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Original Article

Predicting prolonged length of hospital stay in older emergency department users: Use of a novel analysis method, the Artificial Neural Network

C.P. Launay [a], H. Rivière [a], A. Kabeshova [a], O. Beauchet [a,b,c,*]

[a] Department of Neuroscience, Division of Geriatric Medicine, UPRES EA 4638, UNAM, Angers University Hospital, Angers, France
[b] Department of Medicine, Division of Geriatrics, Jewish General Hospital, McGill University, Montreal, Canada
[c] Biomathics, Paris, France

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ABSTRACT

Objective: To examine performance criteria (i.e., sensitivity, specificity, positive predictive value [PPV], negative predictive value [NPV], likelihood ratios [LR], area under receiver operating characteristic curve [AUROC]) of a 10-item brief geriatric assessment (BGA) for the prediction of prolonged length hospital stay (LHS) in older patients hospitalized in acute care wards after an emergency department (ED) visit, using artificial neural networks (ANNs); and to describe the contribution of each BGA item to the predictive accuracy using the AUROC value.

Methods: A total of 993 geriatric ED users admitted to acute care wards were included in this prospective cohort study. Age > 85 years, gender male, polypharmacy, non use of formal and/or informal home-help services, history of falls, temporal disorientation, place of living, reasons and nature for ED admission, and use of psychoactive drugs composed the 10 items of BGA and were recorded at the ED admission. The prolonged LHS was defined as the top third of LHS. The ANNs were conducted using two feeds forward (multilayer perceptron [MLP] and modified MLP).

Results: The best performance was reported with the modified MLP involving the 10 items (sensitivity = 62.7%; specificity = 96.6%; PPV = 87.1; NPV = 87.5; positive LR = 18.2; AUC = 90.5). In this model, presence of chronic conditions had the highest contributions (51.3%) in AUROC value.

Conclusions: The 10-item BGA appears to accurately predict prolonged LHS, using the ANN MLP method, showing the best criteria performance ever reported until now. Presence of chronic conditions was the main contributor for the predictive accuracy.

1. Introduction

Prolonged length of hospital stay (LHS) in acute care wards is a growing adverse outcome in geriatric inpatients, especially in the oldest ones (i.e., aged 80 years and over) hospitalized after an emergency department (ED) visit [1–4]. Prolonged LHS has been associated with greater prevalence of in-hospital morbidity and mortality and increased health expenditures, explaining why previous studies attempted to develop screening tools to identify older inpatients at risk of prolonged LHS [5–7]. Interest in these screening tools is rising because they could be useful to target resources and interventions for vulnerable older ED users [7–10].

Recently, a simple screening tool called "6-item brief geriatric assessment" (BGA) has been developed and proved to be easily usable in clinical routine by non-geriatricians [5,6,10]. Whereas items and their combinations were associated with a greater risk of prolonged LHS, their prognostic value remained limited [5]. Such inconclusive result could be, partly, related to the linear statistical models used to predict prolonged LHS. Indeed, prolonged LHS results from a complex interplay between multiple health and socio-environmental factors [1–9]. Thus, LHS may be considered as a "chaotic" event (i.e., an inherent unpredictable event in a complex system). Until now, prediction of prolonged LHS was exclusively based on linear statistical models, which are not adapted to chaotic events [11,12]. In contrast, artificial neural networks (ANNs) are adapted statistical models to analyze data for the prediction of chaotic events [11–14]. ANNs have already been used for the identification of the several adverse health events [13,14]. To the best of our knowledge, no study has used ANNs yet to predict prolonged LHS.

The low number of the items included in the 6-item BGA and age criteria selection above 74 years could also explain the inconclusive previous results. Indeed, it has been reported that the likelihood of prolonged LHS increased with the number of risk factors [10,15], and

Abbreviations: ANNS, artificial neural networks; AUROC, area under receiver operating characteristic curve; BGA, brief geriatric assessment; ED, emergency department; LHS, length hospital stay; LR, likelihood ratios; MLP, multilayer perceptron; NPV, negative predictive value; PPV, positive predictive value.

* Corresponding author at: Department of Neuroscience, Division of Geriatric Medicine, Angers University Hospital, 49933 Angers cedex 9, France. Tel.: +33 2 41 35 45 27; fax: +33 2 41 35 48 94.
E-mail address: olbeauchet@chu-angers.fr (O. Beauchet).

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that oldest patients (i.e., aged 80 years and over) had a higher risk of prolonged LHS [1–4,10,15]. In general, screening tools do not exceed 10 items [16].

We thus hypothesized that increasing the number of items of the BGA from 6 to 10 and selecting ED users age 80 and over, together with using ANNs, could improve the accuracy and criteria performance (i.e., sensitivity, specificity, positive predictive value [PPV], negative predictive value [NPV], likelihood ratios of positive [LR+] and negative [LR−] tests, area under receiver operating characteristic curve [AUROC]) of BGA for the prediction of prolonged LHS. The study aims 1) to examine performance criteria of a 10-item BGA for the prediction of prolonged LHS using ANNs in geriatric inpatients hospitalized in acute care wards after an ED visit; and 2) to describe the contribution of each BGA item to the predictive accuracy using the AUROC value.

2. Materials and methods

2.1. Participants

In 2012, based on a prospective observational cohort design, 1254 participants were consecutively recruited upon their hospitalization from ED in Angers University Hospital, France. The study procedure of recruitment has been previously described in detail [5]. The inclusion criteria for the present analysis were: hospitalization in acute care wards after an ED visit, age of 80 years and over, and willingness to participate in research. In final, a set of 933 (74.4%) older inpatients was selected for this analysis.

2.2. Assessment of participants

The 6-item BGA was performed upon the ED admission. It was composed of the following items: age > 85 years, gender male, polypharmacy, defined as ≥5 drugs per day; non use of formal and/or informal home-help services), history of falls in previous 6 months and temporal disorientation defined as the inability to give the month and/or year. All items were coded as a binary variable (yes versus no). In addition to 6-item BGA, the living arrangement (i.e., home versus institution) and the reasons for ED admission were also recorded. Reasons for ED admission were categorized using two complementary approaches. First, we differentiated acute organ failure versus non-acute organ failure. Then, we specified the nature of the acute organ failure in four subgroups based on the prevalence of related diseases in the sample of participants: cardio-vascular diseases, respiratory diseases, digestive diseases, neuropsychiatric diseases and other acute diseases [5]. The use of psychoactive drugs including benzodiazepines, antidepressants or neuroleptics, was also noted. We chose these additional items because they have been associated with prolonged LHS. First, because hospitalization in acute care may provoke disabilities, living at home compared to living in institution may be an obstacle to an early hospital discharge [5,6,17]. Second, use of psychoactive drugs may be a marker of neuropsychiatric disorders, which have been associated with the delay of hospital discharge [5,18–20]. Third, it has been recently reported that organ failure and reasons of ED admission may also influence the delay of discharge [6,20].

2.3. Outcome measure

The LHS was calculated using the administrative registry of the University Hospital and corresponded to number of days between ED admission and the last day of hospitalization on acute care medical wards. Prolonged LHS was defined as being in the top third of LHS, which corresponded to 13 days and more in the studied sample.

2.4. Standard protocol approvals, registrations, and participant consents

The study was conducted in accordance with the ethical standards set forth in the Helsinki Declaration (1983). All participants recruited in this study provided a verbal informed consent because the study did not change the usual clinical practice. The verbal informed consent was obtained from the patients themselves in the presence of their trusted person, usually a family member, who helped them to make decision. The participant consent was recorded in the digital file of patients. The entire study protocol and the consent procedure were approved by the Ethical Committee of Angers, France.

2.5. Statistical analysis

Two feeds forward ANNs were used: multilayer perceptron (MLP) and modified MLP [21].

The "*neuralnet: Training of neural networks*" R package was used for MLP [22]. In addition, we developed an algorithm to find the best MLP architecture [23]. This algorithm identified a modified MLP with 4 layers: one input layer, 2 hidden layers and one output layer. Nodes from one layer are connected to all nodes in the following layer, but there were no lateral connections within layer. The output layer comprised one neuron, indicating the presence or absence of prolonged LHS. A total of 10 input neurons corresponding to items of 6-item BGA plus living arrangement, use of psychoactive drugs, reasons for admission, presence or not of an acute organ failure were used.

To perform ANNs analysis, the sample of participants was randomized in two subgroups (i.e., a training group and a testing group). Between-group comparisons were performed using Pearson's chi-squared test with Yates' continuity correction. Performance criteria were: sensitivity, specificity, PPV, NPV, LR+, LR−, and AUROC). Absolute value and relative proportion (expressed in percent) of each BGA item in predictive accuracy measured with AUROC were also calculated. All statistics were performed using R 3.1.0 and NetBeansIDE 8.0.

3. Results

The baseline characteristics and prevalence of each BGA item are shown in Table 1. Those characteristics are similar in the training and the testing groups. LHS was average 8.8 ± 8.4 days for training group and 9.2 ± 7.5 days for testing group without significant difference between groups ($P = 0.242$). The outcome, prolonged LHS, was between 21.6% and 24.9% of the cohort. A total of 61 patients (6.14%) died during hospitalization. They were older than those who did not die but this difference was not significant (mean age ± standard deviation, 88.0 ± 4.6 years versus 87.0 ± 4.6 with $P = 0.106$), and there were a tendency of fewer women in this group of patients (49.2% female versus 62.1% male) with $P = 0.056$. In addition, they had a significant longer LHS compared to those who did not die (11.6 ± 9.4 days versus 8.7 ± 8.2 days with $P = 0.021$). There was not significant difference between training and testing for in-hospital mortality ($P = 0.278$).

In terms of the ANN methods, predictive criteria performance depended on the number of items and the type of ANNs used. The best predictive performance being reported with modified MLP was the one including all 10 items (Table 2). For this 10-item modified MLP model, sensitivity (62.7%), specificity (96.6%), PPV (87.1), NPV (87.5), LR+ (18.2) and AUROC (90.5) had the highest values. The AUROC of previous 6-item BGA was also calculated and was 58.1.

Absolute and relative contributions of each item in predictive accuracy measured with AUC using modified MLP are described in Fig. 1.This figure shows that the contribution of each category of items (i.e., demographics, chronic conditions, acute conditions, and living arrangement) changed with the number of items introduced in the model. In 10-item modified MLP, chronic conditions had the highest contribution (51.3%) followed by demographics (21.6%), environment (13.7%) and acute conditions (13.4%).