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Development and validation of a predictive model for early functional recovery in the post-hip fracture surgery population

Shumei Tan[1], BPhysio(Hons), MSc, Jing Wen Foong[1], BSc, MSc, Jia Wen Kam[2], BSc, MSc, Chia Wen Samantha Foo[1], BSc(Hons), MSc, Kai Xuan Kiyoko Ong[1], BSc, MPH

[1]Rehabilitative Services, [2]Clinical Trials and Research Unit, Changi General Hospital, Singapore

Correspondence: Ms Tan Shumei, Office of Value-Driven Care, Singapore Health Services, 10 Hospital Boulevard, Singapore 168582. tan.shumei@gmail.com

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INTRODUCTION

With a growing ageing population, the incidence of hip fractures and the consequent burden of care are expected to increase.[1,2] To cope with this, effective discharge planning from the acute setting will be paramount. Functional recovery is pertinent to facilitate discharge planning for the elderly population following hip fracture surgery. At present, there is a lack of prognostication studies that can offer insights into functional recovery to guide discharge planning in the acute setting. Our study aimed to identify and analyse pre- and postoperative day (POD) one factors in order to develop and validate a predictive model that can prognosticate functional recovery during the early acute stage (i.e. POD 4). This time frame was chosen, as it is usually when most patients are discharged from the acute setting.

METHODS

This prospective study was conducted at Changi General Hospital (CGH), a public tertiary hospital that admits approximately 500 patients with hip fracture each year. A two-stage recruitment was performed for patients with hip fracture who underwent surgical management. The first-stage recruitment (April 2016 to September 2016) formed the derivation cohort, while the second-stage recruitment (January 2017 to May 2017) formed the validation cohort. Inclusion criteria were patients aged 65–100 years old and who were allowed to weight-bear as tolerated over their operated limb on POD 1. The exclusion criteria are listed in Fig. 1. All the patients received standardised care in accordance with the hospital's Hip Fracture Clinical Pathway. This comprised early surgery, adequate pain management, ortho-geriatric review, early mobilisation on POD 1 (including a physiotherapy review), and early discharge planning coordinated by the hip fracture specialty nurse. The study protocol was approved by the Centralised Institutional Review Board (CIRB), SingHealth, Singapore (CIRB reference number: 2016/2136).

	Derivation cohort	Validation cohort
Assessed for eligibility	**n = 240**	**n = 197**
Excluded patients	**n = 109**	**n = 78**
• Age < 65 yr	18	16
• Age > 100 yr	-	2
• Non-weight bearing	35	21
• Toe-touch weight bearing	1	2
• Partial weight bearing	22	21
• Non-ambulatory premorbid	5	3
• Multiple fractures	14	8
• Pathological fracture	2	2
• Periprosthetic fracture	7	-
• Premorbid or new onset of neurological and/or musculoskeletal deficits limiting ambulation	5	3
Drop Outs	**n = 10**	**n = 14**
Care deviated from CGH Hip Fracture Clinical Pathway		
• Missed POD 1 therapy review	3	2
• Not allowed mobilisation on POD 1	4	8
• Underwent abdominal surgery	1	1
• Transferred to another hospital	-	1
Missing POD 4 measures • Discharged on POD 2	2	2
Patients included for univariate analysis	**n = 121**	**n = 105**

Abbreviations: CGH: Changi General Hospital; POD: postoperative day

Fig. 1 Flow diagram shows the patient selection process for univariate analysis.

For the derivation cohort, 12 variables across six categories were collected from the patients' clinical records to be assessed as potential predictive variables (Table 1). These categories (demographic data, premorbid function, comorbidities, cognition, injury/operative factors and POD 1 function) were chosen based on similar categories that had been investigated by previous studies conducted in the acute setting for this population.[3-6]

On POD 4, functional recovery was determined using data pertaining to the patient's ambulation ability (level of assistance, type of walking aid and distance). The data was retrieved from the physiotherapy clinical records. If no therapy was provided on POD 4, data from the POD 3 therapy session was used. Based on the data, patients were categorised into two groups: 'good recovery' (GR) or 'poor recovery' (PR). GR was defined as the ability to ambulate with at least a walking frame over a distance of 20 m or more, and with minimal or less assistance. Non-achievers formed the PR group. The definition for GR was derived based on the feasibility of goal attainment in this population and also with consideration that this definition was realistic for home discharge.

Univariate and multivariate (blackbox model) analyses were performed for all variables to determine the possible significant factors present between the two groups. Blackbox model was used to determine the best performance of the potential predictors. Significant factors with $p < 0.05$ were selected for the predictive model. Receiver operating characteristics (ROC) curve analysis for the significant factors and comparison of the area under the curve (AUC) value were performed with the blackbox model. Through a further multivariate analysis, we obtained the adjusted odds ratio of the selected significant factors to derive a weighted score for the predictive model. Correspondingly, ROC curve analysis was performed on the weighted predictive model to assess its diagnostic performance. Youden's index was used to determine the optimal cut-off value that distinguished between the GR and PR groups. Lastly, modifications to the weighted predictive model were done to optimise the statistical values and ease of clinical application. All statistical analyses were conducted using IBM SPSS Statistics version 19.0 (IBM Corp, Armonk, NY, USA), and the significance level was determined at $p < 0.05$.

RESULTS

Out of 240 patients who were assessed for eligibility, 121 patients were included in the derivation analysis (Fig. 1). The mean age of the recruited patients was 81.1 ± 7.7 years and 87 (71.9%) patients were female. 62 (51.2%) patients had good premorbid function, as indicated by a 6–9 New Mobility Score (NMS). 77 (63.6%) patients were classified as having neck of femur (NOF) fracture, while 72 (59.5%) received arthroplasty for surgical fixation of their hip fracture. 41 (33.9%) patients fulfilled the criteria for the GR group and the remaining 80 (66.1%) patients formed the PR group.

Through univariate analysis, eight variables were found to be significant between the groups (Table I). Results of the blackbox model is presented in Table II. This model yielded an AUC value of 0.88 (95% confidence interval [CI] 0.81–0.94). Significant factors between the two groups were premorbid NMS of 6–9, ≤ 3 comorbidities, and ability to stand on POD 1 with minimal, standby or no assistance ($p < 0.05$). These three factors were selected for the predictive model and remained significant in the multivariate analysis ($p < 0.05$; Table II). ROC curve analysis of this predictive model yielded an AUC value of 0.84 (95% CI 0.77–0.91), which was similar to the results from the blackbox model ($p = 0.068$).

Table I. Results of univariate analysis of predictive factors for POD 4 functional recovery.

Factor	No. (%)		Univariate analysis	
	Poor recovery (n = 80)	Good recovery (n = 41)	OR (95% CI)	p-value
Age (yr)				
< 85	48 (59.3)	33 (40.7)	1.00	0.023*
≥ 85	32 (80.0)	8 (20.0)	0.36 (0.15–0.89)	
Gender				
Male	24 (70.6)	10 (29.4)	0.75 (0.32–1.78)	0.516
Female	56 (64.4)	31 (35.6)	1.00	
Race				
Chinese	64 (66.0)	33 (34.0)	1.03 (0.40–2.66)	0.949
Non-Chinese	16 (66.7)	8 (33.3)	1.00	
Malay	11 (61.1)	7 (38.9)	1.29 (0.46–3.63)	0.627
Non-Malay	69 (67.0)	34 (33.0)	1.00	
Pre-morbid NMS				
0–5	50 (84.7)	9 (15.3)	1.00	0.000*
6–9	30 (48.4)	32 (51.6)	5.93 (2.49–14.10)	
No. of comorbidities† (n = 120)				
≤ 3	22 (43.1)	29 (56.9)	6.95 (2.97–16.26)	0.000*
> 3	58 (84.1)	11 (15.9)	1.00	
ASA score				
1–2	10 (41.7)	14 (58.3)	3.63 (1.44–9.15)	0.005*
3–4	70 (72.2)	27 (27.8)	1.00	
Presence of dementia				
Present	34 (89.5)	4 (10.5)	1.00	0.000*
Absent	46 (55.4)	37 (44.6)	6.84 (2.23–21.01)	
AMT score† (n = 111)				
< 7	39 (81.2)	9 (18.8)	1.00	0.003*
≥ 7	34 (54.0)	29 (46.0)	3.70 (1.54–8.89)	
Type of hip fracture				
Neck of femur	48 (66.1)	29 (37.7)	1.61 (0.72–3.61)	0.245
Others	32 (72.7)	12 (27.3)	1.00	
Type of surgical fixation				
Arthroplasty	47 (65.3)	25 (34.7)	1.10 (0.51–2.37)	0.813
Others	33 (67.3)	16 (32.7)	1.00	
POD 1 Hb value† (g/DL) (n = 120)				
< 10	40 (78.4)	11 (21.6)	1.00	0.012*
≥ 10	39 (56.5)	30 (43.5)	2.80 (1.23–6.35)	
Able to stand on POD 1 with minimal, standby or no assistance				
No	52 (82.5)	11 (17.5)	1.00	0.000*
Yes	28 (48.3)	30 (51.7)	5.07 (2.21–11.61)	

*Indicates significant p-value. †Indicates some missing data; number of valid cases are shown in brackets. AMT: Abbreviated Mental Test; ASA: American Society of Anaesthesiologists; CI: confidence interval; Hb: haemoglobin; NMS: New Mobility Score; OR: odds ratio; POD: postoperative day

Table II. Results of multivariate analyses of predictive factors for POD 4 functional recovery.

Factor	Blackbox model		Predictive model	
	OR (95% CI)	p-value	OR (95% CI)	p-value
Age (yr)				
< 85	1.00	0.466		
≥ 85	1.59 (0.46–5.53)	0.466		
Gender				
Male	0.42 (0.12–1.46)	0.172		
Female	1.00			
Race				
Chinese	5.05 (0.39–64.74)	0.306		
Non-Chinese	1.00			
Malay	9.98 (0.60–164.97)	0.132		
Non-Malay	1.00			
Premorbid NMS				
0–5	1.00	0.008*	1.00	0.002*
6–9	4.93 (1.51–16.13)		4.83 (1.78–13.13)	
No. of comorbidities† (n = 120)				
≤ 3	6.55 (2.23–19.28)	0.001*	5.80 (2.27–14.83)	0.000*
> 3	1.00		1.00	
Presence of dementia				
Present	1.00	0.265		
Absent	2.34 (0.52–10.48)			
Type of surgical fixation				
Arthroplasty	0.36 (0.11–1.17)	0.09		
Others	1.00			
POD 1 Hb value† (g/DL) (n = 120)				
< 10	1.00	0.125		
≥ 10	2.39 (0.79–7.24)			
Able to stand on POD 1 with minimal, standby or no assistance				
No	1.00	0.040*	1.00	0.018*
Yes	3.11 (1.05–9.21)		3.17 (1.22–8.21)	

*Indicates significant p-value. †Indicates some missing data; number of valid cases are shown in brackets. CI: confidence interval; Hb: haemoglobin; NMS: New Mobility Score; OR: odds ratio; POD: postoperative day

For the development of the weighted scoring model, a total of 120 patients who had complete data for the three selected factors were included for the analysis. Weighted scoring was derived based on the adjusted odd ratios of these three factors. The AUC value of the weighted predictive scoring model was retained at 0.84 (95% CI 0.77–0.91). The optimal cut-off score as determined by Youden's index was 7.5. The resultant initial model had a positive predictive value (PPV) of 59.3% and a negative predictive value (NPV) of 91.8%. Based on clinical and statistical considerations, modifications were done to derive a final model (Fig. 2). This was a three-tier scoring model in which patients who attained all three factors (top tier) were more likely to achieve GR with a PPV of 72.7%. Patients who attained none or one factor (lowest tier) were more likely to have PR with an NPV of 91.8%. The remaining patients (attaining two factors – intermediate tier) formed the third group whose early functional recovery could not be predicted by the model (NPV: 48.6%, PPV: 51.4%). The sensitivity and specificity of this model were 40.0% and 70.0%, respectively.

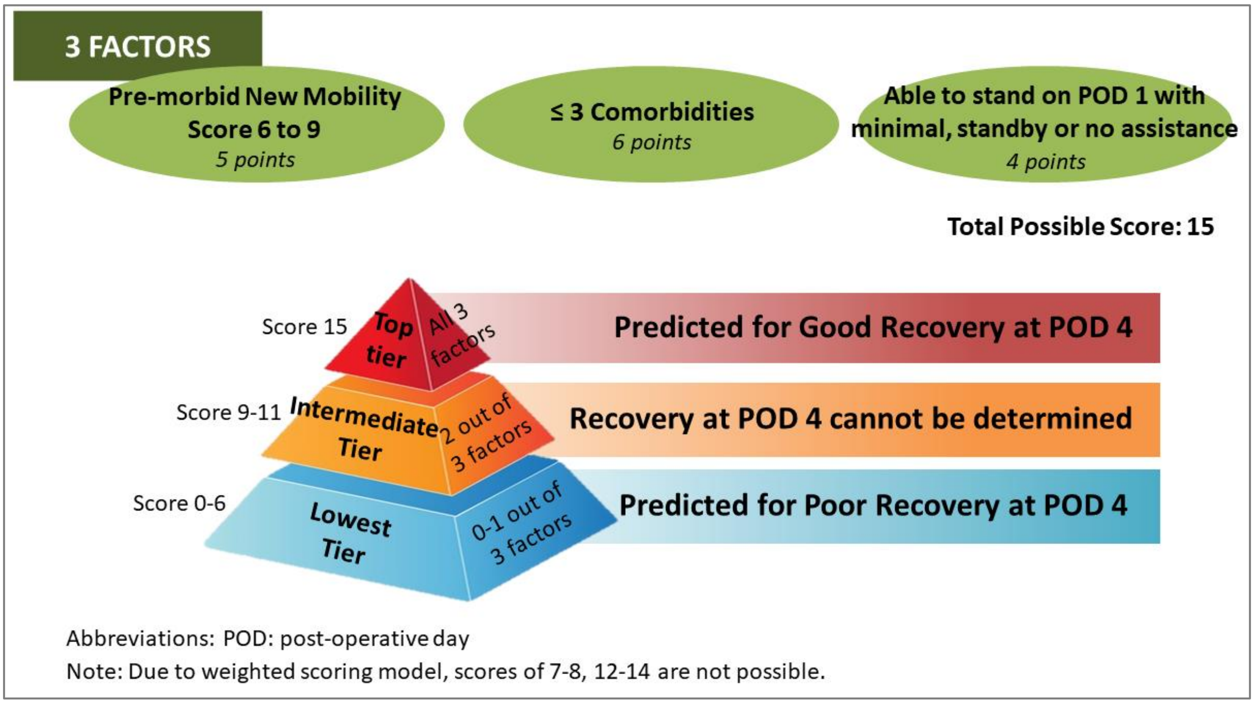

Fig. 2 Diagram shows the overview of the final predictive model.

For the second stage recruitment, 197 patients were assessed for eligibility and 105 patients were included in the validation analysis (Fig. 1). The validation cohort had similar characteristics (age, gender, premorbid function, type of fracture/surgery) as the derivation cohort ($p > 0.005$). 31 (29.5%) patients formed the GR group, while 74 (70.5%) formed the PR group. The scoring model was successfully validated with a PPV of 73.3% and an NPV of

86.1%. The sensitivity was 35.5% and the specificity was 71.6%. It maintained a good AUC value of 0.79 (95% CI 0.69–0.88).

DISCUSSION

This study successfully developed a predictive model to prognosticate early functional recovery in the fragility hip fracture patient population. Previous prognostication studies conducted for this population were mostly carried out for time frames beyond the first month.[7-14] For the small numbers of studies that assessed functional recovery at time frames which were within a month, there were limitations in their application to facilitate discharge planning in the local context. Two of these studies had reviewed prognosticative factors for hip fracture patients who successfully attained ambulation on POD 2 and POD 3, respectively.[3,4] For these studies, the attainment of ambulation comprised patients who needed maximal assistance to those who did not require assistance (full independence). This definition does not provide useful application to facilitate discharge planning, as patients should at least be ambulating with minimal assistance to enable carers to better manage them at home. Two other studies had assessed the prognosticative factors for recovery of independence in basic mobility at the two-week time frame following surgery.[5,6] While this definition of functional recovery is useful in facilitating discharge planning, the two-week time frame is considered too long in the local context, as most hip fracture patients are discharged from the acute setting within one week of surgery. Overall, the development of the predictive model in this study addresses these limitations.

The model was modified to a three-tier model and the scoring was simplified for ease of application in the clinical setting. Prognostication into the GR and PR groups is possible for the top tier and lowest tier with a prediction accuracy of 73.3% and 86.1%, respectively. The top and lowest tiers constitute approximately 70% of the derivation and validation cohorts, indicating that the majority patients can be prognosticated via this model. With the ability to predict early functional status, key clinical implications can be derived.

Firstly, functional recovery is a key milestone for this patient population following surgery. The model identified three factors to be considered for prognostication: premorbid NMS, number of comorbidities and ability to stand on POD 1. This will enable the multi-disciplinary team to advise patients and families on the likely trajectory of functional recovery following surgery. Discussions with patients and families can be initiated as early as the preoperative phase (if the patient fulfils neither of the two preoperative factors) or by POD 1.

Secondly, the model could facilitate discharge planning for this population. It identifies patients who would likely have GR, which is a functional status that is manageable for home discharge. Patients who are prognosticated to have PR in the early acute stage should be considered for further rehabilitation at the appropriate subacute stepdown care facility. Prognostication would be done latest by POD 1, maintaining timeliness for discharge planning. As this model has higher NPV and specificity values than PPV and sensitivity values, it implies greater accuracy in predicting PR and a low false-positive for patients who indeed exhibit PR. Conversely, the model correctly predicted only 35.5% of GR patients due to its low sensitivity. Some GR patients had a false-negative score and were classified as the intermediate tier (38.7%) or lowest tier (25.8%). Nevertheless, this model accurately predicted 73.3% of patients in the top tier as having GR, and this information is useful to identify patients who can be considered for home discharge. Undoubtedly, suitability for discharge from acute care involves considerations such as medical fitness, functional recovery, home situation and availability of carer. This model provides pertinent input specifically on functional recovery. The definition of GR included patients who needed minimal assistance. This was a deliberate decision, as it has been observed that too few patients in this population were able to regain independence in the early acute stage, which would consequently make it impossible to develop a predictive model. This, however, implies that patients with GR must have a suitable carer in order to be considered for home discharge. Furthermore, some patients may need to negotiate stairs in their home environment, but the ability for stair climbing is not accounted for in the model. All in all, clinicians will need to weigh these considerations and adapt the application of this model according to a patient's individual situation to facilitate discharge planning.

Lastly, with the stratification of patients to the different tiers of functional recovery, clinical resources can be allocated accordingly with clear objectives. For example, for patients prognosticated to have GR and who opt for home discharge, training to equip family members to care for the patient on discharge can be initiated early to minimise delay in discharge. If patients who are prognosticated for PR have opted for home discharge, they may require additional and intensified therapy sessions to optimise their function for home discharge.

This study is not without limitations. Firstly, the model was not able to prognosticate patients in the intermediate tier, which was approximately 30% of the study cohort. Stratifying an intermediate tier may reflect the actual clinical scenario, where prognostication of early functional recovery for this subgroup of patients is not possible. It may also be possible that their outcomes are linked to other clinical factors, which are not captured in this study. A relevant reference is the Risk Assessment and Prediction Tool (RAPT), which utilises the same three-tier stratification model.(15) Under RAPT, the highest and lowest tiers of patients can be accurately predicted for home discharge and further step-down rehabilitation, respectively. Similarly, RAPT has an intermediate tier in which prognostication was initially not possible. A subsequent study demonstrated that targeted and more intensive postoperative physiotherapy could alter the outcome of the intermediate group towards home discharge (i.e. change towards good outcome).(16) While it is acknowledged that the patient population evaluated in this study is different from that of RAPT (hip fracture surgery vs. elective arthroplasty), it does highlight the possible areas for future research. If the intermediate tier can be successfully prognosticated in future studies, the sensitivity and specificity values of this model may improve.

Secondly, the predictive values of this model may change in a different healthcare setting if the prevalence rates of GR/PR differ significantly from the study cohort. RAPT likely had a similar issue when it was first developed, as the prevalence of home discharge is likely to vary in different healthcare settings. Nevertheless, it has been shown that RAPT can be successfully revalidated and still retain good predictive values in different settings.[17] Future research from the current study should similarly strive for a larger sample size and across different healthcare settings to strengthen the validation of the model.

In conclusion, this study developed and validated a predictive model that prognosticated early functional recovery for the fragility hip fracture population. It identified three factors to be considered for prognostication: premorbid NMS, number of comorbidities and ability to stand on POD 1. Using this model, clinicians are able to predict a patient's POD 4 ambulation status by POD 1, which would provide valuable insights to guide clinical practice and discharge planning.

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REFERENCES

1. Gullberg B, Johnell O, Kanis JA. World-wide projections for hip fracture. Osteoporos Int 1997; 7:407-13.
2. Cheung CL, Ang SB, Chadha M, et al. An updated hip fracture projection in Asia: the Asian Federation of Osteoporosis Societies study. Osteoporos Sarcopenia 2018; 4:16-21.
3. Barone A, Giusti A, Pizzonia M, et al. Factors associated with an immediate weight-bearing and early ambulation program for older adults after hip fracture repair. Arch Phys Med Rehabil 2009; 90:1495-8.
4. Foss NB, Kristensen MT, Kehlet H. Anaemia impedes functional mobility after hip fracture surgery. Age Ageing 2008; 37:173-8.
5. Kristensen MT, Foss NB, Ekdahl C, Kehlet H. Prefracture functional level evaluated by the New Mobility Score predicts in-hospital outcome after hip fracture surgery. Acta Orthop 2010; 81:296-302.
6. Duke RG, Keating JL. An investigation of factors predictive of independence in transfers and ambulation after hip fracture. Arch Phys Med Rehabil 2002; 83:158-64.
7. Kristensen MT. Factors affecting functional prognosis of patients with hip fracture. Eur J Phys Rehabil Med 2011; 47:257-64.
8. Hagino T, Sato E, Tonotsuka H, et al. Prediction of ambulation prognosis in the elderly after hip fracture. Int Orthop 2006; 30:315-9.
9. Hirose J, Ide J, Yakushiji T, et al. Prediction of postoperative ambulatory status 1 year after hip fracture surgery. Arch Phys Med Rehabil 2010; 91:67-72.
10. Kim JL, Jung JS, Kim SJ. Prediction of ambulatory status after hip fracture surgery in patients over 60 years old. Ann Rehabil Med 2016; 40:666-74.

11. Lee D, Jo JY, Jung JS, Kim SJ. Prognostic factors predicting early recovery of pre-fracture functional mobility in elderly patients with hip fracture. Ann Rehabil Med 2014; 38:827-35.

12. Shyu YIL, Chen MC, Liang J, Wu CC, Su JY. Predictors of functional recovery for hip fractured elders during 12 months following hospital discharge: a prospective study on a Taiwanese sample. Osteoporos Int 2004; 15:475-82.

13. Salpakoski A, Törmäkangas T, Edgren J, et al. Walking recovery after a hip fracture: a prospective follow-up study among community-dwelling over 60-year old men and women. Biomed Res Int 2014; 2014:289549.

14. Samuelsson B, Hedström MI, Ponzer S, et al. Gender differences and cognitive aspects on functional outcome after hip fracture--a 2 years' follow-up of 2,134 patients. Age Ageing 2009; 38:686-92.

15. Oldmeadow LB, McBurney H, Robertson VJ. Predicting risk of extended inpatient rehabilitation after hip or knee arthroplasty. J Arthroplasty 2003; 18:775-9.

16. Oldmeadow LB, McBurney H, Robertson VJ, Kimmel L, Elliott B. Targeted postoperative care improves discharge outcome after hip or knee arthroplasty. Arch Phys Med Rehabil 2004; 85:1424-7.

17. Sconza C, Respizzi S, Grappiolo G, Monticone M. The Risk Assessment and Prediction Tool (RAPT) after hip and knee replacement: a systematic review. Joints 2019; 7:41-5.