ESC European Society of Cardiology

European Heart Journal - Digital Health (2024) **00**, 1–9
https://doi.org/10.1093/ehjdh/ztae089

ORIGINAL ARTICLE
Telehealth, remote monitoring and -consultations

Early discharge programme after transcatheter aortic valve implantation based on close follow-up supported by telemonitoring using artificial intelligence: the TeleTAVI study

Marta Herrero-Brocal[1], Raquel Samper [1], Jorge Riquelme[2], Javier Pineda[1], Pascual Bordes[1], Fernando Torres-Mezcua[1], José Valencia[1], Francisco Torres-Saura[1], María González Manso[2], Raquel Ajo[1], Juan Arenas[3], Eloísa Feliu[3], Juan Gabriel Martínez[1], and Juan Miguel Ruiz-Nodar[1,4,*]

[1]Cardiology Department, Dr Balmis General University Hospital, Alicante Institute for Health and Biomedical Research (ISABIAL), C/Maestro Alonso s/n, Alicante 03010, Spain; [2]Tucuvi Care SL, C. de Hermosilla, Madrid 28001, Spain; [3]Radiology Department, Dr Balmis General University Hospital, Alicante, Spain; and [4]Department of Clinical Medicine, Miguel Hernandez University, Ctra. Alicante-Valencia N 332, Sant Joan D'Alacant, Alicante 03550, Spain

Received 20 July 2024; revised 29 September 2024; accepted 14 October 2024; online publish-ahead-of-print 20 November 2024

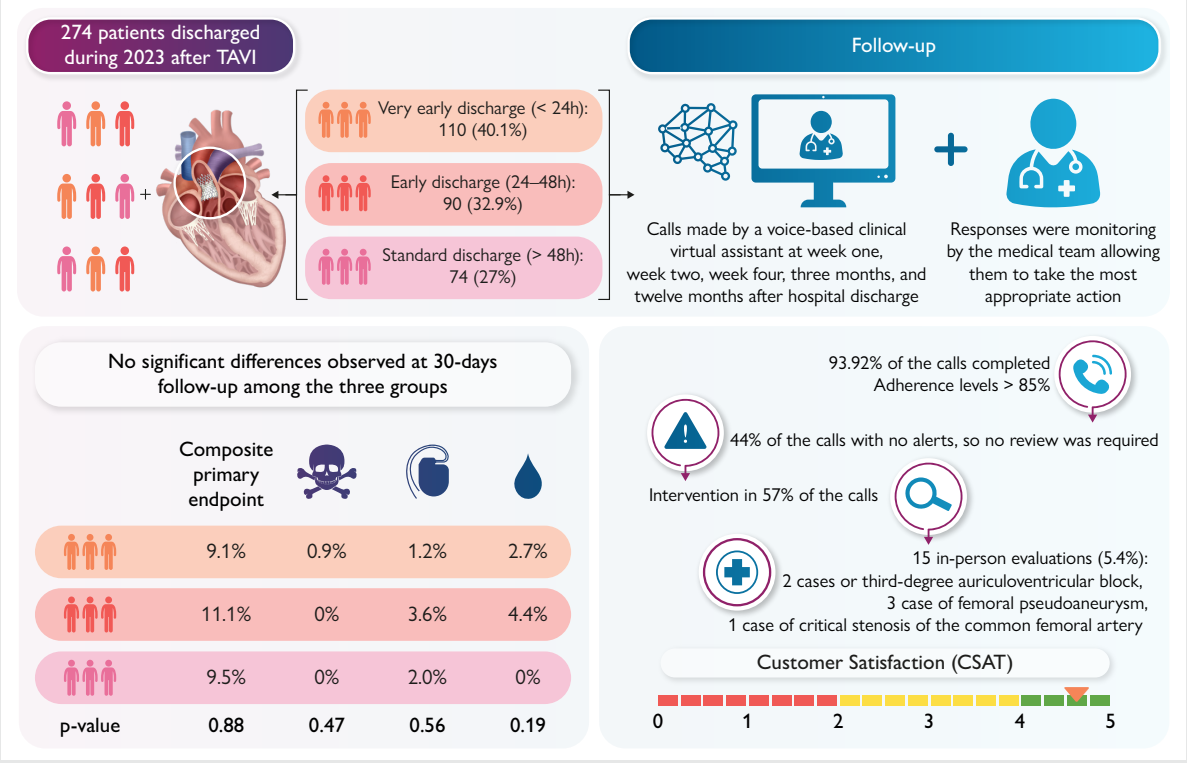
Aims Evidence regarding the safety of early discharge following transcatheter aortic valve implantation (TAVI) is limited. The aim of this study was to evaluate the safety of very early (<24) and early discharge (24–48 h) as compared to standard discharge (>48 h), supported by the implementation of a voice-based virtual assistant using artificial intelligence (AI) and natural language processing.

Methods and results Single-arm prospective observational study that included consecutive patients who underwent TAVI in a tertiary hospital in 2023 and were discharged under an AI follow-up programme. Primary endpoint was a composite of death, pacemaker implantation, readmission for heart failure, stroke, acute myocardial infarction, major vascular complications, or major bleeding, at 30-day follow-up. A total of 274 patients were included. 110 (40.1%) patients were discharged very early (<24 h), 90 (32.9%) early (24–48 h), and 74 (27.0%) were discharged after 48 h. At 30-day follow-up, no significant differences were found among patients discharged very early, early, and those discharged after 48 h for the primary endpoint (very early 9.1% vs. early 11.1% vs. standard 9.5%; $P = 0.88$). The AI platform detected complications that could be effectively addressed. The implementation of this follow-up system was simple and satisfactory for TAVI patients.

Conclusion Early and very early discharge in patients undergoing TAVI, supported by close follow-up using AI, were shown to be safe. Patients with early and very early discharge had similar 30-day event rates compared to those with longer hospital stays. The AI system contributed to the early detection and resolution of complications.

* Corresponding author. Tel: +34965933565, Email: ruiz_jmi@gva.es

Graphical Abstract



Keywords Transcatheter aortic valve implantation (TAVI) • Early discharge • Artificial intelligence (AI) • Telemedicine • Post-discharge monitoring • Complication detection

Introduction

Transcatheter aortic valve implantation (TAVI) has become the treatment of choice for patients with severe aortic stenosis who are at high, intermediate, and low surgical risk.[1,2] The increasing aging population and current guideline recommendations have significantly expanded the number of potential candidates for TAVI, a trend that is expected to grow exponentially in a short future.[2,3] Improvements in both TAVI device design and implantation techniques have led to an increasingly minimalist approach, enabling a significant reduction in procedure-related morbidity and mortality rates.[3,4] This has brought the early discharge strategy into focus, allowing for more efficient use of available resources and improving patient functionality and quality of life.[3–10] Nevertheless, the safety and efficacy of this strategy have not yet been fully established, as available published data are based mostly on single-centre experiences.[3–10] To date, guidelines and consensus documents have not yet provided a recommendation regarding the optimal hospital stay duration following TAVI. Several studies have shown that early discharge (within 72 h after TAVI) is safe, with low rates of complications.[3–10] However, the number of patients discharged early in the aforementioned studies notably ranged from 17 to 59%.[3,8–10] Of note, the main limiting factor for early discharge in all studies was the new-onset conduction disturbances and the consequent risk for pacemaker (PM) implantation.[4,11,12] Despite this, no significant differences in mortality rates, need for PM implantation, or readmissions were found between patients discharged early and those undergoing standard discharge.[3–10] In the *multicentre PROTECT TAVR* study, the safety of same-day discharge post-TAVI was demonstrated in highly selected patients at low risk for postoperative conduction disease and vascular complications.[13] Against this background, telemedicine has the potential to provide an effective and safe alternative for monitoring patients undergoing TAVI, facilitating early detection of complications, and enabling the identification of those patients who might need a prompt in-person assessment. This approach has the potential to reduce the need for in-person consultations and readmissions, thereby alleviating the burden on healthcare systems.[14,15]

Notwithstanding, to date, no evidence regarding the impact of AI and telemedicine on the follow-up of patients after TAVI is available. Therefore, the aim of this study was to evaluate the safety of very early (<24 h) and early (24–48 h) hospital discharge after TAVI, supported by the implementation of a voice-based virtual assistant based on artificial intelligence (AI) and natural language processing (NLP).

Methods

Study design

This observational, prospective, single-centre study involved consecutive patients who underwent TAVI in 2023 at a tertiary hospital and were discharged with the support of a voice-based virtual assistant for patient follow-up to facilitate early or very early discharge. Such AI voice-based

virtual assistant was the Tucuvi Health Manager technology (Tucuvi Care SL, Spain), a certified class I medical device platform under Directive 93/42/EEC ('MDD'), based on AI and NLP, which automates patient follow-up at home by talking to them through autonomous phone calls. This virtual assistant, called 'Lola,' automates communication with patients through pre-scheduled phone calls, without the need for device installation or internet access. The phone calls are based on structured questionnaires, referred to as protocols, which consist of clinically validated conversational flows (questions). The virtual assistant engages in conversations with patients using NLP algorithms. Alerts can be pre-programmed with three levels of severity based on the patient's responses. After the call ends, the information is collected, structured, and provided to the responsible team via a web platform with an accuracy of 100%. More detailed information about the AI and NLP technology is provided in the Supplementary material online.

In our investigation, Tucuvi Health Manager was configured to assist during the post-discharge period following TAVI, with a focus on patient's cardiovascular condition and vascular access (Supplementary material online, *Figure S1*). Calls were scheduled by the researchers at Week 1, Week 2, Week 4, 3 months, and 12 months after hospital discharge. A certain series of alerts were pre-determined by the medical team. Such alerts were classified as severe, moderate, and mild, and were defined as follows:

(1) Severe: dizziness, syncope, or need for emergency department visit or hospitalization.
(2) Moderate: general well-being alterations, major wound complications such as active bleeding or haematoma, symptoms of heart failure such as dyspnoea or oedema, other symptoms such as chest pain or fever, and inadequate medication adherence.
(3) Mild: minor wound complications such as pain, pus, or wound reopening.

Based on these alerts, the physician could take the most appropriate action. When alerts were triggered, the first action taken, in most cases, was a phone call made by the medical or nursing team. If the alert was confirmed as valid through this call, the healthcare team proceeded as they deemed appropriate: schedule an in-person visit, adjust medication, order a blood test, request an ultrasound or electrocardiogram (ECG), refer the patient to another specialist or to emergency services, or admit the patient to the hospital.

The Ethics Committee approved the study protocol, and all eligible patients provided written informed consent before being enrolled. Prior to hospital discharge, patients were provided with a schedule of calls including information on the date and time, along with a questionnaire containing the items that would be asked during the follow-up.

Study population

All patients discharged after percutaneous TAVI in the Cardiology Department of the Dr Balmis General University Hospital during 2023 were consecutively enrolled in the study. Exclusion criteria were as follows: non-transfemoral TAVI, lack of own telephone, and inability to speak Spanish (either the patient or a family member/caregiver). Included patients were stratified in three groups: very early discharge, defined as occurring within 24 h after TAVI; early discharge, 24–48 h after TAVI; and standard discharge, >48 h (*Figure 1*).

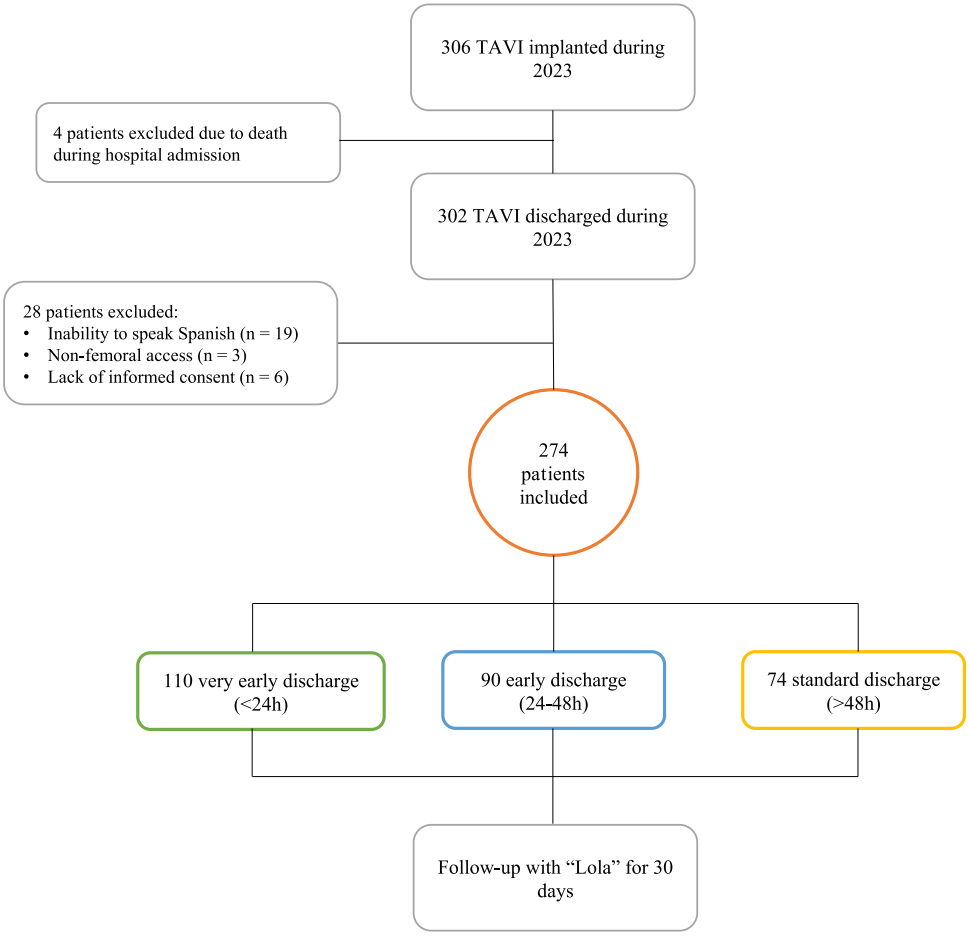


Figure 1 Patient flow.

Data collection and follow-up

Data were collected from the patient's medical history, including demographic and clinical information such as prior diseases, usual treatments, presence of symptoms, results of complementary tests (blood tests, ECG, echocardiogram, and computed tomography scan), and details related to the characteristics of the procedure, medical treatment, and in-hospital events.

After TAVI, the duration of the hospital stay was established according to a pre-defined protocol:

(1) Very early discharge (<24 h): patients with a PM or basal QRS <120 ms, without changes after TAVI or with transient QRS widening in the absence of complications during continuous monitoring; and who did not present major vascular complications, significant echocardiogram findings, or significant clinical or analytical alterations.
(2) Early discharge (24–48 h): patients with QRS >120 ms (basal or new onset) in the absence of the previously described complications or if minor complications were solved.
(3) Standard discharge: patients with advanced conduction disorders after TAVI or during continuous monitoring that required PM implantation, as well as those who presented major vascular complications, significant echocardiogram findings, or significant clinical or analytical alterations.

Events during the 30-day clinical follow-up after hospital discharge were collected by the voice-based virtual assistant and supervised by healthcare professionals. If a patient did not respond to the call (up to six attempts were made over two consecutive days), had visited the emergency room, or had been hospitalized, the patient's electronic medical record was reviewed and/or the patient was contacted. Patient satisfaction with the virtual assistant was assessed using the Customer Satisfaction Score (CSAT), ease of use using the Customer Effort Score (CES), and the likelihood of recommending the system using the Net Promoter Score (NPS).

Study outcomes

The primary endpoint was the composite of all-cause mortality, need for PM implantation, readmission for heart failure, stroke, acute myocardial infarction, major vascular complications, and/or major bleeding according to the Bleeding Academic Research Consortium (BARC ≥ 3a) classification[16] at 30-day follow-up.

Secondary endpoints included the individual components of the composite primary endpoint and patient satisfaction with the implementation of the virtual assistant.

Statistical analysis

Categorical variables were expressed as frequencies (percentages). The comparison of categorical variables was performed using the χ^2 test. The Kolmogorov–Smirnov test was used to determine if continuous variables followed a normal distribution. Quantitative or continuous variables were expressed as mean (± standard deviation) if normally distributed or as median [interquartile range (IQR) or 95% confidence intervals] if non-parametric. The comparison of groups for continuous variables was performed using the ANOVA test for unpaired data and the Kruskal–Wallis test if they were not normally distributed. A *P*-value of <0.05 was considered statistically significant for all analyses. Statistical analysis was performed using the SPSS statistical software package (SPSS Inc., Chicago, IL).

Results

A total of 302 patients were initially screened. Nineteen were excluded due to an inability to speak Spanish, three due to undergoing non-femoral TAVI, and six due to lack of informed consent. Excluded patients were referred to their clinical cardiologists for follow-up after TAVI implantation. Two hundred and seventy-four patients met all the inclusion criteria and none of the exclusion criteria and were finally included. Regarding the timing of discharge, 110 (40.1%) patients were discharged very early, 90 (32.9%) early, and 74 (27%) at the standard time. The mean length of stay for the entire cohort was 2.64 ± 3.64 days, with a median of 2 days (IQR 1–3).

Baseline characteristics

Baseline characteristics of included patients are shown in *Table 1*. The median age was 81 years (IQR 77–84), and approximately half of the patients (49.3%) were female. No significant differences were observed between patients discharged very early, early, or at the standard time in terms of prior diseases, baseline treatments, severity of valvular disease, and patients' frailty (Clinical Frailty Score). However, patients undergoing very early discharge had a significant higher rate of previous PM implantation. Conversely, patients undergoing standard discharge had a longer average baseline QRS interval (very early 104.75 ± 24.17 ms vs. early 111.90 ± 27.35 ms vs. standard 115.22 ± 25.68 ms; $P = 0.02$), mainly due to a higher prevalence of complete right bundle branch block (RBBB) (very early 4.5% vs. early 15.6% vs. standard 29.7%; $P < 0.001$). In addition, a higher rate of baseline complete left bundle branch abnormality (LBBB) was observed in patients discharged early (very early 4.5% vs. early 17.8% vs. standard 6.8%; $P = 0.004$). No differences were found in the average duration of the PR segment or in the prevalence of first- or second-degree atrioventricular block among groups.

Procedural characteristics and complications

Regarding procedural characteristics (*Table 2*), no significant differences were found among groups in the urgency of the procedure, valve size used, or implant depth. In the ECG performed 2 h post-TAVI, both PR segment and QRS interval widening were observed in all groups, with a smaller increase in the very early discharge patients. A lower incidence of periprocedural complications was observed in patients undergoing very early discharge, such as new onset of LBBB (very early 23.8% vs. early 58.1% vs. standard 34.7%; $P = 0.001$), third-degree AV block (very early 0% vs. early 3.3% vs. standard 23%; $P < 0.001$), bleeding according to the BARC ≥3a scale (very early 0% vs. early 1.1% vs. standard 13.5%; $P < 0.001$), and major vascular complications (very early 5.5% vs. early 2.2% vs. standard 21.6%; $P < 0.001$). No significant differences were observed in the rates of stroke, acute myocardial infarction, or cardiac tamponade.

In-hospital clinical outcomes

After TAVI, a lower rate of complications was also observed in the very early discharge group: new onset of LBBB (very early 5.7% vs. early 43.2% vs. standard 23.2%; $P < 0.001$); PM implantation (very early 0% vs. early 7.8% vs. standard 32.3%; $P < 0.001$); bleeding according to the BARC ≥3a scale (very early 0.9% vs. early 2.2% vs. standard 20.3%; $P < 0.001$); and major vascular complications (very early 0% vs. early 1.1% vs. standard 14.9%; $P < 0.001$). No significant differences were observed for the remaining outcomes among groups (*Table 3*). The differences found during the procedure in QRS interval duration persisted, with no differences in the PR segment. Additionally, no significant differences were found in the medical treatment prescribed at discharge.

Remote monitoring

A total of 1039 calls were made using the virtual assistant, with a total of 385 h of automated conversation. Of these calls, 93.92% were completed, with adherence levels consistently above 85%. The average call duration was 4 min and 3 s. The majority of the calls were answered by the patients themselves (89%), with only 11% being answered by family members or caregivers. In 44% of the calls, no alerts were detected, so no review was required. From the remaining calls, a total of 926 alerts were obtained, being the most common cause dizziness ($n = 231$; 24.9%), contact with emergency services ($n = 105$; 11.3%), and general condition alteration ($n = 97$; 10.4%) (see Supplementary material online, *Figure S2A*). A total of 436 alerts were classified as severe (47.08%), 418 as moderate (45.14%), and 72 as mild (7.78%). These alerts prompted at least one intervention in 57% of the calls, with the most common being medical contact (51.3%), nursing contact (31.4%), and medication adjustment

Table 1 Baseline characteristics

		Patient group according to type of discharge			
	Overall[a]	Very early[a]	Early[a]	Standard[a]	*P*
Number (%)	274 (100.0)	110 (40.1)	90 (32.9)	74 (27.0)	
Age (years), median (IQR)	81 (77–84)	80 (77–83)	82 (76–86)	81 (76–84)	0.94
Women	135 (49.3)	52 (47.3)	47 (52.2)	36 (48.6)	0.77
CFS, mean ± SD	3.27 ± 1.25	3.21 ± 1.15	3.19 ± 1.26	3.45 ± 1.37	0.35
Cardiovascular risk factors					
Hypertension	219 (79.9)	85 (77.3)	68 (75.6)	66 (89.2)	0.06
Diabetes mellitus	110 (40.1)	43 (39.1)	28 (31.1)	39 (52.7)	0.01
Dyslipidaemia	174 (63.5)	60 (54.5)	62 (68.9)	52 (70.3)	0.04
BMI (kg/m^2), mean ± SD	27.34 ± 4.32	27.82 ± 4.46	26.54 ± 3.98	27.64 ± 4.46	0.09
Smoking	20 (7.3)	6 (5.5)	6 (6.7)	8 (10.8)	0.62
Medical history					
Coronary revascularization	74 (27.0)	33 (30.0)	19 (21.1)	22 (29.7)	0.30
Heart failure	108 (39.4)	38 (34.5)	38 (42.2)	32 (43.2)	0.39
Atrial fibrillation	91 (33.2)	33 (30.0)	29 (32.2)	29 (39.2)	0.41
Stroke	23 (8.4)	7 (6.4)	9 (10.0)	7 (9.5)	0.60
Peripheral arterial disease	31 (11.3)	12 (10.9)	10 (11.1)	9 (12.2)	0.96
Chronic kidney disease[b]	78 (28.4)	28 (25.5)	24 (26.6)	26 (35.1)	0.24
Previous pacemaker	27 (9.9)	24 (21.8)	0 (0)	3 (4.1)	<0.001
Dyspnoea (NYHA III–IV)	120 (43.8)	44 (40)	38 (42.2)	38 (51.4)	0.29
Baseline pharmacotherapy					
Beta-blockers	104 (38.0)	36 (32.7)	32 (35.6)	36 (48.6)	0.07
Acetylsalicylic acid	107 (39.1)	44 (40)	35 (38.9)	28 (37.8)	0.95
P2Y12 inhibitors	45 (16.4)	19 (17.3)	12 (13.3)	14 (18.9)	0.60
Oral anticoagulants	95 (34.8)	33 (30)	29 (32.2)	33 (44.6)	0.10
Diuretics	145 (52.9)	55 (50)	48 (53.3)	42 (56.8)	0.66
Baseline echocardiography					
LVEF (%), mean ± SD	63.35 ± 10.08	63.10 ± 9.47	63.10 ± 9.08	64.03 ± 12.01	0.79
Peak AVG (mmHg), mean ± SD	78.98 ± 20.45	77.72 ± 18.66	81.11 ± 20.85	78.31 ± 22.45	0.48
Mean AVG (mmHg), mean ± SD	49.95 ± 13.58	48.72 ± 12.13	50.91 ± 14.99	50.62 ± 13.87	0.46
Valve area (cm2), mean ± SD	0.72 ± 0.76	0.73 ± 0.15	0.75 ± 0.19	0.73 ± 0.15	0.74
Aortic insufficiency	125 (45.6)	49 (44.5)	46 (51.1)	30 (40.5)	0.38
Baseline ECG					
PR (ms), mean ± SD	186.41 ± 38.11	185.80 ± 29.06	186.27 ± 40.04	187.42 ± 46.42	0.96
First-/second-degree AV block	57 (20.8)	22 (20)	20 (22.2)	15 (20.3)	0.60
QRS (ms), mean ± SD	110.05 ± 25.98	104.75 ± 24.17	111.90 ± 27.35	115.22 ± 25.68	0.02
Complete RBBB	41 (15.0)	5 (4.5)	14 (15.6)	22 (29.7)	<0.001
Complete LBBB	26 (9.5)	5 (4.5)	16 (17.8)	5 (6.8)	0.004
Baseline blood tests					
Hb (g/dL), mean ± SD	12.77 ± 1.75	12.80 ± 1.71	12.68 ± 1.68	12.83 ± 1.89	0.84
Creatinine (g/dL), mean ± SD	1.22 ± 0.92	1.09 ± 0.34	1.30 ± 1.26	1.31 ± 1.02	0.17
eGFR (mL/min per 1.73 m^2), mean ± SD	59.38 ± 20.54	62.05 ± 18.38	59.54 ± 21.22	58.61 ± 24.17	0.66

AV, atrioventricular; AVG, aortic valve gradient; BMI, body mass index; CFS, Clinical Frailty Score; ECG, electrocardiogram; eGFR, estimated glomerular filtration rate; Hb, haemoglobin; LBBB, left bundle branch abnormality; LVEF, left ventricular ejection fraction; ms, milliseconds; NYHA, New York Heart Association; RBBB, right bundle branch block; SD, standard deviation.

[a]All variables are expressed as number (%) of patients unless otherwise indicated.

[b]eGFR < 60 mL/min per 1.73 m^2 according to the Chronic Kidney Disease Epidemiology Collaboration (CKD-EPI) equation.

(4.8%) (see Supplementary material online, *Figure S2B*). Following this contact, a total of 15 in-person evaluations were conducted (5.4% of the patients), detecting in two cases a third-degree AV block, in three cases femoral pseudoaneurysm, and in one case critical stenosis of the common femoral artery. The number of alerts, and consequently the number of interventions, decreased as the follow-up progressed, reflecting the need for closer monitoring in the early stages after the implant (see Supplementary material online, *Figure S3*).

Table 2 Characteristics and complications of transcatheter aortic valve implantation

		Patient group according to type of discharge			
	Overall[a]	Very early[a]	Early[a]	Standard[a]	*P*
Number (%)	274 (100.0)	110 (40.1)	90 (32.9)	74 (27.0)	
Urgent procedure	16 (5.8)	3 (2.7)	7 (7.8)	6 (8.1)	0.19
Valve size (mm), mean ± SD	26.34 ± 2.97	26.58 ± 3.05	25.82 ± 2.58	26.62 ± 3.22	0.12
Implant depth (mm), mean ± SD	5.02 ± 1.70	5.23 ± 1.83	4.78 ± 1.65	4.99 ± 1.53	0.17
Valve type					
Self-expandable	179 (65.3)	81 (73.6)	56 (62.2)	42 (56.8)	0.04
Balloon-expandable	95 (34.7)	29 (26.4)	34 (37.8)	32 (43.2)	
ECG after procedure					
PR (ms), mean ± SD	193.12 ± 39.24	190.48 ± 31.35	192.56 ± 41.24	198.86 ± 48.44	0.53
First-/second-degree AV block	60 (22.1)	20 (18.3)	26 (28.9)	14 (19.4)	<0.001
QRS (ms), mean ± SD	131.68 ± 27.46	120.51 ± 30.36	140.68 ± 22.23	136.25 ± 23.73	<0.001
Complete RBBB	27 (9.9)	4 (3.6)	11 (12.2)	12 (16.4)	0.01
Complete LBBB	118 (43.2)	30 (27.3)	59 (65.6)	29 (39.7)	<0.001
Peri-procedural complications					
De novo complete LBBB at 2 h	92 (37.1)	25 (23.8)	43 (58.1)	24 (34.7)	0.001
Third-degree AV block	20 (7.3)	0 (0)	3 (3.3)	17 (23.0)	<0.001
Stroke	1 (0.4)	0 (0)	0 (0)	1 (1.4)	0.25
BARC bleeding type ≥ 3a	11 (4.0)	0 (0)	1 (1.1)	10 (13.5)	<0.001
Acute myocardial infarction	0 (0)	0 (0)	0 (0)	0 (0)	—
Cardiac tamponade	0 (0)	0 (0)	1 (1.1)	0 (0)	0.35
Major vascular complications	24 (8.8)	6 (5.5)	2 (2.2)	16 (21.6)	<0.001

AV, atrioventricular; BARC, Bleeding Academic Research Consortium; ECG, electrocardiogram; LBBB, left bundle branch abnormality; ms, milliseconds; RBBB, right bundle branch block; SD, standard deviation.
[a]All variables are expressed as number (%) of patients unless otherwise indicated.

Thirty-day follow-up

The primary endpoint occurred in 9.9% of the patients, with no significant differences observed among the three groups (very early 9.1% vs. early 11.1% vs. standard 9.5%; $P = 0.88$). No significant differences were found among the three groups for the individual components of the primary endpoint, including the need for PM (very early discharge 1.2% vs. early discharge 3.6% vs. standard discharge 2.0%; $P = 0.56$). Only one death (0.4%) was reported at 30-day follow-up, which occurred in a patient allocated in the very early discharge group 19 days after the procedure. This patient had a prior PM implantation, and the death was classified as cardiovascular (*Table 4*).

Satisfaction surveys

The vast majority of patients (88.9%) reported to be satisfied or very satisfied (CSAT 4.68/5); 86.3% of them would recommend the virtual assistant, 'Lola', according to the 'NPS' scale. Additionally, 88% of patients rated the interaction with 'Lola' as very easy or easy (CES 1.31/5). Patients also believed that 'Lola' improved communication with their doctors, with the most prominent benefits being increased follow-up, enhanced communication with the hospital, and increased peace of mind (see Supplementary material online, *Figure S4*).

Discussion

The aim of the present investigation was to analyse an early discharge programme after TAVI supported by a strict follow-up system via phone calls guided by a conversational AI. The main findings of our study can be summarized as follows: (i) 73% of patients were discharged early (≤48 h) and 40.1% were discharged very early (<24 h); (ii) major cardiac events at 30-day follow-up were reassuring low with a mortality rate of only 0.4%; (iii) there were no significant differences in complications rates or the need for readmissions among patients discharged very early, early, or standard; (iv) the AI system detected serious complications that could be effectively addressed; and (v) this AI-based follow-up system was perceived as very simple and highly satisfactory among patients who had undergone TAVI.

The growing number of patients undergoing TAVI is generating a significant care burden on cardiology departments. Early discharge programmes should be a priority for implant centres to reduce bed occupancy and efficiently and safely discharge eligible patients. These programmes must prioritize patient safety and ensure follow-up care that is equivalent to or superior to that for patients with longer hospitalizations. The close automated telephone monitoring we present offers these characteristics. In our study, the vast majority of patients (73%) were able to be discharged very early (<24 h) or early (24–48 h), with a median stay of 2 days. These findings contrast with the existing literature, where several registries report a highly variable percentage of early discharge (usually defined as discharge within 72 h after TAVI), ranging from 17 to 58%.[3,8–10] Although the length of stay after TAVI can vary greatly, some current national registries describe a median stay of up to 6 days.[17] Its noteworthy to highlight the safety of early discharge observed in our investigation among patients who did not present in-hospital conduction system alterations and/or vascular

Table 3 Events, laboratory values, and electrocardiogram values at hospital discharge

		Patient group according to type of discharge			
	Overall[a]	Very early[a]	Early[a]	Standard[a]	*P*
Number (%)	274 (100.0)	110 (40.1)	90 (32.9)	74 (27.0)	
Length of stay (days), mean ± SD	2.64 ± 3.64	1 ± 1	2 ± 2	4.48 ± 7.20	
In-hospital complications					
De novo complete LBBB	54 (21.7)	6 (5.7)	32 (43.2)	16 (23.2)	<0.001
Pacemaker implant	30 (12.1)	0 (0)	7 (7.8)	23 (32.3)	<0.001
Stroke	0 (0)	0 (0)	0 (0)	0 (0)	—
BARC bleeding type ≥ 3a	18 (6.6)	1 (0.9)	2 (2.2)	15 (20.3)	<0.001
Acute myocardial infarction	0 (0)	0 (0)	0 (0)	0 (0)	—
Cardiac tamponade	0 (0)	0 (0)	0 (0)	0 (0)	—
Major vascular complications	12 (4.4)	0 (0)	1 (1.1)	11 (14.9)	<0.001
ECG on discharge					
PR (ms), mean ± SD	188.57 ± 38.86	185.13 ± 32.24	185.97 ± 36.87	197.53 ± 49.26	0.15
First- or second-degree AV block	62 (22.6)	21 (19.1)	23 (25.6)	18 (24.3)	0.34
QRS (ms), mean ± SD	126.33 ± 30.43	109.44 ± 26.73	136.83 ± 28.11	137.82 ± 27.14	<0.001
Complete RBBB	30 (11.0)	3 (2.7)	10 (11.1)	17 (23)	<0.001
Complete LBBB	80 (29.2)	11 (10)	48 (53.3)	21 (28.4)	0.001
Blood test at discharge					
Hb (g/dL), mean ± SD	11.47 ± 1.86	11.86 ± 1.89	11.52 ± 1.84	10.89 ± 1.71	0.003
Creatinine (g/dL), mean ± SD	1.19 ± 0.88	1.06 ± 0.34	1.38 ± 1.22	1.27 ± 0.90	0.14
eGFR (mL/min/1.73 m^2), mean ± SD	60.28 ± 20.99	62.06 ± 18.38	59.54 ± 21.22	58.61 ± 24.17	0.53
Pharmacotherapy at discharge					
Beta-blockers	109 (39.8)	41 (37.3)	30 (33.3)	38 (51.4)	0.05
Acetylsalicylic acid	173 (63.1)	75 (68.2)	56 (62.2)	42 (56.8)	0.28
P2Y12 inhibitors	47 (17.2)	20 (18.2)	14 (15.6)	13 (17.6)	0.88
Oral anticoagulants	95 (34.6)	33 (30)	30 (33.3)	32 (43.2)	0.17

AV, atrioventricular; BARC, Bleeding Academic Research Consortium; ECG, electrocardiogram; eGFR, estimated glomerular filtration rate; Hb, haemoglobin; LBBB, left bundle branch abnormality; ms, milliseconds; RBBB, right bundle branch block; SD, standard deviation.
[a]All variables are expressed as number (%) of patients unless otherwise indicated.

Table 4 Complications and mortality 30 days after transcatheter aortic valve implantation

		Patient group according to type of discharge			
	Overall[a]	Very early[a]	Early[a]	Standard[a]	*P*
Number (%)	274 (100.0)	110 (40.1)	90 (32.9)	74 (27.0)	
Composite primary endpoint	27 (9.9)	10 (9.1)	10 (11.1)	7 (9.5)	0.88
All-cause mortality	1 (0.4)	1 (0.9)	0 (0)	0 (0)	0.47
Pacemaker implant	5 (2.3)	1 (1.2)	3 (3.6)	1 (2.0)	0.56
Admission for heart failure	6 (2.2)	3 (2.7)	0 (0)	3 (4.1)	0.18
Stroke	1 (0.4)	0 (0)	1 (1.1)	0 (0)	0.35
Acute myocardial infarction	0 (0)	0 (0)	0 (0)	0 (0)	—
Major vascular complications	10 (3.6)	3 (2.7)	4 (4.4)	3 (4.1)	0.79
BARC bleeding type ≥ 3a	7 (2.6)	3 (2.7)	4 (4.4)	0 (0)	0.19

BARC, Bleeding Academic Research Consortium.
[a]All variables are expressed as number (%) of patients unless otherwise indicated.

complications. Key criteria for the very early discharge group include having a prior PM before TAVI or exhibiting a narrow QRS on the ECG 24 h post-implantation. Patients discharged early or very early experienced a very low rate of complications during the first month, similar to those with standard discharge, without requiring more admissions or interventions.

Other studies focusing on early discharge of patients after TAVI have demonstrated similar hospital discharge rates to those described

in our study, although with a lower rate of very early discharge. García-Carreño *et al.*[5] reported a 30.2% discharge rate at <24 h and 30.7% at 24–48 h, and Krishnaswamy *et al.*[6] have shown a 22.1% discharge rate at <24 h and 63.8% at 24–48 h. However, these studies advocated for early discharge with close follow-up through phone calls and/or in-person consultations, which require significant human and economic resources. In the *multicentre PROTECT TAVR*, all patients had either virtual or in-person follow-up visits on post-discharge Day 1 with median time to routine follow-up of 31 days.[13]

The novel and remarkable aspect of our study is the use of a voice-based virtual assistant for early follow-up as an alternative to in-person and/or phone consultations by the medical team. This support system has allowed us to implement this early discharge programme, ensuring close and direct contact with our patients from the early days after discharge. All patients were contacted by the virtual assistant within a week after TAVI, enabling early detection of puncture-related and general complications. Since this is an entirely novel system created by us, we are discovering areas of improvement. Initially, it was designed as a 'static' system with calls for all patients treated uniformly. However, the workflow for future patients could be further optimized by intensifying the follow-up with a greater number of calls or more frequent calls based on the timing of their discharge. This AI- and NLP-based technology is already known and applied in other conditions, mainly for the control and follow-up of patients with chronic diseases.[18] For the first time, we present a novel application of the software specifically developed and tested in our hospital with the aim of providing a safe and effective follow-up for patients undergoing TAVI. The configuration period allowed us to optimize the questionnaire and call cadence for optimal implementation in daily clinical practice.

Some important aspects of this investigation should be highlighted. First, this strategy is applicable to practically the entire TAVI population. In our cohort, 90.7% of patients were directed to robotized follow-up with 'Lola', with the primary exclusion criterion being non-Spanish speakers. While this aspect would not pose a limitation today (since 'Lola' supports over 100 different languages), we decided not to implement it as TeleTAVI was still in the investigational initial phase. Therefore, currently, only patients who refused this type of follow-up (six patients in our cohort) or those with alternative access, where early discharge is not an objective, would be excluded. Second, early resolution of alerts. Detection and resolution of alerts and problems are equally important. This system uploads all information onto a secure web platform after the phone contact. All alerts are reviewed by the haemodynamic unit staff and resolved quickly. Most actions involved medical team contact with the patient, nursing contact regarding the puncture wound, medication adjustments, and less frequently, ECGs or consultations with other specialties. Third, decrease in the number of alerts as follow-up progresses. This aspect reflects the need for close follow-up especially during the first weeks after TAVI. It is known that long-term follow-up of patients undergoing TAVI, 25% of major adverse events occur in the first month and approximately half (51.9%) during the first year,[19] making this period the most vulnerable. Fourth, very low need for human resources. This tool ensured strict follow-up of all our patients, with at least five calls during the first year. Almost half of these follow-ups required no action. Fifth, high degree of patient satisfaction. This aspect is crucial despite the elderly population (median 81 years; IQR 77–84) included. Nearly 90% of patients reported to be satisfied or very satisfied with this AI virtual follow-up and, 88% found interacting with 'Lola' to be easy or very easy. This was evidenced by a critical data point: 89% of calls were answered by the patients themselves and only 11% by family members or caregivers.

The low event rate at 30-day follow-up in our cohort, similar to rates described in other studies with standard discharge,[3–11] and the very low mortality in this period (0.4%) reflect the safety of our early discharge programme with the robotized follow-up employed.

Limitations

Several limitations have to be considered. First, this study is based on data from a single high-volume centre. Therefore, the results may not be generalizable to other centres with lower caseloads where TAVI programmes are not as established. Secondly, the sample size could potentially hamper the power of the analysis provided in terms of adverse event occurrence in the short-term follow-up. The lack of statistical difference between the three groups could potentially reflect the relatively small sample size. Thirdly, there is not control group to compare the follow-up method based on the voice-based virtual assistant with standard follow-up. Although there is extensive information in the literature that allows us to compare the data presented here with that described to date, a study using a matched control group with a contemporary cohort from another institution would further elucidate the role of this follow-up. Fourthly, although this system offers 100% accuracy in the transcription of the information, the overdetection or underdetection of symptoms has not been assessed. Our personal assessment is that with 'Lola', based on how we have configured the protocol, we tend to overdetect symptoms. A clear example is when asking patients about 'dizziness'. Given that this is an elderly population, a significant majority consistently respond 'yes' to the presence of dizziness. However, due to the severity of the potential consequences of this symptom, we believe it is necessary to overdetect it and then confirm through a phone call from the medical team whether that alert is valid and if further action is required. This is reflected in the fact that most interventions carried out by our team consist solely of phone contact, with other interventions (blood tests, in-person consultations, ECGs, etc.) being much less frequent. We believe that we cannot truly speak of underdetection since, as mentioned, our protocol is quite conservative in identifying symptoms. However, it is inevitable that, on occasion, complications may arise during periods without phone contact from 'Lola', particularly in cases of sudden complications such as atrioventricular block. Finally, this programme was only applied to patients who could speak Spanish, which was exclusively due to the nature of the research study.

Conclusions

This study demonstrates the feasibility and safety of early and very early discharge of patients after TAVI, supported by close follow-up through a voice-based virtual assistant based on AI. Patients with early and very early discharge had similar events at 30-day follow-up as compared to patients with longer discharge periods. This AI system contributed to the early detection of complications and their subsequent resolution.

Lead author biography

I am Dr Marta Herrero-Brocal, born on 2 October 1993, in Salinas, Alicante. I graduated with distinction in medicine from the Universidad Miguel Hernández, Elche, in 2017. I completed my cardiology residency at Dr Balmis General University Hospital, Alicante, and obtained a Master's in Advances in Cardiology from the Universidad Católica San Antonio, Murcia. Currently, I am a Fellow in Interventional Cardiology at Dr Balmis General University Hospital, Alicante. I actively contribute to academic research and teaching, having

published in esteemed cardiology journals and presented at numerous conferences. My dedication lies in advancing cardiovascular medicine through innovative research and clinical excellence.

Supplementary material

Supplementary material is available at *European Heart Journal – Digital Health*.

Author contribution

M.H.-B. and J.M.R.-N. conceived and designed the study. M.H.-B., J.M.R.-N., R.S., J.P., P.B., F.T.-M., J.V., F.T.-S., R.A., J.A., and E.F. participated in the data acquisition. M.H.-B. and R.S. participated in the clinical follow-up of the patients. J.R. and M.G.M. contributed to the technological aspects of this paper. M.H.-B. and J.M.R.-N. analysed the data and drafted the manuscript. All authors revised and approved the final version of the manuscript.

Funding

None declared.

Ethical approval

The research protocol complies with the Declaration of Helsinki and was approved by the Ethics Committee of the participating hospital. Tucuvi is approved by Spanish Agency of Medicines and Medical Devices (AEMPS) as a medical device software and complies with data protection regulations (GDPR) as well as national and international cybersecurity requirements [ISO 27001, Spanish National Security Framework (ENS)].

Conflict of interest: J.R. and M.G.M. are employees of Tucuvi Care SL, which is the provider of the technology utilized in this study. This association may be perceived as a potential conflict of interest. However, these individuals have contributed solely to the technical aspects of the study and were not involved in the analysis or interpretation of the data. For that reason, we assure that the analysis and conclusions presented in this study are based on objective and unbiased evaluations. All other authors declare no competing interests at this time.

Data availability

The data underlying this article are available in the article and in its online Supplementary material.

References

1. Vahanian A, Beyersdorf F, Praz F, Milojevic M, Baldus S, Bauersachs J, *et al.* 2021 ESC/EACTS guidelines for the management of valvular heart disease: developed by the task force for the management of valvular heart disease of the European Society of Cardiology (ESC) and the European Association for Cardio-Thoracic Surgery (EACTS). *Eur Heart J* 2021;**43**:561–632.
2. Rogers T, Thourani VH, Waksman R. Transcatheter aortic valve replacement in intermediate and low risk patients. *J Am Heart Assoc* 2018;**7**:e007147.
3. Serletis-Bizios A, Durand E, Cellier G, Tron C, Bauer F, Glinel B, *et al.* Prospective analysis of early discharge after transfemoral transcatheter aortic valve implantation. *Am J Cardiol* 2016;**118**:866–872.
4. Baekke PS, Jørgensen TH, Søndergaard L. Impact of early hospital discharge on clinical outcomes after transcatheter aortic valve implantation. *Catheter Cardiovasc Interv* 2021;**98**:E282–E290.
5. García-Carreño J, Zatarain E, Tamargo M, Elízaga J, Bermejo J, Fernández-Avilés F. Factibilidad y seguridad del alta precoz tras el implante percutáneo de válvula aórtica. *Rev Esp Cardiol* 2023;**76**:655–663.
6. Krishnaswamy A, Isogai T, Agrawal A, Shekhar S, Puri R, Reed GW, *et al.* Feasibility and safety of same-day discharge following transfemoral transcatheter aortic valve replacement. *JACC Cardiovasc Interv* 2022;**15**:575–589.
7. Hanna G, Macdonald D, Bittira B, Horlick E, Ali N, Atoui R, *et al.* The safety of early discharge following transcatheter aortic valve implantation among patients in northern Ontario and rural areas utilizing the Vancouver 3 M TAVR study clinical pathway. *CJC Open* 2022;**4**:1053–1059.
8. Barbanti M, Capranzano P, Ohno Y, Attizzani GF, Gulino S, Immè S, *et al.* Early discharge after transfemoral transcatheter aortic valve implantation. *Heart* 2015;**101**:1485–1490.
9. Noad RL, Johnston N, McKinley A, Dougherty M, Nzewi OC, Jeganathan R, *et al.* A pathway to earlier discharge following TAVR: assessment of safety and resource utilization. *Catheter Cardiovasc Interv* 2016;**87**:134–142.
10. Aldalati O, Keshavarzi F, Kaura A, Byrne J, Eskandari M, Deshpande R, *et al.* Factors associated with safe early discharge after transcatheter aortic valve implantation. *Cardiol J* 2018;**25**:14–23.
11. Khawaja MZ, Rajani R, Cook A, Khavandi A, Moynagh A, Chowdhary S, *et al.* Permanent pacemaker insertion after CoreValve transcatheter aortic valve implantation: incidence and contributing factors (the UK CoreValve Collaborative). *Circulation* 2011;**123**:951–960.
12. Nazif TM, Dizon José M, Hahn RT, Xu K, Babaliaros V, Douglas PS, *et al.* Predictors and clinical outcomes of permanent pacemaker implantation after transcatheter aortic valve replacement: the PARTNER (Placement of AoRtic TraNscathetER Valves) trial and registry. *JACC Cardiovasc Interv* 2015;**8**:60–69.
13. Barker M, Sathananthan J, Perdoncin E, Devireddy C, Keegan P, Grubb K, *et al.* Same-day discharge post-transcatheter aortic valve replacement during the COVID-19 pandemic: the multicenter PROTECT TAVR study. *JACC Cardiovasc Interv* 2022;**15**:590–598.
14. Brahmbhatt DH, Cowie MR. Remote management of heart failure: an overview of telemonitoring technologies. *Card Fail Rev* 2019;**5**:86–92.
15. Fácila Rubio L, Lozano-Granero C, Vidal-Pérez R, Barrios V, Freixa-Pamias R. Nuevas tecnologías para el diagnóstico, tratamiento y seguimiento de las enfermedades cardiovasculares. *Rev Esp Cardiol* 2024;**77**:88–96.
16. Wells GA, Elliott J, Kelly S, Bai Z, Boucher M, Skidmore B, *et al.* Standardized bleeding definitions for cardiovascular clinical trials: a consensus report from the bleeding academic research consortium. *Circulation* 2011;**123**.
17. Jiménez-Quevedo P, Nombela-Franco L, Muñoz-García E, del Valle-Fernández R, Trillo R, de la Torre Hernández JM, *et al.* Resultados clínicos tempranos tras el implante percutáneo de válvula aórtica por acceso transaxilar comparado con el acceso transfemoral. Datos del registro español de TAVR. *Rev Esp Cardiol* 2022;**75**:479–487.
18. Bermúdez IG, Manso MG, Sánchez ES, Hita AR, Rubio MR, Fernández CS. Utilidad y aceptación del seguimiento telefónico de un asistente virtual a pacientes COVID-19 tras el alta. *Rev Clín Esp* 2021;**221**:464–467.
19. Salinas P, Moreno R, Calvo L, Sánchez-Recalde Á, Jiménez-Valero S, Galeote G, *et al.* Long-term follow-up after transcatheter aortic valve implantation for severe aortic stenosis. *Rev Esp Cardiol* 2016;**69**:37–44.