QTUG™

FALLS PREVENTION CASE STUDY: IRISHTOWN PRIMARY CARE CENTRE

VERSION 1.1

Kinesis Health Technologies

Executive summary

25 older adults were assessed at the Irishtown primary care centre, Irishtown, Dublin 4, Ireland, 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 are a spin-out of University College Dublin and a large ageing research centre, the Technology Research for Independent Living (TRIL) Centre. Our 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 and frailty 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[19, 28]. 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[6]. Crucially gait and mobility are **modifiable** risk factors in that they can respond to appropriate therapy. Studies have shown that falls prevention and intervention programmes can reduce the incidence of falls by 30-40% [6, 7]. Currently there is no fast, reliable and accurate method to assess frailty and risk of falls.

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

QTUG™ case study

25 older adults (22 female, 3 male), were assessed at the Irishtown primary care centre (Dublin, 4, Ireland). Patients were aged 64-87 (mean age: 75.4) and recruited as part of community falls prevention services.

Some patients were asked to complete the AGS/BGS 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?
3	Are you taking 4 or more prescription medications?
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?
6	Do you feel dizzy when you stand up from a sitting position?
7	Do you have any problems with your vision?
8	Have you had any change in your ability to manage your routine activities in the home?

Table 1: QTUG™ Falls Questionnaire based on AGS/BGS falls questionnaire.

Clinical data for the trial cohort are shown in Table 2 below.

ID	Age (yrs)	Gender	Weight (kg)	Height (cm)	Manual TUG (s)
204057	76	F	77.00	163	11.22
206954	79	F	70.00	158	15.22
207709	66	F	98.00	148	7.41
207709	66	F	98.00	148	10.05
207709	66	F	98.00	148	8.88
207735	73	F	55.00	153	10.93
207955	87	M	55.00	156	14.44
210367	84	F	65.00	152	13.27
213633	68	F	52.00	152	14.64
213729	82	F	55.00	155	14.44
213729	82	F	55.00	155	13.47
215784	74	F	75.00	164	14.74
217911	75	F	69.00	155	12.00
218373	79	F	61.00	145	11.32
219246	70	F	50.00	152	18.94
219497	76	F	59.00	154	12.49
219830	74	F	58.00	153	17.08
219906	72	F	54.00	168	9.46
219910	74	F	58.00	151	18.64
888881	82	F	79.00	152	17.37
888882	76	F	65.00	143	15.62
888882	76	F	65.00	143	14.83
888883	73	M	92.00	164	13.86

888884	69	F	64.00	158	23.13
888885	79	F	68.00	162	21.18
888886	83	F	57.00	142	19.13
888887	83	F	70.00	153	22.94
888889	67	F	83.00	157	11.32

Table 2: Clinical data from Irishtown trial.

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 each patient performed a Timed Up and Go (TUG) test. The TUG test is a standard mobility assessment and contains standing, walking and turning phases[21]. Each patient stood from a chair, walked 3 metres, turned around, walked 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 the patients' risk of having a fall is calculated. QTUG™ also produces an estimate of a patient's frailty state[5, 13] using Fried's frailty phenotype. If the optional falls questionnaire is selected, QTUG™ will use these data to improve the falls risk score. The gait and mobility data for each test is automatically compared against average values for patients' age and gender obtained from a large reference population. The comparison against reference data is used to determine if a patient has mobility or gait impairment.

Results

Falls risk estimate

The falls risk and frailty scores for each test are shown along with the falls history of the patient. 29 Timed up and Go (TUG) tests were conducted for 25 patients using QTUG™. Data from one recording was not usable and falls history data from two tests were not available, leaving a total of 26 valid QTUG™ tests. In order to validate the performance of the tool in assessing falls risk in the Irishtown trial population, we categorized each patient based on their history of falls, as previous falls history is considered a good surrogate for future falls.

Figure 1 details how falls risk estimate (FRE) scores produced by QTUG™ should be interpreted[9, 11, 13].

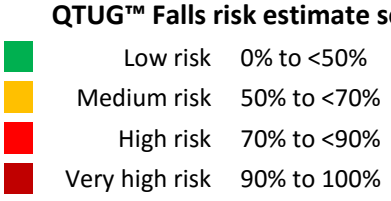

Figure 1: Interpretation of falls risk estimate scores

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.

Frailty estimate

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

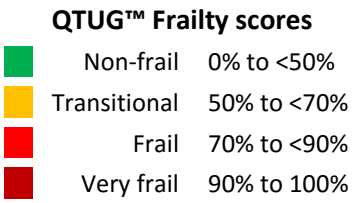

Figure 2: Interpretation of frailty score.

Results for falls risk assessment for each test are detailed in Table 3 below. QTUG™ correctly identified 18 of 26 tests as being a 'faller' on a 'non-faller' yielding a **69.23%** accuracy in falls risk assessment.

ID	Falls risk estimate (%)	Frailty score (%)	Falls History
204057	37.03	77.10	Y
206954	87.10	93.82	Y
207709	0.87	25.34	N
207709	3.99	48.13	N
207709	1.76	37.92	N
207735	17.33	59.75	N
207955	60.14	99.97	Y
210367	20.24	88.42	N
213633	96.76	86.97	Y
213729	90.77	91.03	N
215784	83.56	90.51	Y
217911	50.07	77.71	Y
218373	95.25	69.28	
219246	100.00	98.29	
219497	33.15	82.46	N
219830	98.47	95.07	Y
219906	53.75	50.34	N
219910	100.00	98.56	N
888881	95.28	97.24	Y
888882	99.85	98.23	Y
888882	19.69	95.53	Y
888883	93.14	25.77	N
888884	100.00	99.74	Y
888885	33.57	99.88	N
888886	83.81	99.32	N
888887	98.57	99.89	N
888889	70.16	61.39	Y

Comparison to reference data

Gait and mobility data for each 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).

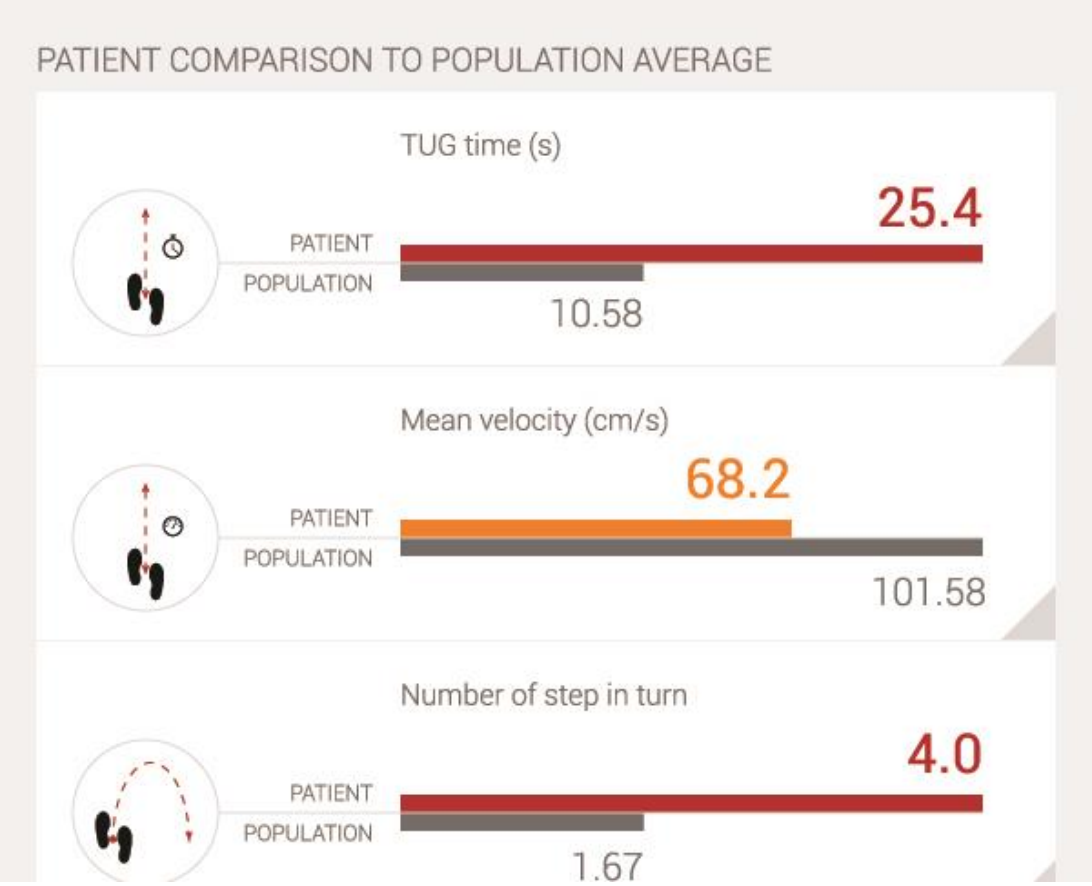

Figure 3: Comparison of a patient's mobility to reference data

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.

Figure 4: Interpretation of comparison to reference data

Detailed results for all patients are provided in Table 3 below. Results illustrate how each patient compares against average values for their age and gender (as calculated using a large reference data set.

ID	Parameter	Patient	Population
204057	Number of steps in turn	1	2.13

	Stance time (s)	1.51	0.84
	Double support (%)	0.46	0.26
	Step time (s)	0.95	0.63
	Stride time (s)	2.01	1.35
206954	Number of steps in turn	1	2.13
207709	Cadence (steps/min)	134.40	98.18
207735	*No abnormal gait/mobility parameters*		
207955	*No abnormal gait/mobility parameters*		
210367	*No abnormal gait/mobility parameters*		
213633	Number of gait cycles	8.00	4.94
	Number of steps	19.00	11.87
213729	Variability in gait velocity (%)	91.29	35.94
	Time to stand (%)	10.08	4.44
	Single support variability (%)	44.78	19.89
	Double support (%)	0.47	0.26
215784	*No abnormal gait/mobility parameters*		
217911	*No abnormal gait/mobility parameters*		
218373	Swing time variability (%)	71.10	22.30
	Single support variability (%)	54.76	19.89
	Double support (%)	0.47	0.26
	Average angular velocity at mid-swing (deg/s)	47.34	103.05
219246	Number of steps in turn	4.00	1.84
	TUG test time (s)	18.94	9.75
	Time taken to walk to turn (s)	7.05	3.63
	Number of steps	23.00	11.87
	Number of gait cycles	9.00	4.94
219497	*No abnormal gait/mobility parameters*		
219830	TUG test time (s)	17.08	9.75
	Stride time (s)	1.67	1.28
219906	Single support variability (%)	48.36	
	Stance time variability (%)	81.41	39.90
	Time taken to turn (s)	5.47	2.80
	Average angular velocity at mid-swing	60.86	113.21
219910	Number of steps in turn	5.00	1.84
	Time taken from turn to end of TUG test (s)	8.59	3.93
	Time spent walking during TUG test (s)	16.22	7.56
	Time taken to walk to turn (s)	7.63	3.63
	Number of gait cycles	10.00	4.94
888881	Average angular velocity at mid-swing	37.83	103.05
	Number of steps	23.00	14.42
888882	Swing time variability (%)	94.07	22.30
	Single support variability (%)	75.77	19.89

	Double support (%)	0.67	0.26
	Swing time (s)	0.16	0.48
	Single support (%)	0.20	0.37
888883	Swing time variability (%)	52.90	20.42
	Double support (%)	0.55	0.22
	Single support variability (%)	41.84	19.28
	Stride time variability (%)	58.56	29.87
	Number of gait cycles	8.00	4.41
888884	Time taken to get to turn (s)	11.46	3.63
	Swing time variability (%)	54.19	19.64
	Time spent walking during TUG test (s)	18.26	7.56
	TUG test time (s)	23.13	9.75
	Time to stand (s)	9.68	4.11
888885	Swing time variability (%)	67.11	22.30
	Single support variability (%)	49.51	19.89
	Time taken to turn (s)	8.08	3.64
	Gait velocity (cm/s)	18.60	88.06
	Double support (%)	0.44	0.26
888886	Gait velocity (cm/s)	17.93	88.06
	Average angular velocity at mid-swing	39.32	103.05
	Stride length (cm)	49.48	111.11
	Swing time (s)	0.66	0.48
888887	*No abnormal gait/mobility parameters*		
888888	Swing time variability (%)	60.80	20.42
	Time taken to get to turn (s)	9.07	3.47
	Single support variability (%)	50.27	19.28
	Double support (%)	0.52	0.22
	Number of gait cycles	10.00	4.41
888889	*No abnormal gait/mobility parameters*		
207709	*No abnormal gait/mobility parameters*		
213729	Swing time variability (%)	62.22	22.30
	Double support variability (%)	118.10	46.14
	Average angular velocity at mid-swing	40.32	103.05
	Single support (%)	0.46	0.37
888882	Number of steps in turn	1	2.13
	Single support (%)	0.27	0.37
207709	*No abnormal gait/mobility parameters*		

Table 3: Comparison to reference data results for trial cohort. 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

A number of individual case studies for patients in this Irishtown cohort are provided below. Each is intended to demonstrate how the data provided by QTUG™ can be interpreted clinically.

Patient ID: 207709

Female aged 66 years, height 148cm, weight 98kg. TUG time: 7.4s.

ID	Falls History (y/n)	No. falls	TUG time (s)	Falls risk estimate (%)	Frailty score (%)	Comparison to reference data		
						Parameter	Population	Patient
207709	N	0	7.4	0.87	25.34	None		

Table 4: QTUG™ results for patient 207709. Patient is considered to be at low risk of falls and frailty.

Patient reports no falls in the past year. Patient's TUG time is excellent for their 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 **non-frail** based on frailty score.

The results indicates that patient does not have any substantial gait issues or risk of falls and frailty.

Patient ID: 204057

Female, aged 76. Height 163cm, weight 77kg.

ID	Falls History (y/n)	No. falls	TUG time (s)	Falls risk estimate (%)	Frailty score (%)	Comparison to reference data		
						Parameter	Patient	Population
204057	Y	1	11.2	37.03	77.10	Number of steps in turn	1	2.13
						Stance time (s)	1.51	0.84
						Double support (%)	0.46	0.26
						Step time (s)	0.95	0.63
						Stride time (s)	2.01	1.35

Table 5: QTUG™ results for patient 204057. Patient is considered to be frail but at low risk of falls.

Patient reported one fall in the past year. QTUG™ reported patient as having a TUG time in the normal range and 37.03% risk of fall, this is considered **low** falls risk. However, patient was also found to be **frail**. Patient was found to have significant mobility impairment, in terms of temporal gait parameters. In particular QTUG™ identified a number of temporal gait parameters such as stride time, stance time and double support (proportion of time spent on both feet) as being abnormally high. This is suggestive of unsteady or unsure gait. Patient did not exhibit problems with turning, suggesting physiotherapy rehabilitation effort should be focused on locomotion rather than balance and lateral stability.

Patient ID: 219830

Female aged 74. Height 53cm, weight 58kg.

ID	Falls History (y/n)	No. falls	TUG time (s)	Falls risk estimate (%)	Frailty score (%)	Comparison to reference data		
						Parameter	Patient	Population

219830	Y		1	17.1	98.47	95.07	TUG test time (s)	17.08	9.75
							Stride time (s)	1.67	1.28

Table 6: QTUG™ results for patient 219830. Patient is considered to be very frail and at very risk of falls. Mobility results suggest patient exhibits general gait and mobility issues.

QTUG™ reported patient's falls risk as 98.47%, which is considered **very high risk**. Patient is also considered to be **very frail**.

Patent exhibited high TUG time and stride time (both of which are associated is associated with falls[16, 25]) and suggests patient has general issues with locomotion and walking.

Patient ID: 888887

Female, aged 83, height 153cm, weight 70kg.

ID	Falls History (y/n)	No. falls	TUG time (s)	Falls risk estimate (%)	Frailty score (%)	Comparison to reference data		
						Parameter	Population	Patient
888887	N	0	22.9	98.57	99.89	None		

Table 7: QTUG™ results for patient 888887. Patient is considered to be very frail and at very high risk of falls and frailty.

Patient reported no history of falls in the past 12 months but was deemed to be at **very high** risk of falls by QTUG™ (falls risk estimate 98.57%) and to be **very frail** (frailty score 99.89%). Patient took a very long time to complete the TUG test (22.9s) however given the patient's age (83) this is just inside the normal range, despite evident general mobility issues. These results in addition to the patients reported clinical falls risk (polypharmacy, problems walking, vision problems) indicate the patient is extremely frail and *heavily at risk of falls*, despite no previous history of falls.

Patient ID: 888884

Female, aged 69, height 158cm, weight 64kg. Patient reported two falls in the past 12 months and reported a number of other clinical falls risks such as polypharmacy, vision problems and problems with feet.

ID	Falls History (y/n)	No. falls	TUG time (s)	Falls risk estimate (%)	Frailty score (%)	Comparison to reference data		
						Parameter	Patient	Population
888884	Y	2	23.1	100.00	99.74	Time taken to get to turn (s)	11.46	3.63
						Swing time variability (%)	54.19	19.64
						Time spent walking during TUG test (s)	18.26	7.56
						TUG test time (s)	23.13	9.75
						Number of steps	20.00	11.87

Table 8: QTUG™ results for patient 888884. Patient is considered to be very frail and at very high risk of falls and frailty with significant gait and mobility impairment.

QTUG™ estimated patient as being at **very high risk** of falls (falls risk estimate: 100%) and **very frail**.

Patients' swing time variability was very high (54%) compared to a population average of 19%. Gait variability has been strongly linked to unstable gait and risk of falls[17]. Patient's TUG time was 23.1s, which is very high, indicating general mobility issues. These data indicate this patient is very frail and could benefit from strength and balance training.

Patient ID: 219910

Female, aged 74, height 151cm, weight 58kg.

ID	Falls History (y/n)	No. falls	TUG time (s)	Falls risk estimate (%)	Frailty score (%)	Comparison to reference data		
						Parameter	Patient	Population
219910	Y	2	18.64	99.99	98.56	Number of steps taken to turn	5.00	1.91

Time to walk back from turn (s)	8.59	3.95
Time spent walking (s)	16.22	7.60
Time to walk to turn (s)	7.63	3.65
Number of gait cycles	10.00	4.94

Table 9: QTUG™ results for patient 219910. Patient is considered to be very frail and at very high risk of falls and frailty with significant gait and mobility impairment.

QTUG™ estimated this patient to be highly at risk of falls and frailty. Patient exhibits problems with turning (number of steps taken to turn is 5 compared to average value of 1.9), as well as general walking problems. Patient might benefit from balance training focusing on turn stability as well as general strength training.

QTUG™ falls care pathway

Figure 5 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%[7]) and personal emergency response (PERS) monitoring.

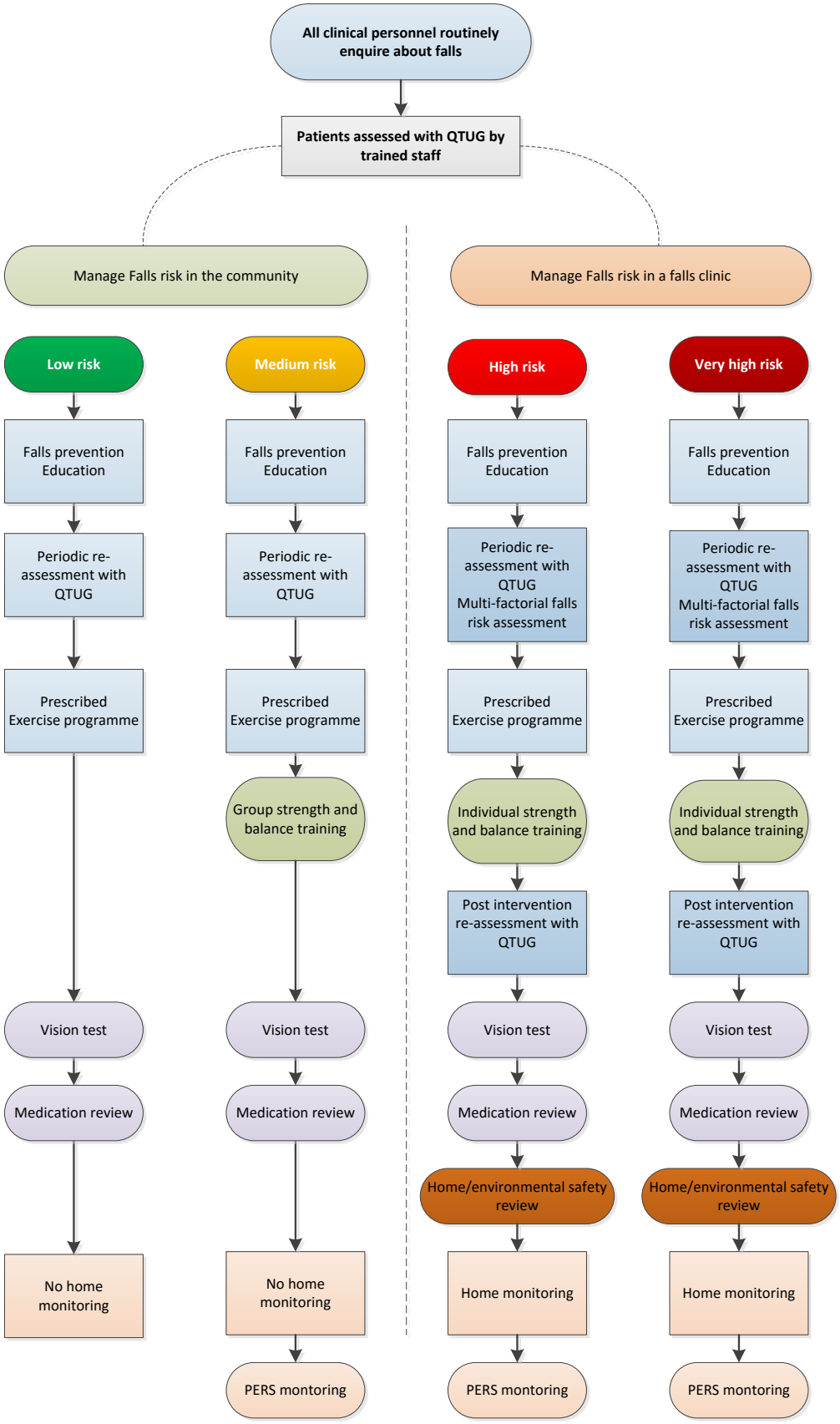

Figure 5: Falls prevention care pathway with Kinesis QTUG™.

Summary

25 community based primary care patients were assessed using Kinesis QTUG™ as part of a falls prevention programme. QTUG™ identified falls risk and mobility impairments in patients with no previous history of falls or obvious falls risk. QTUG™ can determine that patients are 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 and improve management of frailty as a clinical condition.

Definition of mobility parameters produced by QTUG™

Parameter definition	Description
Falls risk estimate (%)	*Statistical risk of having a fall (defined for community dwelling older adults over 60 years of age).* *Values below 50% are considered **low risk**. Values between 50 and 70% are considered **medium risk**. Values above 70% are **high risk** while values above 90% are considered **very high risk**.*
Frailty estimate (%)	*Statistical estimate of frailty level (defined using Fried's phenotype for patients over 60 years of age* *Values below 50% are considered **non-frail**. Values between 50 and 70% are considered **transitionary**. Values above 70% are **frail** while values above 90% are considered **very frail**.*
TUG test time (s)	*Recording time for entire TUG test as recorded using body-worn sensors.* *Longer TUG times are associated with increased risk of falls[25, 27]. Longer TUG times have also been associated with increased frailty[13, 22].*
Spatial gait parameters	
Average stride velocity (cm/s)	*Average gait (walking) speed during TUG test.* *Lower values of gait speed (stride velocity) are associated with increased falls risk and morbidity as well as with survival[23]. Gait velocity can be improved through targeted physiotherapy.*
Stride velocity variability (%)	*Variation in walking speed during TUG test.* *Too much or too little variability in gait velocity is associated with increased falls risk[3]. High gait velocity variability could indicate unsteady gait.*
Average stride length (cm)	*Mean stride length during TUG test.* *Shorter stride length values are associated with increased falls risk. Shorter stride length can also be an indicator of Parkinson's as well as other neurological disorders such as multiple sclerosis. Stride length is strongly correlated with gait velocity.*
Stride length variability (%)	*Coefficient of variability in stride length over TUG test.* *Increased stride length variability has been associated with increased risk of falls.*

Temporal gait parameters

Time taken to stand (s)	*Time from 'go' to first heel strike or toe-off point.* *A long time taken to stand may be indicative of lower limb weakness. Lower limb weakness (along with grip strength)[24] is a surrogate measure of core and overall physical strength. Higher values of time to stand are associated with increased risk of falls. Targeted strength training can be used to increase lower limb strength. Overall strength can be improved by strength and balance training.*
Time taken to sit (s)	*Time from last heel strike or toe-off to end of test.* *A long time taken to sit may be indicative of poor balance or instability. Higher values of time to sit are associated with increased risk of falls. Targeted physiotherapy can be used improve balance and lower limb strength.*
Number of gait cycles	*Number of gait cycles in total test.* *Higher numbers of gait cycles are associated with increased falls risk and suggest patient is taking smaller steps.*
Number of steps	*Number of steps in TUG test.* *Higher numbers of steps are associated with increased falls risk and suggest patient is taking smaller steps. High step count during a TUG can indicate stability of gait problems as well as overall weakness and can be addressed by targeted strength and balance training*
Cadence (steps/min)	*Average number of steps taken per minute during test.* *Lower values of cadence are associated with higher falls risk and may also indicate neurological disorders. High cadence is a leading indicator of Parkinson's disease.*
Walk time (s)	*Time from first to last heel-strike or toe-off point. Length of time participant actually spends in locomotion during TUG test.* *Higher values of walk time are associated with increased falls risk. If turn parameters are normal and walk time high, patient may have walking impairment.*
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.*
Swing time variability (%)	*Coefficient of variation in swing time during TUG test.* *Longer swing times and increased (as well very low) swing time variability are associated with increased falls risk. Many measures of gait variability have been associated with increased falls risk [2, 4]. Gait variability has also been associated with cognitive decline and dementia [8, 26]. Measures of gait*

	variability during TUG have been shown to be highly variable due to the nature of the test (and so not reliable) across multiple trials.
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.*
Stance time variability (%)	*Variation in stance time over TUG test.* *Longer stance times and increased (as well very low) stance time variability are associated with increased falls risk.*
Average stride time (s)	*Time for one stride (time between successive heel-strikes), averaged over all gait cycles.*
Stride time variability (%)	*Variation in stride time during the TUG test.* *Longer stride times are associated with increased falls risk. Too much or too little stride variability has been associated with increased falls risk[3, 4, 18]. Measures of gait variability during TUG have been shown to be highly variable due to the nature of the test (and so not reliable) across multiple trials.*
Average step time (s)	*Average time between heel-strike on one foot to heel strike of the opposite foot, measured in seconds.*
Step time variability (%)	*Variation in step time during the TUG test.* *Longer steps times are associated with increased falls risk. Too much or too little step time variability is associated with increased falls risk[3].*
Average double support (%)	*Proportion of a gait cycle spent on both feet during TUG test.*
Double support variability (%)	*Variation in proportion of a gait cycle spent on both feet during TUG test.* *High values of double support are associated with increased falls risk. High double support variability can indicate highly unstable or unsure gait.*
Average single support (%)	*Proportion of a gait cycle (time between successive steps) spent on either foot.*
Single support variability (%)	*Variation in the proportion of a gait cycle spent on a single foot.* *High values of single support are associated with increased falls risk. High single support variability can indicate unstable or unsure gait. Gait instability can be addressed through balance re-training.*

Turn parameters

Pre-turn time (s)	*Time from 'go' to median gait event of TUG test.* *Time to the 'middle' of the TUG. Disparities between pre-turn time, turn time and post-turn time can be used to identify if patient lacks endurance (time slower in returning from turn), has trouble turning or has general gait and mobility issues.*

Post-turn time (s)	*Time from median gait event of TUG to end of test.* *Time from the 'middle' of the TUG test to return to the chair and reseat. Slower post-turn times than pre-turn times can indicate patient has trouble turning or may lack endurance.*
Ratio of pre-turn to post-turn times	*Ratio of time taken from 'go' to median gait event of TUG to the time from the median gait event during TUG, to the end of test.* *If patient is faster at walking to turn than in walking back? Lower values of this ratio indicate that patients may be struggling to turn or may lack endurance.*
Time taken to turn (s)	*Time taken to turn through 180°.* *Longer times taken to turn are strongly indicative of higher falls risk. Turning problems can also be indicator of balance or vestibular issues. Balance re-training and targeted physiotherapy improve time to taken to turn. Note long times taken to turn cannot also indicate that patient has adopted a careful turn strategy with a wide base of support which is a positive strategy to maintain stability during walking and turning.*
Number of steps in turn	*Number of steps taken to turn through 180°.* *Patients taking more steps to turn than normal (see reference data below) is strongly indicative of higher falls risk. Turning problems can also be indicator of balance or vestibular issues. Balance re-training may improve patient's ability to turn along with associated stability.*
Turn steps/time ratio	*Ratio of the number of steps taken to turn to the time taken to turn.* *This is indicative of patients turn strategy. More steps taken to turn (even if time taken to turn is normal) could be considered less stable and can indicate higher falls risk.*

Angular velocity parameters

Forward rotation speed at turn time (deg/s)	*Angular velocity in sagittal plane at median event of TUG test.* *Speed patient performs turn during TUG. Slower turn speeds are associated with increased falls risk. More variable turn speed can be associated with more unsteady turning.*
Range of peak forward rotation speed (deg/s)	*Range of angular velocity in the sagittal plane at mid-swing over entire walk.* *Larger range denotes increased lower limb rotation in the forward direction. Too much or too little variation has been associated with increased falls risk.*
Average peak forward rotation speed (deg/s)	*Average angular velocity in the sagittal plane over entire walk.* *Linked to minimum ground clearance (also known as toe-clearance)[15, 20] as well as foot speed. Higher foot speed is associated with higher walking speed*

	and reduced falls risk. Low minimum ground clearance is associated with risk of tripping[20].
Minimum side-to-side rotation speed (deg/s)	*Minimum angular velocity in the side-to-side direction during the assessment.* *Linked to lateral foot speed, associated with more variable and unsteady walking and higher falls risk.*
Maximum side-to-side rotation speed (deg/s)	*Maximum angular velocity in the side-to-side direction during the assessment.* *Linked to lateral foot speed, associated with more variable and unsteady walking and higher falls risk.*
Average side-to-side rotation speed (deg/s)	*Average angular velocity in the side-to-side direction during the assessment.* *Linked to lateral foot speed and increased unsteadiness in walking.*
Minimum forward rotation speed (deg/s)	*Minimum forward angular velocity in the sagittal plane during the assessment.* *Linked to gait velocity, has also been linked to minimum ground clearance, e.g. risk of tripping, a known falls risk. Decreased values are associated with increased falls risk.*
Maximum forward rotation speed (deg/s)	*Maximum forward angular velocity during the assessment.* *Linked to gait velocity, has also been linked to minimum ground clearance, e.g. risk of tripping, a known falls risk[20]. Decreased values are associated with increased falls risk.*
Average forward rotation speed (deg/s)	*Average forward angular velocity during the assessment.* *Linked to gait velocity, has also been linked to minimum ground clearance [15], e.g. associated with risk of tripping, a known falls risk. Decreased values are associated with increased falls risk.*
Variation in forward rotation speed (%)	*Coefficient of variation in forward angular velocity during the assessment.* *More variable rotation of lower limbs is associated with increased falls risk. This has also been associated with increased variability in minimum ground clearance (MGC) [20]. Low MGC can be addressed through targeted physiotherapy and may be indicative of poor lower or hip-flexor mobility.*
Variation in side-to-side rotation speed (%)	*Coefficient of variation in angular velocity in the side-to-side direction during the assessment.* *Increased variation in lateral rotation of lower limbs may indicate less stability under locomotion while completing the TUG test.*
Minimum horizontal rotation speed (deg/s)	*Minimum angular velocity in the transverse plane during the assessment.* *Linked to minimum ground clearance (minimum distance from bottom of foot the ground during the swing phase). Low MGC is a known falls risk.* *Maximum angular velocity in the transverse plane during the assessment.*

Maximum horizontal rotation speed (deg/s)	*Linked to minimum ground clearance (minimum distance from bottom of foot the ground during the swing phase). Low MGC is a known falls risk.*
Average horizontal rotation speed (deg/s)	*Average angular velocity in the transverse plane during the assessment.* *Linked to minimum ground clearance (minimum distance from bottom of foot the ground during the swing phase). Low MGC is a known falls risk.*
Variation in horizontal rotation speed (%)	*Coefficient of variation in angular velocity in the transverse plane during the assessment.* *High values are associated with more variable lower limb movement.*

Angular velocity x Height parameters

Minimum forward rotation speed x Height (deg.m/s)	*Related to average velocity of shank in forward direction.* *Linked to foot speed. Higher foot speed is associated with higher walking speed and reduced falls risk.*
Maximum forward rotation speed x Height (deg.m/s)	*Related to maximum linear velocity of shank in forward direction.* *Linked to foot speed. Higher foot speed is associated with higher walking speed and reduced falls risk.*
Average forward rotation speed x Height (deg.m/s)	*Related to minimum linear velocity of shank in forward direction.* *Related to lateral vertical speed, i.e. speed of foot while moving upward.*
Minimum side-to-side rotation speed x Height (deg.m/s)	*Related to minimum linear velocity of shank in side-to-side direction.* *Related to lateral foot speed.*
Maximum side-to-side rotation speed x Height (deg.m/s)	*Related to maximum linear velocity of shank in side-to-side direction* *Related to lateral foot speed.*
Average side-to-side rotation speed x Height (deg.m/s)	*Related to average linear velocity of shank in side-to-side direction* *Related to lateral foot speed.*
Minimum horizontal rotation speed x Height (deg.m/s)	*Related to minimum linear velocity of shank in vertical direction* *Related to forward foot speed.*
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.*

Further information on QTUG™ clinical research studies can be found in references[1, 8-14] and on http://www.kinesis.ie/research/

References

1 Barry R. Greene, Stephanie Rutledge, Iain McGurgan, Christopher McGuigan, Karen O'Connell, Brian Caulfield, and Niall Tubridy, 'Assessment of Early Stage Multiple Sclerosis with Inertial Sensors', *IEEE J. Biomed. Health Inform.,* In review (2015).

2 O. Beauchet, G. Allali, C. Annweiler, S. Bridenbaugh, F. Assal, R.W. Kressig, and F.R. Herrmann, 'Gait Variability among Healthy Adults: Low and High Stride-to-Stride Variability Are Both a Reflection of Gait Stability', *Gerontology,* 55 (2009).

3 Jennifer Brach, Jaime Berlin, Jessie VanSwearingen, Anne Newman, and Stephanie Studenski, 'Too Much or Too Little Step Width Variability Is Associated with a Fall History in Older Persons Who Walk at or near Normal Gait Speed', *Journal of NeuroEngineering and Rehabilitation,* 2 (2005), 21.

4 JS Brach, R Berthold, R Craik, JM VanSwearingen, and A Newman, 'Gait Variability on Community-Dwelling Older Adults', *J Am Geriatr Soc,* 49 (2001), 1646 - 50.

5 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.

6 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.

7 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).

8 B. R. Greene, and R. A. Kenny, 'Assessment of Cognitive Decline through Quantitative Analysis of the Timed up and Go Test', *IEEE Trans. Biomed. Eng.,* 59 (2012), 988-95.

9 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.

10 B.R. Greene, E.P. Doheny, R.A. Kenny, and B. Caulfield, 'Classification of Frailty and Falls History Using a Combination of Sensor-Based Mobility Assessments', *Physiol. Meas. ,* 35 (2014), 2053-66.

11 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.

12 Barry R. Greene, Alan O'Donovan, Roman Romero-Ortuno, Lisa Cogan, Cliodhna Ni Scanaill, and Rose A. Kenny, 'Quantitative Falls Risk Assessment Using the Timed up and Go Test', *IEEE Trans. Biomed. Eng.,* 57 (2010), 2918-26.

13 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.

14 Barry R. Greene, Michael Healy, Stephanie Rutledge, Brian Caulfield, and Niall Tubridy, 'Quantitative Assessment of Multiple Sclerosis Using Inertial Sensors and the Tug Test', in *IEEE Engineering in Medicine and Biology* (2014), pp. 2977 - 80.

15 Barry R. Greene, Denise McGrath, Timothy G. Foran, Emer P. Doheny, and Brian C. Caulfield, 'Body-Worn Sensor Based Surrogates of Minimum Ground Clearance in Elderly Fallers and Controls', in *Engineering in Medicine and Biology Society (EMBC), 2011 Annual International Conference of the IEEE* (Boston, MA: 2011).

16 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.

17 JM Hausdorff, HK Edelberg, SL Mitchell, AL Goldberger, and JY Wei, 'Increased Gait Unsteadiness in Community-Dwelling Elderly Fallers', *Arch Phys Med Rehabil,* 78 (1997), 278 - 83.

18 JM Hausdorff, DA Rios, and HK Edelberg, 'Gait Variability and Fall Risk in Community-Living Older Adults: A 1-Year Prospective Study', *Arch Phys Med Rehabil,* 82 (2001), 1050 - 56.

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

20 Denise McGrath, Barry R. Greene, Cathal Walsh, and Brian Caulfield, 'Estimation of Minimum Ground Clearance (Mgc) Using Body-Worn Inertial Sensors', *Journal of Biomechanics,* 44 (2011), 1083-88.

21 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.

22 George M. Savva, Orna A. Donoghue, Frances Horgan, Claire O'Regan, Hilary Cronin, and Rose Anne Kenny, 'Using Timed up-and-Go to Identify Frail Members of the Older Population', *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences,* 68 (2013), 441-46.

23 Stephanie Studenski, Subashan Perera, Kushang Patel, Caterina Rosano, Kimberly Faulkner, Marco Inzitari, Jennifer Brach, Julie Chandler, Peggy Cawthon, Elizabeth Barrett Connor, Michael Nevitt, Marjolein Visser, Stephen

Kritchevsky, Stefania Badinelli, Tamara Harris, Anne B. Newman, Jane Cauley, Luigi Ferrucci, and Jack Guralnik, 'Gait Speed and Survival in Older Adults', *JAMA : the journal of the American Medical Association,* 305 (2011), 50-58.

24 Holly Syddall, Cyrus Cooper, Finbarr Martin, Roger Briggs, and Avan Aihie Sayer, 'Is Grip Strength a Useful Single Marker of Frailty?', *Age and Ageing,* 32 (2003), 650-56.

25 Gyrd Thrane, Ragnar Joakimsen, and Eline Thornquist, 'The Association between Timed up and Go Test and History of Falls: The Tromso Study', *BMC Geriatrics,* 7 (2007), 1.

26 Joe Verghese, Cuiling Wang, Richard B Lipton, Roee Holtzer, and Xiaonan Xue, 'Quantitative Gait Dysfunction and Risk of Cognitive Decline and Dementia', *Journal of Neurology, Neurosurgery & Psychiatry,* 78 (2007), 929-35.

27 Susan Whitney, L. , Gregory Marchetti, F. , Annika Schade, and Diane Wrisley, M. , 'The Sensitivity and Specificity of the Timed "up & Go" and the Dynamic Gait Index for Self-Reported Falls in Persons with Vestibular Disorders', *Journal of Vestibular Research,* 14 (2004), 397-409.

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