Title: Assessing functional exercise capacity using telehealth: Is it valid and reliable in patients with chronic heart failure?

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ABSTRACT

Introduction: This study aimed to determine the validity and reliability of video-based telerehabilitation assessments in patients with heart failure. **Methods:** Seventeen consecutive participants (mean age 69 years, SD 12 years and 88% males) undertook assessments of three functional tests via both telerehabilitation and face-to-face approaches, on the same day. The assessment order was randomised and conducted by independent assessors. Outcome measures included functional tests: timed up and go (time), six minute walk (distance), grip strength (kilograms); system usability scale to rate participant experience with telerehabilitation assessment; and number of technical issues encountered. Validity and inter- and intra-rater reliability of telerehabilitation assessments were examined using limits of agreement, intra-class correlation coefficients (ICC), and paired t-tests. **Results:** The limits of agreement for telerehabilitation assessments were within the clinically acceptable limits for timed up and go and grip strength. Telerehabilitation assessments for all functional tests were strongly associated with face-to-face assessments, with ICCs of between 0.85 and 0.96. Inter- and intra-rater reliability of telerehabilitation assessments for all functional tests were excellent (all ICC >0.95). The mean (SD) system usability scale score was 85 (15)/100. Some incidences of Internet drop-outs, video freezing and auditory fading occurred. **Discussion:** The use of telehealth for the assessment of functional exercise capacity appears to be valid and reliable in patients with heart failure.

INTRODUCTION

Australia is a geographically vast country with reduced access to specialised heart failure exercise programs in the rural and remote areas. Telerehabilitation, the delivery of rehabilitation services via telecommunication technologies, is a potential service delivery model which may overcome many issues related to access of services. Telerehabilitation treatment has been trialled in patients with cardiopulmonary diseases,^{1,2} but the use of telerehabilitation as an assessment tool to determine functional exercise capacity has not been established in patients with chronic heart failure (CHF).

Telerehabilitation assessment has been used in other patient groups. For example, the use of telerehabilitation assessment to gather information and form a diagnosis, has been shown to be valid and reliable in patients with shoulder disorders.³ Similarly, telerehabilitation assessments of pulse oximetry⁴ and manual muscle test⁵ have been demonstrated to be feasible and valid, compared to face-to-face assessment in healthy individuals.⁴ In a pilot study, functional capacity assessment using the three minute step test has been reported to be feasible and accurate via video-based telerehabilitation in patients with cystic fibrosis.⁶ This is consistent with a study on the accuracy and reliability of telerehabilitation assessment for the timed up and go test (TUGT) and step test in patients with Parkinson's disease.⁷ As these patient groups, telerehabilitation assessment may be feasible for people with CHF.

Assessment tools typically used in heart failure exercise programs include the six minute walk test (6MWT), the TUGT and muscle strength test.^{8,9} The 6MWT is a self-paced test frequently used to measure functional exercise capacity.¹⁰ It has been

shown to predict mortality⁹ and hospital readmission in patients with CHF;¹¹ to correlate with measures of maximal exercise capacity;⁸ and is a valid, reliable and responsive measure to changes in clinical status following cardiac rehabilitation.¹² Another functional test, the TUGT, is used to assess mobility and balance.¹³ It has demonstrated validity and reliability in patients with CHF,¹⁴ and demonstrates similar relative changes following cardiac rehabilitation as the 6MWT.¹⁵ It is also important to assess muscle strength using the hand-grip test in patients with CHF, as decreased muscle strength has been highlighted to be a hallmark feature of the condition and can contribute to exercise intolerance.¹⁶ For instance, weak grip strength was a risk factor for hospital admissions in a group of patients with CHF.¹⁷ These three assessments play a role in evaluating functional exercise capacity, determining prognosis, and establishing response to treatment including heart failure exercise programs.

The aim of this study was to compare the validity and reliability of video-based telerehabilitation assessments of the 6MWT, TUGT and grip strength with traditional face-to-face assessments. It was hypothesised that these telerehabilitation assessments would be valid and reliable in patients with CHF.

METHODS

Design, setting and participants: This paper reports on a nested telerehabilitation assessment study within a randomised controlled trial of heart failure telerehabilitation. In brief, the larger trial recruited patients with stable CHF, who were enrolled in a 12-week comprehensive heart failure disease management program. Participants were randomised either to a 12-week real-time video-based telerehabilitation program delivered twice-weekly, or a control group of traditional

centre-based heart failure exercise program of the same duration and frequency. Participants were enrolled from two tertiary hospitals in Brisbane, Australia, between 2013 and 2015. The trial was approved by the Human Research Ethics Committees of participating hospitals, and was included in the Australian Clinical Trials Registry (ACTRN12613000390785).

Assessments for this study occurred immediately after the 12-week exercise program in the intervention trial. The same assessments were also undertaken via the face-to-face approach as baseline measurements prior to the start of the exercise program. Seventeen consecutive participants who had been assigned to the telerehabilitation group undertook post-program assessments via telerehabilitation, as well as via the traditional face-to-face approach. Participants performed assessments on two separate occasions within the same day, each of which was assessed using one of the assessment types (telerehabilitation or face-to-face approaches). The assessment order was randomised through the use of concealed opaque envelopes. A balanced block randomisation code was generated and administered by an experienced independent researcher. Assessments were undertaken by four hospital physiotherapists (with an average of 11.5 years of work experience in physiotherapy), and included the 6MWT, TUGT and grip strength. The therapists had an unequal number of assessments: Therapist 1 undertook assessments for nine participants, Therapist 2 had four participants, Therapist 3 had a participant, and Therapist 4 had three participants. The same therapist undertook the telerehabilitation assessment, the face-to-face assessment and the repeat telerehabilitation assessment for the same participant.

Telerehabilitation assessment procedure: During the telerehabilitation assessment, an independent examiner was geographically located within the same hospital building as the participant, but in a separate room. As the examiner had no physical contact with the participant during the telerehabilitation assessment, the examiner verbally led the participant through the tests, demonstrating on themselves where appropriate, for the participant to copy. The participant was given an opportunity to practice prior to commencing the assessment. The participant also received written and pictorial instructions detailing the steps involved in operating the laptop computer (Dell Inspiron 15) and accessing the online videoconferencing software (Adobe Connect 9.2, Adobe Systems Inc., San Jose, CA), which was connected via a 3G wireless broadband Internet connection (Optus). Telephone contact details for the remotely located examiner were included in the event that the participant needed additional assistance or encountered technical difficulties. The telerehabilitation assessment was recorded by the videoconferencing system to enable the performance of the reliability element of the study.

6 minute walk test

To enable the performance of this test, the laptop was positioned by the participant at the start of the six minute walk track, so that the examiner could see the whole 30 metre track. The participant also had a stopwatch to mark the beginning and end of the functional tests, as well as other monitoring devices including automatic sphygmomanometer (Riester ru-champion) and finger pulse oximeter (Digit). The participant self-monitored and verbally reported blood pressure, heart rate and oxygen saturation levels at the start of the assessment. The examiner counted the number of laps completed during the 6MWT and gave standardised encouragements as per

recommended guidelines.¹⁸ A lap counter was also used by the participant or the participant's family member, to confirm the number of laps achieved during the test. The participant was asked to read the nearest distance marker on the track when the test was terminated. The 6MWT distance (6MWD) was recorded to the nearest metre. Note that each participant undertook a single 6MWT.

Timed up and go test

The TUGT was measured in real-time by observing the participant via videoconference. The examiner used a standard stop-watch to record the time taken for the participant to stand from a 45 centimetre high chair with arm rests, walk three metres at a comfortable pace, turn 180 degrees, walk to the starting point, and return to a seated position.^{13,19} The participant sat with their back resting on the chair backrest, using regular footwear and mobility aid. This test was performed twice, with adequate rest time (until symptom resolution) between the two tests. The quicker of the two tests was recorded as the best TUGT time, in seconds with two decimal places.

Grip strength test

Maximum grip strength for each hand was measured three times with a hand-held dynamometer (Jamar) as described previously.²⁰ The examiner verbally guided the participant through grip strength test and operation of the associated equipment. The best measurement of three tests was used in the analysis as maximum voluntary contraction, in kilograms.

System usability scale

The system usability scale is a validated measurement tool that rates a user's experience of technology.²¹ It uses 5-point Likert Scale and contains 10 questions covering various aspects of a system's use, such as the need for support, training, and complexity. This questionnaire was administered to the participant at the end of the telerehabilitation assessment.

Patient demographic details were collected from the medical chart and questionnaires. The number and nature of technical issues encountered during the telerehabilitation assessment were also recorded. Similarly the number and nature of adverse events were noted.

Face-to-face assessment procedure: Due to a large variability with repeated 6MWT detailed in previous studies,^{22,23} we chose to conduct the traditional face-to-face assessment using two approaches: concurrent and separate testing occasions. In a subset of participants (n=9), the face-to-face assessment was conducted at the same time as the telerehabilitation assessment (concurrent assessment), with the second examiner in the same location as the participant to observe and record the 6MWT administered by the telerehabilitation examiner. This approach enabled a direct comparison between the two assessment types, as both examiners assessed the same occasion with the telerehabilitation examiner taking an active role and the face-to-face examiner a passive role.

For the second face-to-face approach, the assessment was conducted in hospital on the same day, at least 30 minutes either-side of the telerehabilitation assessment (separate assessment). During this face-to-face assessment, the examiner was physically

present to supervise the testing session and actively led the participant through all functional tests in line with recommended guidelines.^{13,18,20} The same walking aids and footwear were used for both telerehabilitation and face-to-face assessments.

Statistics: Analyses were performed using IBM SPSS Statistics 22 (SPSS Inc., Chicago, IL). Descriptive analyses of clinical variables were undertaken. Data were presented as means (standard deviations, SD) and counts (percentages) as appropriate. Data were also checked for missing values, distribution (with Q-Q plots and Kolmogorov-Smirnov test for normality), and outliers. Using the minimal clinically important difference of 36m reported for the 6MWT²⁴ and SD from our previous study,¹⁴ we estimated a sample size requirement of 17 pairs to achieve a power of 90%, at 5% significance level and considering a 10% drop-out rate.

Validity of the telerehabilitation assessment was initially determined using paired t-tests between telerehabilitation and the concurrent face-to-face assessment. Validity was then determined using limits of agreement statistics as described by Bland and Altman,²⁵ between telerehabilitation and the separate face-to-face assessment. The clinically acceptable limit for each functional test was determined prior to study recruitment: the 6MWD was 36m,²⁴ the TUGT was 5 seconds according to previously reported intra- and inter-rater reliability,¹³ and grip strength was 6.5kg.²⁶ Limits of agreement which fell within the minimal clinically important difference were considered as valid and acceptable for each outcome measure.²⁵ Validity of the telerehabilitation assessment was also established by comparing telerehabilitation with the separate face-to-face assessment, using mean difference of the assessments, paired t-tests and intra-class correlation coefficient (ICC_{1,1}).

The inter- and intra-rater reliability of telerehabilitation assessments was examined using ICC.²⁷ Inter-rater reliability was determined by a second examiner independently analysing the video-recordings captured from the original telerehabilitation assessment and results were analysed using ICC_{2,1}. Intra-rater reliability was determined by the original examiner re-analysing the videos after a six week waiting period in line with previous research,³ and was analysed using ICC_{1,1}. The strength of the reliability was interpreted using recommended guidelines, where fair was defined as scores of greater than 0.7 and excellent as greater than 0.9.²⁸ Significance level for all analysis was set at 0.05.

RESULTS

Of the 17 participants, 88% were male, with a mean age of 69 (range 39 to 87) years. Sixty-five percent had ischaemic cardiomyopathy and 88% were New York Heart Association (NYHA) functional class II. Table 1 summarises participant characteristics and Table 2 presents the means and SD of functional tests.

Validity

When comparing telerehabilitation with the concurrent face-to-face assessment, there were no significant differences between the two assessment types for all three functional tests ($p>0.05$).

When comparing telerehabilitation with the separate face-to-face assessment, Figure 1 illustrates the mean difference and limits of agreement for all three functional tests.

There was also no significant difference on the 6MWD between telerehabilitation and

face-to-face assessments when the tests were conducted on two separate occasions, with a mean difference (95% CI) of 4 (-25 to 17) metres. The values found in our study are compared with previous research on repeated 6MWTs using the traditional face-to-face approach (Table 3). There was no significant difference on the TUGT time between telerehabilitation and face-to-face assessments when the tests were conducted on two separate occasions, with a mean difference (95% CI) of 0.24 (-0.56 to 1.03) seconds. There were also no significant differences for grip strength between telerehabilitation and face-to-face assessments ($p>0.05$). There was no significant time effect on the 6MWT and the TUGT ($p>0.05$). Validity of the telerehabilitation assessment was fair to excellent, with an ICC of between 0.85 and 0.96 (refer to Table 4).

Inter- and intra-rater reliability

As illustrated in Table 4, inter- and intra-rater reliabilities of all three functional tests were excellent in patients with CHF, with an ICC of greater than 0.95.

Patient satisfaction and adverse events

The mean (SD) system usability scale total score was 85 (15) out of 100. As shown in Table 5, some incidences of internet drop-outs, auditory fading, audio feedback, video freezing and transmission delays were observed. There were two incidences of angina experienced during the telerehabilitation assessment, but these were resolved with rest and anginine, and did not require further medical attention.

DISCUSSION

To our knowledge, this is the first study to investigate the use of telerehabilitation assessment in determining functional exercise capacity in patients with CHF. More specifically, our study confirmed the validity and reliability of using telehealth to administer the TUGT and grip strength in this group of patients with CHF.

Preliminary evidence supports the validity and reliability of telerehabilitation assessment for the 6MWT. These findings resonate with previous research, where telerehabilitation assessments were valid and reliable when compared with face-to-face assessments in other patient populations.^{4,6} For example in patients with cystic fibrosis,⁶ there were no significant differences in oxygen saturation, heart rate and rate of perceived exertion between telerehabilitation and face-to-face assessments for the three minute step test.

When determining the validity of telerehabilitation assessment, our results found no significant differences between telerehabilitation and face-to-face assessments for all three functional tests, when the tests were conducted on the same occasion. Similar results were confirmed for testing on separate occasions. Our study also demonstrated fair to excellent ICC between telerehabilitation and face-to-face assessments for all three functional tests, however the limits of agreement results were mixed. The limits of agreement for the TUGT and grip strength were within the clinically acceptable levels, suggesting that for these tests, the telerehabilitation assessments were of acceptable accuracy. In contrast, the limits of agreement for the 6MWT were wide and outside of the clinically acceptable level. This may be partly explained by a large SD of the difference reported in our study, which may reflect a difference between two separate testing occasions, rather than true a difference in assessment types. This SD is consistent with other studies,^{22,23} which also reported a

learning effect and large SD in repeated 6MWT using the face-to-face approach (refer to Table 4).

To note, a few participants experienced technical difficulties during the telerehabilitation assessment, including loss of connectivity, prolonged delay in data transmission, video freezing and audio fading. Despite these technical difficulties, patient satisfaction with telerehabilitation assessment remained high and most study participants found the system easy to use, in line with previous research.^{4,6}

Telerehabilitation assessment may improve access; reduce travel time and cost; and reduce waiting times for specialised services such as cardiac rehabilitation programs, thereby addressing current shortcomings imposed by living in such a geographically challenging country such as Australia.²⁹ These potential benefits may also have a positive impact on patient satisfaction.

Clinical considerations

Telerehabilitation assessments appear to be feasible in patients with CHF. However there are different etiquettes for this type of assessment. For instance, as there is no direct patient contact during the assessment, the clinician needs to provide clear and concise instructions and take turns when speaking.³⁰ Although there were no serious adverse events encountered during the assessment, careful patient selection and a protocol for management of adverse events are recommended. As such, we only invited patients with stable CHF to participate in the study and observed exercise testing contraindications in line with recommended standards.³¹

Telerehabilitation assessment may best be suited for patients with some experience with using telerehabilitation technologies, such as those who have completed a telerehabilitation exercise program. Functional exercise capacity assessments could be undertaken via telehealth and relevant questionnaires returned via e-mail to evaluate the outcome of an exercise program immediately after program completion as well as during the follow-up period. There are a few possible options for measuring grip strength. For example, there are low-cost hand dynamometers which may be loaned to the patient at home and returned later via the post. However this approach will need further validation. Alternatively, some small regional health centres and general practices may have access to a dynamometer which can enable the grip strength test to be undertaken in-person face-to-face.

Study strengths and limitations

This study is strengthened by the use of low-cost technologies and functional tests instead of maximum exercise stress tests, as these are the tests which are commonly used in the hospital clinics, community settings and may be more amenable to the home environment. There was a range of disease severity and aetiology amongst participants, which increases the generalisability of our results. Limitations include a small sample size and recruitment bias where participants who agreed to undertake this innovative assessment mode may be more favourable towards the telerehabilitation assessment. Moreover our participants had previous experience with the functional tests having previously completed a telerehabilitation program. Novice participants may have different results. As there was no precedence with using telerehabilitation to assess functional capacity in patients with CHF, we chose a conservative approach of conducting the assessments within the hospital environment.

More specifically, the participant and the examiner were located in separate areas, but were in close enough proximity to offer support if required. This support could have inflated the participant's confidence with the telerehabilitation assessment. A limitation associated with a low-cost solution was that the participants were required to manually report the vital signs and potentially increase patient demand during multitasking.

Directions for future research

Future studies should adopt a large sample size and examine the feasibility of conducting telerehabilitation assessment within the home. Bluetooth technology and wireless headphones may also be trialled to minimise the participant demand and reduce audio feedback. With advances of new technologies and faster internet access, new videoconferencing software may alleviate some of the technical difficulties encountered in this study, but will need further validation. A clinician questionnaire may also be useful in determining the examiner's experience with the telerehabilitation assessment.

CONCLUSION

This study achieved its aim of determining the validity and reliability of assessing functional exercise capacity using telehealth in patients with CHF. The limits of agreement for telerehabilitation assessments were within the clinically acceptable limits for the TUGT and grip strength, but outside of the limits for the 6MWT. There were strong associations between telerehabilitation and face-to-face assessments. Results also showed that the telerehabilitation assessment had excellent inter- and intra-rater reliabilities for the 6MWT, the TUGT and grip strength. Some incidences

of connectivity and audiovisual difficulties were encountered. The use of video-based telerehabilitation assessment appears promising in patients with CHF.

ACKNOWLEDGEMENTS

The authors would like to thank Dr Anne Bernard for statistical advice; Gretta Palmer, Carly Turner, Sharyn Furze and Maureen Peasey for assistance with data collection; and the staff and patients of the heart failure services at participating hospitals for support with the study.

DECLARATION OF CONFLICTING INTERESTS

The authors declare that there is no conflict of interest.

FUNDING ACKNOWLEDGEMENT

The primary author is a recipient of the Heart Foundation Health Professional Scholarship (ID: 100297).

GUARANTOR AND STATEMENT OF CONTRIBUTORSHIP

RH conceived and designed the study, collected and analysed the data, and drafted the manuscript. AM, NM, DK and TR were consulted on study design and statistical analysis and edited the draft manuscript. All authors reviewed and approved the manuscript.

Table 1. Participant characteristics

Characteristics	Total
	(n=17)
Age (years), mean (SD)	69 (12)
Men, n (%)	15 (88)
BMI (kg/m ²), mean (SD)	31 (5)
Ethnicity, n (%)	
Caucasian	15 (88)
Other	2 (12)
Aetiology, n (%)	
Ischaemic cardiomyopathy	11 (65)
Idiopathic cardiomyopathy	3 (18)
Heart failure with preserved ejection fraction, n (%)	3 (18)
LVEF (%), mean (SD)	34 (14)
Co-morbidities, n (%)	
Atrial arrhythmia in past 5 years	8 (47)
Diabetes mellitus	10 (59)
COPD or asthma	2 (12)
Arthritis	3 (18)
NYHA, n (%)	
I	1 (6)
II	15 (88)
III	1 (6)
IV	0
Walking aid, n (%)	

Characteristics	Total
	(n=17)
None	15 (88)
Stick	2 (12)
Experienced at least one fall in last 3 months, n (%)	2 (12)

Abbreviations: BMI, body mass index; COPD, chronic obstructive pulmonary disease; LVEF, left ventricular ejection fraction; n, number; NYHA, New York Heart Association scale; SD, standard deviation.

Table 2. Means and standard deviations for functional tests

Functional exercise tests	Telerehabilitation Examiner 1 (n=17)	Face-to-face Examiner 2 (n=9)	Face-to-face Examiner 1 (n=17)	Telerehabilitation Examiner 2 (n=17)	Telerehabilitation Examiner 1 after 6 weeks (n=17)
6MWD (metres), mean (SD)	369 (91)	369 (71)	373 (83)	368 (91)	369 (91)
TUGT (seconds), mean (SD)	9.16 (2.73)	8.79 (2.07)	8.92 (2.82)	9.25 (2.95)	9.09 (2.90)
Right best grip strength (kilograms),	30.1 (9.7)	31.7 (10.8)	30.0 (8.7)	30.1 (9.7)	30.1 (9.7)

Functional exercise tests	Telerehabilitation Examiner 1 (n=17)	Face-to-face Examiner 2 (n=9)	Face-to-face Examiner 1 (n=17)	Telerehabilitation Examiner 2 (n=17)	Telerehabilitation Examiner 1 after 6 weeks (n=17)
mean (SD)					
Left best grip strength (kilograms), mean (SD)	27.5 (10.5)	29.1 (11.6)	27.3 (9.1)	27.5 (10.5)	27.5 (10.5)

Abbreviations: 6MWD, six minute walk test distance; n, number; SD, standard deviation; TUGT, timed up and go test.

Table 3. Validity comparison of the 6 minute walk test with previous research

Study	Assessment types	Mean difference in 6MWD (SD)	Limits of agreement	
			Lower limit	Upper limit
Current study	Within-day difference between telerehabilitation & separate face-to-face 6MWD in heart failure	-4.29 (40.72)	-84.10	75.52
Adsett et al. (2011)*	Within-day test-retest difference in face-to-face 6MWD in heart failure	11.84 (31.08)	-49.08	72.76
Bellet et al. (2011)	Test-retest 6MWD in cardiac rehabilitation	15.8 (28)	-39	70.6

Abbreviations: 6MWD, six minute walk test distance; SD, standard deviation.

*calculation performed using additional data from the authors.

Table 4. Validity and reliability

Functional exercise tests	Validity ICC _{1,1}	Inter-rater reliability ICC _{2,1}	Intra-rater reliability ICC _{1,1}
6MWD, ICC (95% CI)	0.90 (0.74-0.96)	> 0.99	> 0.99
TUGT, ICC (95% CI)	0.85 (0.64-0.94)	0.95 (0.86-0.98)	0.96 (0.90-0.99)
Right best grip strength, ICC (95% CI)	0.94 (0.84-0.98)	> 0.99	> 0.99
Left best grip strength, ICC (95% CI)	0.96 (0.89-0.98)	> 0.99	> 0.99

Abbreviations: 6MWD, six minute walk test distance; 95% CI, 95% confidence interval; ICC, intra-class correlation; n, number; TUGT, timed up and go test.

Table 5. Technical issues

Technical issues	Number of participants encountering this technical issue (n=17)	Total number of incidences encountered (n=36)	Problem-solving approach used
No issues, n (%)	6 (35)		
Internet drop-outs, n (%)	5 (29)	15 (42)	Internet re-connections
Auditory clarity difficulties, n (%)	2 (12)	2 (6)	Repeated conversations
Visual clarity difficulties - freezing and delays with transmissions, n (%)	4 (24)	19 (53)	Video-conferencing system rebooting and reliance on audio communication.

Abbreviations: 6MWD, six minute walk test distance; n, number.

Figure 1. Bland and Altman plots of the difference against the mean of telerehabilitation and separate face-to-face assessments

----- Black dash lines represent mean difference, upper and lower limits between two assessment types.

..... Red dotted lines represent clinically acceptable limits.

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