [1.76; 1.53–1.86]
Mass (kg)*	83.74 ± 18.74 [82.28; 60.0–135.0]	82.69 ± 10.24 [85.05; 65.0–105.1]	83.26 ± 15.43 [83.25; 60.0–135.0]
Years post injury*	6.75 ± 10.3 [2; 0.5–47]	10.75 ± 10.7 [4; 1–33]	8.8 ± 10.8 [4; 0.5–47]
Traumatic:Non-traumatic#	17:25	4:31	21:56
More affected side (R:L) #	25:17	23:12	48:29
Gait aid (Y:N) #	13:29	25:10	38:39
Female (n =)	**Tetraplegia 5 (10%)**	**Paraplegia 6 (13%)**	**TOTAL 11 (23%)**
Age (years)*	39.6 ± 8.2 [42; 24–48]	54.5 ± 14.5 [49; 40–83]	47.7 ± 14.2 [44; 24–83]
Height (m)*	1.64 ± 0.09 [1.65; 1.52–1.77]	1.60 ± 0.11 [1.60; 1.42–1.78]	1.62 ± 0.10 [1.60; 1.42–1.78]
Mass (kg)*	65.13 ± 14.74 [68.15; 40.0–80.2]	62.45 ± 13.62 [56.28; 51.4–89.9]	63.67 ± 14.20 [58.80; 40.0–89.9]
Years post injury*	2.7 ± 2.0 [2; 0.5–6]	10.0 ± 11.4[3; 1–27]	6.7 ± 9.2 [3; 0.5–27]
Traumatic:Non-traumatic#	4:6	0:13	4:19
More affected side (R:L)#	8.3:2.2	8.3:4.2	16.6:6.4
Gait aid (Y:N)#	4.2:6.3	8.3:4.2	12.5:10.5

Abbreviations: R = right; L = left; Y = yes; N = no.
* Values are average ± 1 standard deviation (SD) [median; range].
# Values are presented as percent of the total population.

Table 2
Participant classification of level and aetiology of spinal cord damage.

Clinical Classification	Tetraplegia		Paraplegia		Total	
	n	%	n	%	n	%
Traumatic spinal cord injury						
Transport	7	14.5	1	2.1	8	16.7
Fall	2	4.2	1	2.1	3	6.2
Other (Surfing)	1	2.1	0	0	1	2.1
Non-traumatic spinal cord dysfunction	9	18.7	4	8.3	13	27.1
Degenerative disorder						
Tumour	2	4.2	4	8.3	6	12.5
Vascular disorder	1	2.1	4	8.3	5	10.4
Inflammatory – Transverse myelitis	0	0	5	10.4	5	10.4
Miscellaneous – Syringomyelia	2	4.2	1	2.1	3	6.2
Congenital – Spinal dysraphism	0	0	2	4.2	2	4.2
Toxic	0	0	2	4.2	2	4.2

Table 3
Clinical Question associated with each participant referral.

Clinical Question	n	%
Identify management options	17	35.4
Identify cause of poor gait & optimise management	9	18.7
Optimise muscle selection for Botulinum toxin-A	7	14.6
Identify impact of spasticity &/or weakness on gait	6	12.5
AFO or anti-spasticity management	3	6.25
Suitability of ITB management	3	6.25
Review impact of AFO on gait	2	4.2
Orthopaedic surgery planning	1	2.1

orthotics require outcome measures that are valid, reliable, and sensitive to change in order to optimise patient management and resource utilization [2,8,9].

Three-dimensional gait analysis (3DGA) is considered the gold standard in the evaluation of walking abnormality and in guiding strategies to optimize walking [10]. The complexity of gait abnormalities in any neuromuscular disorder warrants the application of 3DGA in guiding decision-making [11].While there has been a plethora of literature demonstrating that the addition of 3DGA leads to changes in surgical treatment plans in children with cerebral palsy [12], there is less evidence of its utility in other neurological populations. Current literature suggests the use of 3DGA significantly influences treatment planning in chronic post-stroke patients [13], and in patients with traumatic brain injury [14]. Despite some early evidence of gait analysis being valuable in SCD to document the effects of an intervention [15,16], the application of it to aid treatment decision making and document improvement has had little consideration in the literature. This is despite the conclusion in a study examining the impact of gait analysis in clinical decision making in children and adolescents with SCD that the quality of treatment methods would improve if the application of gait analysis was expanded [17].

More recently, 3DGA has been reported as being sufficiently sensitive to evaluate change in knee flexion during the swing phase of gait post Botulinum toxin-A injections in the rectus femoris in patients with SCD [18]. Furthermore, using the Gait Profile Score as the primary outcome measure, 3DGA was found to be a highly reliable tool to evaluate gait in adults with SCD, with intrinsic variation of gait being very small [19]. This encouraging evidence advocates that 3DGA has the potential to contribute to understanding gait deficits and contribute to treatment planning in patients with SCD. In their deliberations ten years ago a consensus panel of spinal cord experts did not consider the role of 3DGA [9], in spite of the argument that it should play a more prominent role in the assessment and management of walking in patients with SCD [20]. Demonstrating the role of 3DGA in clinical decision-making in this population is therefore imperative.

This study reports how 3DGA for ambulant patients with SCD referred to a specialist Clinical Gait Analysis laboratory contributed to establishing individualised recommendations to optimize their walking. The aim of our study was twofold: (1) investigate how 3DGA impairment based reporting guides individualised clinical decision-making regarding gait optimisation in people with incomplete SCD and (2) to

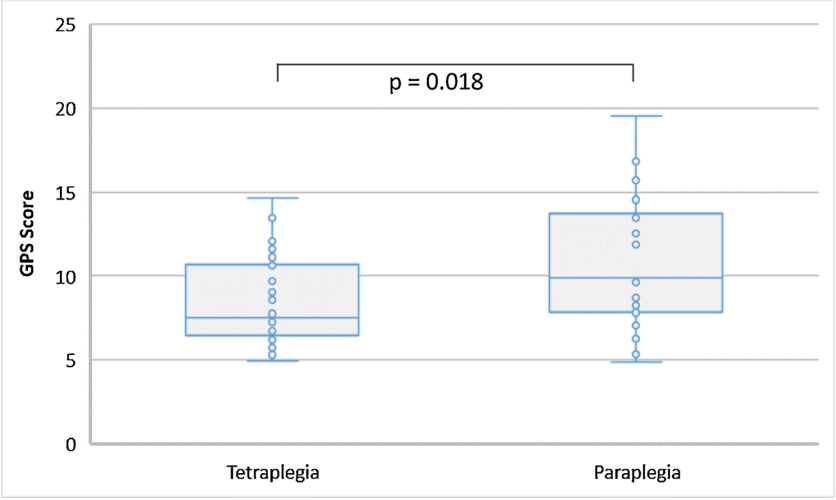

Fig. 1. Box plot of Gait Profile Score (GPS) with 75% confidence intervals grouped by neurological level.

Table 4
Barefoot spatial-temporal data for the most impaired side based on neurological level of spinal cord damage and comparison with unimpaired.

No. of Trials used per participant	Tetraplegia n = 24 *7.5 ± 1.6*	Paraplegia n = 24 *6.9 ± 1.2*	Unimpaired
Speed (m/s)	0.95* ± 0.32 [0.94; 0.30–1.64]	0.79* ± 0.28 [0.77; 0.24–1.52]	1.41 ± 0.14
Cadence (steps/min)	100.80# ± 21.40 [107; 39–140]	92.73* ± 19.84 [97; 41–126]	118 ± 10.00
Step Length (m)	0.58* ± 0.12 [0.58; 0.27–0.83]	0.51* ± 0.12 [0.52; 0.20–0.77]	0.71 ± 0.05
Stride Length (m)	1.12* ± 0.22 [1.08; 0.51–1.47]	1.00* ± 0.23 [1.00; 0.43–1.51]	1.43 ± 0.10
Step Width (m)	0.18# ± 0.06 [0.17; 0.08–0.38]	0.21* ± 0.05 [0.21; 0.06–0.31]	0.14 ± 0.03
Double Support (s)	0.40 ± 0.30 [0.30; 0.13–1.71]	0.47* ± 0.26 [0.37; 0.19–1.76]	0.22 ± 0.04
Single Support (s)	0.41 ± 0.08 [0.39; 0.24–0.71]	0.42 ± 0.07 [0.40; 0.29–0.64]	0.40 ± 0.03

Note: All data presented as mean ± 1SD [median; range].
Significant difference between tetraplegia and unimpaired and paraplegia and unimpaired indicated by *P = 0.001, #P = 0.002.

determine the quality of gait in patients with SCD.

2. Methods

2.1. Study design

A retrospective open cohort case series evaluating 3DGA data in ambulant patients with SCD.

2.2. Participants

Participants included all adults ≥ 18 years of age with a confirmed diagnosis of SCD due to traumatic spinal cord injury or non-traumatic spinal cord dysfunction who attended the Monash Health Clinical Gait Analysis Service (CGAS) in Melbourne, Australia, between July 2006 and December 2017. Eligible patients were contacted by the CGAS to obtain informed consent to use their previously collected gait data in this study. Due to a moderate response rate, approval from the Monash Health Human Research and Ethics committee (MHHREC) (No. 10252B) was obtained to include data from patients who were unable to be contacted, using the consent obtained at the time of their initial assessment to use their data in future research projects.

Participants were included in the study if: three-dimensional data had been collected, they had a minimum walking speed of 30 cm/sec, had the ability to walk a minimum of 100 m, and were able to stand for 5–10 min at a time. These inclusion criteria replicate the eligibility criteria set by the CGAS for referral purposes. Those with significant lower limb or other pathologies (other than their original diagnosis of SCD) that affected gait (e.g. joint replacements) were excluded.

For the purpose of comparing gait data, a reference group was selected from the laboratory normative database (MHHREC approved Project No. 06017B). Inclusion criteria were: matching at least one patient with SCD in gender, and within 5% of two of the three parameters; age, height and weight.

2.3. Referral

Prior to July 2014, patients were referred to the CGAS by medical specialists only, with the referrer base expanding to include senior physiotherapists and orthotists post-July 2014. Referrers are required to provide a specific clinical question relating to gait and indicate the intervention under consideration. This enables the Clinical Gait Analysis (CGA) team, consisting of senior physiotherapists experienced in neurological rehabilitation, rehabilitation physicians, orthotists, and biomechanists, to focus their recommendations.

2.4. Gait analysis procedure

The CGA included a semi-structured interview to acquire medical history, details of previous management and interventions relating to gait. A comprehensive physical examination was performed by a senior physiotherapist with goniometric measurements of lower limb joint range of motion, muscle strength using the Medical Research Council (MRC) classification (0–5) [21], muscle tone (Modified Ashworth Scale) [22] and muscle spasticity (Tardieu scale) [23]. For the 3DGA the senior physiotherapist placed eighteen retroreflective markers on the skin of participants in line with the requirements of the Plug-in-Gait model of Vicon (Workstation 5.2.9 and Nexus 1.8.5, Oxford, UK). All the physiotherapists in the CGAS participate in biennial reliability and repeatability testing to ensure within and between assessor errors in the sagittal plane are < 5°.

2.5. Data collection

Three-dimensional gait data and two-dimensional video were collected with the patient walking at preferred walking speed in bare feet along a 10 m vinyl covered walkway. A minimum of five force plate

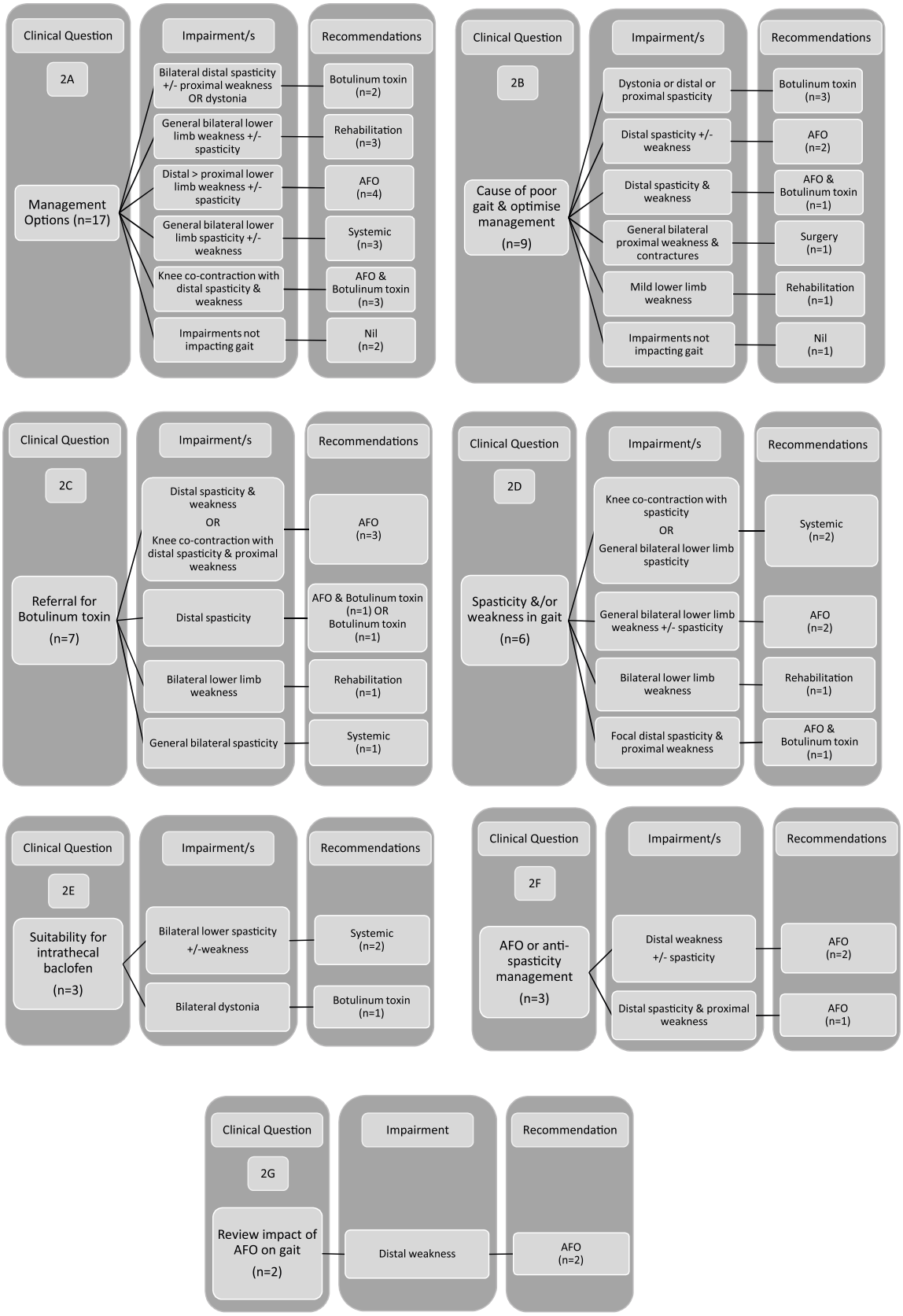

Fig. 2. 2A-1G: Recommendation associated with each of the seven clinical questions and accompanying primary impairment/s as determined using 3DGA; 2A = Management options; 2B = Cause of poor gait & optimise management; 2C = Referral for Botulinum toxin; 2D = Spasticity &/or weakness in gait; 2E = Suitability for intrathecal baclofen; 2 F = AFO or anti-spasticity management; 2 G = Review impact of AFO on gait.

Table 5
Recommendation distribution among condensed five categories of clinical question.[a]

Clinical Question	Recommendation						Total
	AFO	BoNT-A	Nil	Rehab.	Systemic	Surgery	
Management options*	13	5	3	5	5	1	32
AFO management#	5						5
Referral for Botulinum toxin injections	4	1		1	1		7
Suitability for intrathecal baclofen		1			2		3
Surgery		1					1
Total	**22**	**8**	**3**	**6**	**8**	**1**	**48**

[a] AFO = Ankle foot orthosis; BoNT-A = Botulinum toxin A; Rehabil. = Referral to rehabilitation program; Systemic = Systemic spasticity management; Surgery = Referral to orthopaedic surgeon.

* Combines the clinical questions of Management Options (n = 17), Cause of poor gait to optimise management (n = 9) and Spasticity and/or weakness impacting gait (n = 6), N = 32.

Combines the clinical question of AFO or anti-spasticity management (n = 3) and Review impact of AFO on gait (n = 2), N = 5.

contacts for the right and left legs were collected for each condition. An eight camera system (Vicon 612 [pre April 2012] & T10 [post-April 2012]), (Vicon, Oxford, UK) was used to track the position of the markers in space at 100 Hz. Ground reaction data were also collected by two force plates (Kistler Instruments, Winterthur, Switzerland), sampling at 1000 Hz, however this data will not be presented here.

2.6. Gait data analysis

Three-dimensional data were processed using Workstation software (pre April 2012) and Nexus software (Nexus 1.8.5, Oxford, UK). Kinematic data were smoothed via a Woltring filter with a mean squared error of 20 mm^2 and gaps in marker trajectories no greater than 12 frames were filled. All spatial-temporal and kinematic data were calculated using the Plug-in-Gait model of Vicon. Patient data are plotted against an age appropriate control group at a similar gait speed.

The more affected side kinematic data, based on presentation of spasticity and strength, were used to classify gait patterns using the plantarflexor-knee extension couple index [24]. This index calculates the difference between the participant's ankle and knee sagittal plane kinematic data from normative data. To further explore any potential differences between neurological levels the Gait Profile Score (GPS) was calculated [25]. The GPS is a useful and valid tool that represents the root mean square difference between a person's data and the average of the reference dataset taken over nine relevant kinematic variables for the entire gait cycle. The raw score represents how far from the reference dataset a person's kinematics are through stance and swing phases and is a reliable measure in assessing gait quality in people with SCD [19].

2.7. Clinical and demographic data

The neurologic level of SCD was classified as either tetraplegia or paraplegia. The aetiology of SCD was classified as either traumatic spinal cord injury or non-traumatic spinal cord dysfunction based on accepted international classification [26]. Demographic data, years post injury, clinical question and recommendation/s based on CGA data were collated.

Primary outcome variables were: the reason for referral, the primary impairment and the recommendation made. These were retrospectively extracted from the clinical assessment documentation.

2.8. Data integration and team decision-making

All video, spatial-temporal and 3D data were presented by the assessing physiotherapist to the clinical team for consideration. The collation of all biomechanical data acquired in a 3DGA identifies gait dysfunction that assists in differentiating between the important clinical features that can affect gait in people with SCD, spasticity and weakness [27]. The clinical team's interpretation of all data was used to finalise the list of impairments for the patient and their management recommendations, based on the priority order of impairments and the goals of the patient.

In order to illustrate the potential value of 3DGA in clinical decision making, for each clinical question presented by referrers of patients with SCD, decision trees were developed by two of the authors (AM and SK). These decision trees highlighted the primary impairment/s and associated recommendations.

2.9. Statistical methods

Summary statistics were used to describe the population, their gait and clinical management.

Spatial-temporal data were grouped according to the neurological level of injury of the participants. Data for the most impaired side based on neurological level (paraplegia or tetraplegia) of SCD was compared with unimpaired controls using a two-tailed *t*-test assuming unequal variance. The GPS were also grouped by neurological level and compared using a two-tailed *t*-test assuming unequal variance. P-values less than 0.05 were deemed statistically significant.

3. Results

Sixty-three patients met the inclusion criteria. Ten patients were lost to follow-up, five patients declined, nine were unable to be contacted but had provided consent at their initial appointment for their data to be used. Data on 48 eligible participants (n = 37, 77% males) were included in this study. In summary, the average age of participants was 50.6 ± 14.3 years, average height was 1.71 ± 0.10 m and an average weight of 78.8 ± 17.3 kg. The 29 reference participants were well matched in age, gender, height and weight; 48.8 ± 15.2 years, 19 males, 1.74 ± 0.09 m and 77.2 ± 14.2 kg. Participants were on average 8.3 ± 10.5 years post injury, 24 of the participants (50%) had a tetraplegic level of injury and 11 (25%) of injuries were due to trauma. Further details are presented in Table 1.

The classification of level and SCD aetiology of participants is shown in Table 2. The dominant reason for SCD was associated with degenerative causes (27%), followed by transport accidents (17%). Of the degenerative causes, four were associated with canal or spinal stenosis, four had a disc prolapse and five had a vertebral column degenerative disorder.

The reason for referral is summarised in Table 3. Fifty-four percent of participants were referred to determine management options. Only three referrals had specific interventions querying whether ankle-foot orthoses (AFO) would be appropriate to manage gait impairment.

While the gait pattern of each participant could be classified using the plantarflexor-knee extension couple index, the extensive range in patterns resulted in there being no specific gait pattern emerging for

any aetiology, neurological level of injury or cause of injury. When the GPS were grouped by neurological level there was a significant difference between the groups (Fig. 1). The spatial-temporal data is summarised by neurological level in Table 4. There were no significant differences between those with tetraplegia and paraplegia (P-values all > 0.05) but each group was significantly different to the control data.

The decision trees presented in Fig. 2 summarise the recommendations made with respect to the clinical question. Recommendations were related to similar impairments, rather than similar clinical presentation. Thirty-three percent of recommendations made were for an AFO with an additional 12.5% recommending an AFO and Botulinum toxin-A injections. In all participants where Botulinum toxin-A was recommended, the muscles to be injected were specified. There was no intervention recommended for three participants as there was no indication that spasticity or weakness was impacting gait. When the recommendations were condensed into five categories, of the 32 participants referred for management options, 41% were recommended an AFO (Table 5). On seven occasions (14.6%) the recommendation after 3DGA was different from the referrer's proposed intervention. For example, two Botulinum toxin-A injections were recommended following 3DGA instead of seven injections considered before 3DGA.

4. Discussion

In this study we provide a benchmark of the types of gait impairments seen in ambulant people with SCD. Forty-eight participants were grouped by the level and cause of their injury. Kinematic patterns could be classified using the plantarflexor-knee extension couple index but the distribution of these patterns demonstrated that gait cannot be characterised according to aetiology of SCD. The GPS score was significantly associated with a higher level of impairment. The decisions trees, considering the referrer's clinical question and the recommendation/s made, illustrate how 3DGA can inform clinical decision-making regarding gait optimisation in people with incomplete SCD.

This is the largest study of gait assessment using 3DGA in people with SCD. While there was a large spread of walking ability, the mean gait speed was reduced in this cohort when compared to the reference participants. This is consistent with previous studies investigating gait in people with SCD, which suggest that gait speed is associated with level of injury [19], strength deficit [28] and degree of spasticity [29].

Our results using the plantarflexor-knee extension couple index highlighted the variances in sagittal plane kinematic patterns in this cohort. All participants could be classified, however no consistent or dominant pattern emerged when grouped by aetiology or neurological level of SCD. This suggests that stratification of this population using sagittal plane kinematic data is not appropriate, and recommendations should be based on individual results.

To further explore and qualify the variance within the population, the GPS was calculated for each participant and grouped according to neurological level. This method eliminates the widespread presentation of gait patterns to understand the quality of gait in this cohort. Our results suggest that the paraplegia group were significantly more impaired than the tetraplegia group, with a higher average GPS. This may reflect the nature of the SCD being more severe or the cause of SCD more widespread in the paraplegia group. Unfortunately, the only other comparable study to use the GPS in SCD did not differentiate between their tetraplegia and paraplegia participants [19]. Regardless, the spread in scores in this population suggests that the type of impairments vary independently from the neurological level, and that a pre-defined approach to planning interventions for improving gait is not likely to be effective.

Three-dimensional gait analysis provides a sensitive method to determine the primary impairment and associated compensations [20,30], and identify strategies for management. In this study, the most frequent recommendation to improve gait was provision of an AFO. This imparts evidence that the gait impairments affecting this population are likely to be improved with provision of a stable base of support to control the ankle and/or knee joints during stance phase and adequate foot clearance in swing phase. This closely aligns with a prior observational study that categorised and ranked by clinical importance gait impairments by stance phase stability; swing phase foot clearance; foot positioning and step length [31]. That population was also diverse, but had similar findings regarding the importance of foot position during stance and swing phase.

Management options for gait dysfunction in this population appear complex, with over half the referrals unsure of the required/targeted intervention to improve walking. Few clinical questions considered the use of an AFO to assist with ankle and knee motion, yet it was the most common recommendation. A hinged AFO was used to compare barefoot walking with and without functional electrical stimulation of the common peroneal nerve in a group of 19 participants with SCD [32]. The improvement in gait speed when both used concurrently, suggested the use of such devices is effective, most significantly for those with reduced lower limb strength. Therefore, it is surprising that so few referrers had considered the prescription of an AFO to assist gait as part of their reason for referral, indicating a potential knowledge gap in clinical practice in this patient population.

Three-dimensional gait analysis in this study provided specific information to guide targeted management plans to optimize the gait of people with SCD. In particular, it provided guidance for treatment options such as: spasticity management, including the direct selection of muscles for injection of Botulinum toxin-A, or if oral agents/intrathecal baclofen trial was warranted; orthotics, including specific features such as hinged or rigid; surgery for tendon transfers or joint fusion; or rehabilitation programs for progressive resistive strength training or specific gait rehabilitation programs. The objective, quantifiable information obtained by 3DGA differentiates the primary gait abnormality and secondary compensatory effects to assist in determining the most appropriate intervention. A post intervention 3DGA can quantify the degree of change in an individual's gait, and hence the effectiveness of the prescribed intervention. We routinely offer this as part of our service.

This study has a number of limitations. There is referral bias, with the participants coming from a convenience sample of patients referred to a specialist gait laboratory, and the sample size was not large. The cohort of participants had varied presentation in SCD, and it is uncertain the degree to which they would be representative of a sample of ambulatory people with SCD from other regions. We believe, however, that there is no reason that the utility of 3DGA would not be generalizable to other regions. The population was dominated by non-traumatic causes of SCD, in particular degenerative causes. This is in keeping with the reported higher incidence of non-traumatic SCD in Australia, compared with traumatic causes [33,34]. The traumatic group is relatively consistent with the national statistics, in that it is a group dominated by males and the cause of injury is consistent with the national average [35]. The age of injury is higher in this study. We were not able to report the AIS level, as it was not always collected as part of the routine information in the referral/assessment process. A further limitation of this study is that we did not control for the level of injury, rather participants were classified as either paraplegia or tetraplegia, and further described and grouped by their clinical classification. However, when data were grouped by patients' clinical classification, the distribution of spatial-temporal and kinematic data was wide and variable, suggesting that the aetiology and level are not as relevant as strength and spasticity.

5. Conclusions

People with SCD who regain walking ability have a complex range of impairments that impact their gait, with clinical decision-making for

treatment options reliant on the level of clinician expertise. 3DGA has the potential to improve the accuracy of the gait assessment in people with SCD, and subsequently provide more targeted/individualised recommendations for the optimization of their gait, independent of clinician expertise. Where available, we recommend that 3DGA be used as the gold standard for determining gait impairments in this highly variable population when trying to develop strategies to optimise walking. Utilization of 3DGA in people with SCD may also prevent ineffective or inappropriate intervention, impacting on cost, potential patient discomfort, and functional capacity.

Declaration of Competing Interest

The authors have no conflicts of interest relevant to this article to disclose.

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