QTUG™

CASE STUDY: INDEPENDENT LIVING/SHELTERED HOUSING

VERSION 2.1

Kinesis
Health Technologies

Executive summary

16 older adults were assessed at the Circle housing facility in Tonbridge (Kent, U.K.), using the Kinesis QTUG™ mobility and falls risk assessment tool.

QTUG™ was used to assess each patient's risk of falls as well as to identify any mobility or gait impairments (as compared to average values for patient's age and gender).

Summary results for the patient cohort are provided as well as individual patient case studies. Individual case studies highlight patients with falls risk not currently identified by current methods as well as patients with specific mobility impairment that might suggest a propensity to fall. A suggested falls prevention care pathway incorporating QTUG™ is also provided.

About Kinesis

Founded in 2013, **Kinesis Health Technologies** is an award-winning Irish health technology start-up company. Kinesis is a spin-out of University College Dublin and a large ageing research centre, the Technology Research for Independent Living (TRIL) Centre. Its proprietary technology has been validated as part of an extensive programme of top-tier internationally peer-reviewed research in Falls Prevention over the past seven years.

Kinesis QTUG™, a patent protected Mobility and Falls Risk Assessment technology, is based on the Timed Up and Go (TUG) test. Patients are instrumented with body-worn sensors to provide a quantitative assessment of mobility. The technology provides an objective assessment of mobility, a statistical estimate of falls risk as well as identification of mobility impairment by comparison against a large reference population of older adults.

QTUG™ is a Class I medical device in the EU, US and Canada. It is intended for use by a range of healthcare professionals assessing or managing falls in older people across primary, secondary and residential care. www.kinesis.ie.

Contents

Introduction

Falls are the most common cause of injury and hospitalization and one of the principal causes of death and disability in older adults worldwide[8, 10]. Accurate identification of patients at risk of falls could lead to timely medical intervention, reducing the incidence of falls related injuries along with associated costs.

Gait and mobility and one of the most prevalent falls risk factors[2]. Crucially gait and mobility are **modifiable** risk factors in that appropriate to appropriate therapy. Studies have shown that falls prevention intervention programmes can reduce the incidence of falls by 30-40% [2, 3]. Currently there is no fast, reliable and accurate method to assess risk of falls.

Kinesis QTUG™ can identify patients at risk of falls as well as identifying gait and mobility impairments.

QTUG™ case study

16 older adults (7 female, 9 male) assessed at the Circle Housing, Frome Court sheltered housing facility (Tonbridge, Kent, UK). Patients were aged 72-80 (mean age: 81) and recruited through the Frome court falls clinic. Five patients reported a history of falls at the time of assessment, while 11 patients reported no history of falls. All patients were asked to complete a Falls history questionnaire detailed in Table 1.

#	Question
1	Have you fallen in the last 12 months? *Y/N, if Y: How many times?*
2	Have you had any problems walking or moving around? *Y/N*
3	Are you taking 4 or more medications? *Y/N*
4	Do you have any problems with your feet? *Y/N*
5	Have you had any problems with your blood pressure dropping when you stand up? *Y/N*
6	Do you feel dizzy when you stand up from a sitting position? *Y/N*
7	Do you have any problems with your vision? *Y/N*
8	Have you had any change in your ability to manage your routine activities in the home? *Y/N*
9	Have you had a diagnosis of stroke or Parkinson's disease? *Y/N*
10	Do you feel you have any problems with your balance? *Y/N*
11	Are you unable to rise from a knee height chair without using the arm rests to push up? *Y/N*

Table 1: Centra Falls Questionnaire

Clinical data for the cohort are summarised in Table 2 below.

ID:	Age	Gender	Height (cm)	Weight (kg)
1	72	Female	153	110
2	80	Male	175	76
4	84	Male	180	101
5	79	Female	101	61
6	81	Male	160	69
7	86	Female	165	75
8	70	Male	177.8	96
9	84	Male	177.8	76
10	88	Female	152.9	57
11	86	Male	167	65
12	77	Female	162.56	69
13	72	Female	160	60
14	90	Female	157	60

115	83	Male	182.88	69
116	84	Male	177.8	88
117	80	Male	177.8	63

Table 2: Clinical data for Frome court trial.

Results - Mobility assessment

All patients were assessed using Kinesis QTUG™ falls and mobility assessment technology. Body-worn sensors were applied to the left and right shin of each patient as they performed a Timed Up and Go (TUG) test. The TUG test is standard mobility assessment and contains standing, walking and turning phases[9]. Each patient stood from a chair, walked 3 metres, turned around, walked and to the chair and sat back down.

The Kinesis QTUG™ technology provides a detailed assessment of patient's standing, walking and turning performance. An estimate of patients' risk of having a fall as well as a comparison against a large reference population is also provided. If the optional falls questionnaire is selected, QTUG™ will use these data to produce an additional falls risk score. QTUG™ also produces an estimate of a patients frailty state[1, 6]. The comparison against reference data is used to determine if patients have mobility or gait impairment.

Falls risk estimate

Figure 1 details how falls risk estimate (FRE) scores produced by QTUG™ should be interpreted[4-6].

QTUG Falls risk estimate scores:
Low risk: 0-49%   🟢
Medium: 50-69%   🟡
High: 70-90%   🔴
Very high: >90%   🔴

Figure 1: Interpretation of falls risk estimate scores

A suggested falls prevention care pathway based on this interpretation is provided in section "QTUG™ falls care pathway" below. Further information can be found in the Kinesis QTUG™ results interpretation and guidance document.

The Frailty score for each patient should be interpreted in the same manner as the FRE (using Fig .1).

Frailty estimate

Figure 2 details how frailty scores produced by QTUG™ should be interpreted.

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QTUG Frailty scores:

🟢 Non-frail: 0-49%
🟡 Transitional: 50-69%
🔴 Frail: 70-90%
🔴 Very frail: >90%

Figure 2: Interpretation of frailty score.

Comparison to reference data

Each inertial sensor parameter for a given patient is compared to a reference population average for their age and gender. Values outside normal range may indicate mobility impairment or very high performance (see Figure 3 below).
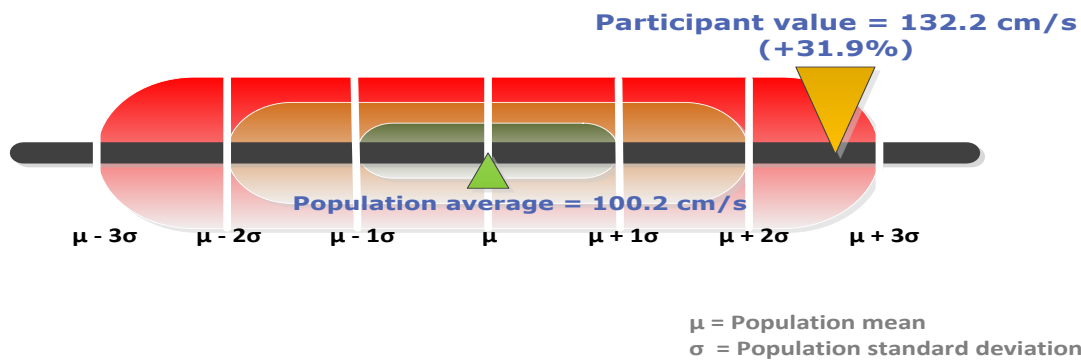

Participant value = 132.2 cm/s (+31.9%)

Population average = 100.2 cm/s

μ - 3σ   μ - 2σ   μ - 1σ   μ   μ + 1σ   μ + 2σ   μ + 3σ

μ = Population mean
σ = Population standard deviation

Figure 3: Comparison of a patient's mobility to reference data

Parameter values that may indicate a specific mobility impairment compared to the reference population are highlighted in **Red** (e.g. TUG time value of 20.9s compared to population average of 10.8s), see Figure 4 below. Parameters highlighted in **Green** are considered better than the population average while **Amber** may indicate a tendency towards mobility impairment.

🟢 **7.8**   🟡 **12.3**   🔴 **20.9**

Figure 4: Interpretation of comparison to reference data

Detailed results for all patients in terms of TUG time, FRE and comparison to reference data are provided in Table 3 below.

ID	Falls History (y/n)	No. falls	TUG time (s)	Falls risk estimate (%)	Frailty score (%)	Comparison to reference data		
						Parameter	Population	Patient
101	Y	2	11.3	29.4	73.4	None		
102	N	0	13.8	44.6	93.6	None		
104	N	0	20.9	89.7	99.9	Time taken to turn (s)	3.0	6.9
						Turn time (s)	3.7	6.0

ID						Comparison	Value	Ref
						Time to stand (s)	2.9	6.1
						No. gait cycles	4.7	10.0
						TUG time (s)	10.8	20.9
105	Y	1	9.6	44.3	56.7	Stride time variability	27.8	4.7
						Single support (%)	0.41	0.51
106	N	0	19.3	58.4	99.9	Step time (s)	0.61	0.86
107	N	0	23.9	72.3	100.0	Time to stand (s)	3.2	7.3
						TUG time(s)	12.5	23.9
						Walk time (s)	9.5	16.6
108	N	0	16.4	75.7	100.0	Steps taken to turn	1.7	4.0
109	N	0	15.6	74.3	90.2	Return time (s)	4.1	7.3
						Double support (%)	0.21	0.34
						Stance time (s)	0.78	1.3
						Cadence (steps/min)	92.5	61.3
110	N	0	17.0	54.6	99.0	None		
111	Y	1	16.1	68.4	100.0	Time to stand (s)	2.9	5.8
112	N	0	12.9	50.9	96.2	Ratio of turn steps to turn time	0.61	1.55
						Stride time variability (%)	28.6	3.9
						Stance time variability (%)	41.4	8.3
113	N	0	18.3	83.4	99.8	Time to stand (s)	2.5	6.4
						TUG time(s)	9.5	18.3
						Turn time (s)	3.5	6.2
						No. gait cycles	4.9	8.0
						No. steps	11.7	19.0
114	N	0	31.5	93.4	100.0	Return time (s)	5.0	13.7
						Walk time (s)	9.5	24.4
						TUG time (s)	12.9	31.5
						Turn time (s)	4.6	10.8
						Time to stand (s)	3.3	7.1
115	N	0	41.6	86.1	100.0	No. gait cycles	4.7	23.0
						Turn time (s)	3.7	17.8
						Walk time (s)	7.8	35.4
						Return time (s)	4.1	17.6
						No steps	11.5	46.0
116	Y	1	14.4	50.4	88.9	None		
117	Y	1	17.3	75.6	96.2	Time to stand (s)	2.9	7.9

Table 3: Falls risk, frailty and comparison to reference data results for trial cohort. TUG time, falls risk estimate, frailty scores and any statistical deviations from the reference population are shown. Values that are outside of the normal range are indicated in the 'Comparison to reference data' column. Values that may indicate specific mobility impairment are highlighted in Red, while values that may indicate a warning are highlighted in Amber. Green values are those deemed high performing relative to the reference population.

Case studies

Patient ID: 101

Female aged 71 years, height 153cm, weight 110kg, **BMI: 47**.

ID	Falls History (y/n)	No. falls	TUG time (s)	Falls risk estimate (%)	Frailty score (%)	Comparison to reference data		
						Parameter	Population	Patient
101	Y	2	11.3	29.4	73.4	None		

Patient reports two falls in the past year. Patient's TUG time is normal for age and gender. Assessment with QTUG™ reports patient has a **low falls** risk and does not exhibit any mobility differences when compared to the reference population. Patient is considered **frail** based on frailty score.

The results indicates that patients previous falls history does not arise from problems with gait and mobility. Patient falls may also arise from other intrinsic factors such as cardiovascular issues (patients has an abnormally high BMI of 47, indicating obesity and potential cardio-pulmonary issues). Patient indicated polypharmacy (three or more prescribed medications, a known falls risk) and vision issues (also a known falls risk).

Patient ID: 113

Female, aged 72. Height 160cm, weight 60kg.

ID	Falls History (y/n)	No. falls	TUG time (s)	Falls risk estimate (%)	Frailty score (%)	Comparison to reference data		
						Parameter	Population	Patient
113	N	0	18.3	83.4	99.8	Time to stand (s)	2.5	6.4
						TUG time(s)	9.5	18.3
						Turn time (s)	3.5	6.2
						No. gait cycles	4.9	8.0
						No. steps	11.7	19.0

Patient reported no history of falls in the past year. QTUG™ reported patient as having a 83.4% risk of fall, this is considered **high** falls risk. Patient was also found to be **very frail**. Patient was found to have significant mobility impairment, in particular QTUG™ identified the TUG test time (TUG time) of 18.3s (compared to population average for age and gender of 9.5. Patients' "Time to stand" was also highly abnormal (6.4s compared to population average of 2.5s). High "Time to Stand" values may indicate poor lower limb strength which is a surrogate measure for core strength.

Patient ID: 112

Female aged 77. Height 162.56cm, weight 69kg. Patient reported no history of falls in the past 12 months.

ID	Falls History (y/n)	No. falls	TUG time (s)	Falls risk estimate (%)	Frailty score (%)	Comparison to reference data		
						Parameter	Population	Patient
112	N	0	12.9	50.9	96.2	Ratio of turn steps to turn time	0.61	1.55
						Stride time variability (%)	28.6	3.9

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Stance time variability (%)	41.4	8.3

QTUG reported patient's falls risk as 50.9%, which is considered **medium risk**. Patient is considered to be **very frail**. Patent exhibited low "stride time variability" (high stride time variability is associated with falls[7]) and suggests patient walks carefully and precisely. Patient exhibited a high ratio of the number of steps taken to turn to the time taken to turn, which may indicate problems turning. Turning problems with otherwise normal gait may be indicative of vestibular or balance issues or lack of confidence in turning.

Patient ID: 104

Male, aged 84, height 180cm, weight 101kg.

ID	Falls History (y/n)	No. falls	TUG time (s)	Falls risk estimate (%)	Frailty score (%)	Comparison to reference data		
						Parameter	Population	Patient
104	N	0	20.9	89.7	99.9	Time taken to turn (s)	3.0	6.9
						Turn time (s)	3.7	6.0
						Time to stand (s)	2.9	6.1
						No. gait cycles	4.7	10.0
						TUG time (s)	10.8	20.9

Patient reported no history of falls in the past 12 months but was deemed to be at **high** risk of falls by QTUG (falls risk estimate 89.7%) and to be **very frail** (frailty score 99.9%). Patient exhibited difficulties standing (Time to stand 6.1s compared to population average of 2.9s), walking (very large number of gait cycles, 10.0 compared to population average of 4.7) and general mobility (very slow TUG test time, 20.9s compared to average for gender of 10.8s). These results in addition to the patients reported polypharmacy and Parkinson's indicate the patient is extremely frail and *heavily at risk of falls*, despite no previous history of falls.

Patient ID: 110

Female, aged 88, height 152.9cm, weight 57kg. Patient reported no history of falls in the past 12 months and did not report any other medical falls risk.

ID	Falls History (y/n)	No. falls	TUG time (s)	Falls risk estimate (%)	Frailty score (%)	Comparison to reference data		
						Parameter	Population	Patient
110	N	0	17.0	54.6	99.0	None		

QTUG™ reported patient as being at **medium risk** of falls (falls risk estimate: 54.6%) and **very frail**. QTUG™ did not observe any potential mobility impairment (when compared to average values for age and gender).

Patient ID: 117

Male, aged 90, weight 63kg, height 178cm. Patient reported a history of falls in the past 12 months.

ID	Falls History (y/n)	No. falls	TUG time (s)	Falls risk estimate (%)	Frailty score (%)	Comparison to reference data		
						Parameter	Population	Patient
117	Y	1	17.3	75.6	96.2	Time to stand (s)	2.9	7.9

QTUG™ reported patient's risk of falls as 75.6% which is considered **high**. Similarly, frailty score is 96.2% which is considered **very high**. Patients' "Time to stand" was 7.9s, compared to a population average of 2.9s, indicating poor lower limb strength. Patients TUG time was 17.3s, which is also very high. These data in addition to patients low body weight, indicate this patient is very frail, could benefit from strength and balance training.

QTUG™ falls care pathway

Figure 4 below illustrates a suggest falls prevention care pathway integrating QTUG™. The care pathway ranges from education and recommended exercise programmes for patients considered at **low risk** of falls to one-on-one assessment, tailored physiotherapy programmes as well as home/personal monitoring for patients deemed at **high risk** and **very high** risk. Patients deemed at **medium** risk receive falls prevention education as well as group exercise classes (exercise interventions have been proven to reduce incidences falls by 30-40%[3]) and personal emergency response (PERS) monitoring.

All clinical personnel routinely enquire about falls

Patients assessed with QTUG by trained staff

Manage Falls risk in the community

Manage Falls risk in a falls clinic

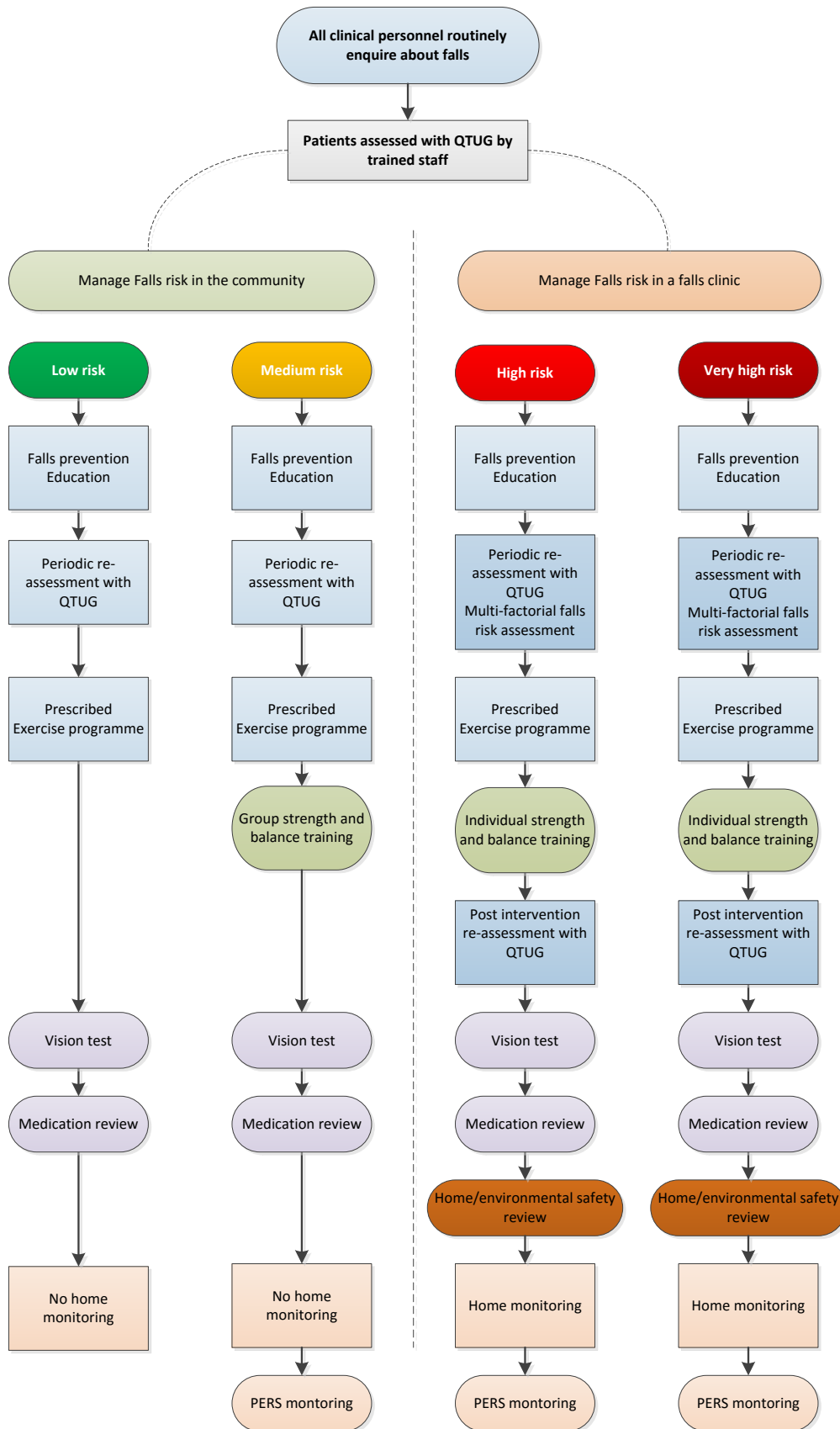| **Low risk**	**Medium risk**	**High risk**	**Very high risk**
Falls prevention Education	Falls prevention Education	Falls prevention Education	Falls prevention Education
Periodic re-assessment with QTUG	Periodic re-assessment with QTUG	Periodic re-assessment with QTUG Multi-factorial falls risk assessment	Periodic re-assessment with QTUG Multi-factorial falls risk assessment
Prescribed Exercise programme	Prescribed Exercise programme	Prescribed Exercise programme	Prescribed Exercise programme
	Group strength and balance training	Individual strength and balance training	Individual strength and balance training
		Post intervention re-assessment with QTUG	Post intervention re-assessment with QTUG
Vision test	Vision test	Vision test	Vision test
Medication review	Medication review	Medication review	Medication review
		Home/environmental safety review	Home/environmental safety review
No home monitoring	No home monitoring	Home monitoring	Home monitoring
	PERS montoring	PERS montoring	PERS montoring

Figure 5: Falls prevention care pathway with Kinesis QTUG™.

Summary

16 patients from a sheltered housing facility were assessed using Kinesis QTUG™ as part of a falls prevention clinic. QTUG™ identified falls risk and mobility impairments in patients with no previous history of falls or obvious falls risk. QTUG™ determined that all patients were clinically frail (according to Fried's phenotype). Taken in conjunction with a standard clinical falls risk assessment (to include a falls questionnaire, vision test, polypharmacy etc), QTUG™ may provide greater insights into patient falls.

Definition of mobility parameters produced by QTUG

Parameter definition	Description
Falls risk estimate (%)	*Statistical risk of falling (defined for community dwelling older adults over 60 years of age)*
TUG test time (s)	*Recording time for entire TUG test as recorded using sensors*

Spatio-temporal gait parameters	
Average stride velocity (cm/s)	*Average walking speed during TUG test*
Stride velocity variability (%)	*Variation in walking speed during TUG test*
Average stride length (cm)	*Mean stride length during TUG test*
Stride length variability (%)	*Coefficient of variability in stride length over TUG test*

Temporal gait parameters	
Time taken to stand (s)	*Time from 'go' to first heel strike or toe-off point*
Number of gait cycles	*Number of gait cycles in total test*
Number of steps	*Number of steps in TUG test*
Cadence (steps/min)	*Average number of steps taken per minute during test*
Walk time (s)	*Time from first to last heel-strike or toe-off point - time participant actually spends in locomotion during TUG test*
Average swing time (s)	*Average swing time over all gait cycles, averaged across both legs, swing time is defined as the time between a toe-off point and the heel strike point on the same foot.*
Average stance time (s)	*Average stance time over all gait cycles, stance time is defined as the time between a heel-strike and toe-off point on the same foot*
Average stride time (s)	*Time for one stride (time between successive heel-strikes), averaged over all gait cycles*
Average step time (s)	*Average of times between heel-strike of one foot to heel strike of the opposite foot measured in seconds (sec).*
Average single support (%)	*Proportion of a gait cycle spent on either foot*
Average double support (%)	*Proportion of a gait cycle spent on both feet*
Swing time variability (%)	*Variation in swing time*

Stance time variability (%)	*Variation in stance time*
Stride time variability (%)	*Variation in stride time*
Step time variability (%)	*Variation in step time*
Single support variability (%)	*Variation in the proportion of a gait cycle spent on a single foot*
Double support variability (%)	*Variation in proportion of a gait cycle spent on both feet*

Turn parameters

Pre-turn time (s)	*Time from 'go' to median gait event of TUG*
Post-turn time (s)	*Time from median gait event of TUG to end of test*
Ratio of pre-turn to post-turn times	*Ratio of Time from 'go' to median gait event of TUG to Time from median event of TUG to end of test*
Time taken to turn (s)	*Time taken to turn*
Number of steps in turn	*Number of steps taken to turn through 180º*
Turn steps/time ratio	*Ratio of the number of steps taken to turn to the time taken to turn*

Angular velocity parameters

Forward rotation speed at turn time (deg/s)	*Angular velocity in sagittal plane at median event of TUG test*
Range of peak forward rotation speed (deg/s)	*Range of angular velocity in the sagittal plane at mid-swing over entire walk*
Average peak forward rotation speed (deg/s)	*Average angular velocity in the sagittal plane at mid-swing over entire walk*
Minimum side-to-side rotation speed (deg/s)	*Minimum angular velocity in the side-to-side direction during the assessment*
Maximum side-to-side rotation speed (deg/s)	*Maximum angular velocity in the side-to-side direction during the assessment*
Average side-to-side rotation speed (deg/s)	*Average angular velocity in the side-to-side direction during the assessment*
Minimum forward rotation speed (deg/s)	*Minimum forward angular velocity in the sagittal plane during the assessment*
Maximum forward rotation speed (deg/s)	*Maximum forward angular velocity during the assessment*
Average forward rotation speed (deg/s)	*Average forward angular velocity during the assessment*

Variation in forward rotation speed (%)	*Coefficient of variation in forward angular velocity during the assessment*
Variation in side-to-side rotation speed (%)	*Coefficient of variation in angular velocity in the side-to-side direction during the assessment*
Minimum horizontal rotation speed (deg/s)	*Minimum angular velocity in the transverse plane during the assessment*
Maximum horizontal rotation speed (deg/s)	*Maximum angular velocity in the transverse plane during the assessment*
Average horizontal rotation speed (deg/s)	*Average angular velocity in the transverse plane during the assessment*
Variation in horizontal rotation speed (%)	*Coefficient of variation in angular velocity in the transverse plane during the assessment*

Angular velocity x Height parameters	
Minimum forward rotation speed x Height (deg.m/s)	*Related to average velocity of shank in forward direction*
Maximum forward rotation speed x Height (deg.m/s)	*Related to maximum linear velocity of shank in forward direction*
Average forward rotation speed x Height (deg.m/s)	*Related to minimum linear velocity of shank in forward direction*
Minimum side-to-side rotation speed x Height (deg.m/s)	*Related to minimum linear velocity of shank in side-to-side direction*
Maximum side-to-side rotation speed x Height (deg.m/s)	*Related to maximum linear velocity of shank in side-to-side direction*
Average side-to-side rotation speed x Height (deg.m/s)	*Related to average linear velocity of shank in side-to-side direction*
Minimum horizontal rotation speed x Height (deg.m/s)	*Related to minimum linear velocity of shank in vertical direction*
Maximum horizontal rotation speed x Height (deg.m/s)	*Related to maximum linear velocity of shank in vertical direction*
Average horizontal rotation speed x (deg.m/s)	*Related to average linear velocity of shank in vertical direction*

References

1   Linda P. Fried, Catherine M. Tangen, Jeremy Walston, Anne B. Newman, Calvin Hirsch, John Gottdiener, Teresa Seeman, Russell Tracy, Willem J. Kop, Gregory Burke, and Mary Ann McBurnie, 'Frailty in Older Adults: Evidence for a Phenotype', *J Gerontol A Biol Sci Med Sci,* 56 (2001), M146-57.

2   LD Gillespie, WJ Gillespie, R Cumming, SE Lamb, and BH Rowe, 'American Geriatrics Society; British Geriatrics Society; American Academy of Orthopaedic Surgeons Panel on Falls Prevention. Guideline for the Prevention of Falls in Older Persons Interventions for Preventing Falls in the Elderly', *J Am Geriatr Soc,* 49 (2001), 664 - 72.

3   Robertson MC Gillespie LD, Gillespie WJ, Lamb SE, Gates S, Cumming RG, Rowe BH. , 'Interventions for Preventing Falls in Older People Living in the Community', *Cochrane Database of Systematic reviews,* CD007146 (2009).

4   B. R. Greene, D. McGrath, and B. Caulfield, 'A Comparison of Cross-Sectional and Prospective Algorithms for Falls Risk Assessment', in *IEEE Engineering in Medicine & Biology Conference* (2014), pp. 4527 - 30.

5   Barry R. Greene, Emer P. Doheny, Cathal Walsh, Clodagh Cunningham, Lisa Crosby, and Rose A. Kenny, 'Evaluation of Falls Risk in Community-Dwelling Older Adults Using Body-Worn Sensors ', *Gerontology,* 58 (2012), 472-80.

6   Barry R. Greene, Emer P. Doheny, Aisling O'Halloran, and Rose A. Kenny, 'Frailty Status Can Be Accurately Assessed Using Inertial Sensors and the Tug Test', *Age and Ageing,* 43 (2014), 406-11.

7   J. Hausdorff, D.A. Rios, and H.K. Edelberg, 'Gait Variability and Fall Risk in Community Living Older Adults: A 1-Year Prospective Study', *Archives of Physical Medicine and Rehabilitation,* 82 (2001), 1050-56.

8   T. Masud, and R.O. Morris, 'Epidemiology of Falls', *Age Ageing,* 30 (2001), 3-7.

9   D Podsiadlo, and S Richardson, 'The Timed "up & Go": A Test of Basic Functional Mobility for Frail Elderly Persons', *J Am Geriatr Soc,* 39 (1991), 142-48.

10   WHO, 'Who Global Report on Falls Prevention in Older Age. ', *WHO Department of Ageing and Life Course* 2007.