

# Delirium as a Predictor of Physical and Cognitive Function in Individuals Aged 80 and Older After Transcatheter Aortic Valve Implantation or Surgical Aortic Valve Replacement

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**OBJECTIVES:** To determine how development of delirium after surgical aortic valve replacement (SAVR) or transcatheter aortic valve implantation (TAVI) could predict activity of daily living (ADL) and instrumental ADLs (IADL) disability, cognitive function, and self-reported health in individuals aged 80 and older.

**DESIGN:** Prospective cohort study.

**SETTING:** Tertiary university hospital.

**PARTICIPANTS:** Individuals aged 80 and older undergoing elective SAVR or TAVI (N = 136).

**MEASUREMENTS:** Delirium was assessed for 5 days using the Confusion Assessment Method. The Barthel Index, Nottingham Extended ADL Scale, and SF-12 were used to determine ADL and IADL ability and self-reported health at baseline and 1- and 6-month follow-up. Cognition was assessed using the Mini-Mental State Examination at baseline and 6-month follow-up.

**RESULTS:** Participants had lower IADL scores 1 month after SAVR than at baseline (baseline 58, 1 month: delirium 42, no delirium 50,  $P \leq .02$ ), but scores had returned to baseline levels at 6 months. The Medical Outcomes Study 12-item Short-Form Health Survey (SF-12) Physical Component Summary (PCS) score was higher at 6-month follow-up (48) than at baseline (39), especially in participants who did not develop delirium ( $P < .001$ ). No differences in other outcomes were found. Regression models suggest that delirium may help predict IADL disability 1 month after baseline

( $P \leq .07$ ) but does not predict large differences in ADL disability, cognitive function, or SF-12-scores. Individuals who underwent TAVI and developed delirium had lower ADL (baseline 19, 1-month 16,  $P < .001$ ) and IADL (baseline 49, 1-month 40,  $P = .003$ ) scores at 1-month follow-up. SF-12 PCS score (baseline 30) increased from baseline to 1- (35,  $P = .04$ ) and 6- (35,  $P = .02$ ) month follow-up in individuals who underwent TAVI and did not develop delirium. Delirium after TAVI predicted greater ADL and IADL disability at 1-month but not at 6-month follow-up.

**CONCLUSION:** Individuals who develop delirium after SAVR and TAVI have poorer short-term IADL function but do not seem to have long-term reductions in physical, mental, or self-reported health. *J Am Geriatr Soc* 64:1178–1186, 2016.

**Key words:** aortic stenosis; delirium; self-reported health status; TAVI

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A high incidence of delirium occurs in elderly adults undergoing cardiac surgery.<sup>1–3</sup> The prevalence of aortic stenosis is greater in elderly adults than in the general population.<sup>4</sup> Even though symptomatic aortic stenosis has high mortality when untreated,<sup>5</sup> the risk of performing surgical aortic valve replacement (SAVR) might be too high in frail elderly adults with several comorbidities.<sup>6</sup> Transcatheter aortic valve implantation (TAVI) is an option for individuals for whom SAVR is unsuitable.<sup>6,7</sup>

Functional and cognitive decline have been reported in individuals experiencing delirium after hip fracture<sup>8</sup> and cardiac surgery.<sup>9–11</sup> For aortic stenosis, current knowledge about delirium is mostly based on individuals treated with SAVR and those younger than 80.<sup>9,11</sup> Individuals aged 80 and older undergoing TAVI have a lower incidence of delirium than those undergoing SAVR,<sup>12</sup> although it is unclear whether delirium after the less-invasive TAVI leads to equally adverse

effects in terms of activities of daily living (ADLs), instrumental activities of daily living (IADLs), and cognitive function when assessed 1 and 6 months after treatment.

Perception of health is important when longevity is not a dominant priority.<sup>13</sup> Measurement of self-reported health status in elderly populations has been suggested as being important,<sup>14</sup> and quality of life after TAVI has been studied to some extent,<sup>15,16</sup> but little is known about how delirium affects the self-reported health of individuals aged 80 and older after aortic valve implantation. The aim of this study was therefore to determine how delirium could predict ADL and IADL function, cognitive function, and self-reported health status in individuals aged 80 and older 1 and 6 months after treatment with SAVR or TAVI.

## METHODS

This was a prospective cohort study of individuals consecutively undergoing elective TAVI or SAVR in a tertiary hospital in western Norway.

### Study population

Individuals were recruited into the larger Delirium in Octogenarians Undergoing Cardiac Surgery or Intervention (CARDELIR) study.<sup>12</sup> Inclusion criteria were aged 80 and older, severe aortic stenosis, and elective treatment with TAVI or SAVR. Exclusion criteria were inability to speak and understand Norwegian or declined consent to participate. According to guidelines on management of valvular heart diseases, severe aortic stenosis is defined as aortic valve area of less than 0.6 cm<sup>2</sup>/m<sup>2</sup>, mean gradient of greater than 40 mmHg, and maximum jet velocity of greater than 4.0 m/s.<sup>17</sup> A specialist heart team comprising cardiothoracic surgeons and invasive cardiologists identified individuals who were unsuitable for SAVR. Previous coronary artery bypass graft, severe respiratory insufficiency, comorbidities that could compromise recovery, calcified ascending aorta, and prior thoracic radiotherapy were the main reasons for being ineligible for treatment with SAVR.

From February 2011 until August 2013, 162 individuals aged 80 and older were treated with SAVR or TAVI. Of these, 15 failed to fulfill the inclusion criteria. The remaining 147 received study information, and 144 of these agreed to participate, although data analyzed for this study included those from only 136 individuals, because one withdrew consent before treatment, and delirium was not established in seven because they were nonresponsive or had died. An individual was classified as having experienced delirium if delirium was identified on at least 1 of the 5 postoperative days. Individuals who were not tested for delirium because of administrative or other reasons were classified according to delirium status for the days that they were tested.

### Measurements

#### *Delirium*

The Confusion Assessment Method (CAM), which identifies delirium based on acute onset and fluctuating course, inattention, disorganized thinking, and altered level of consciousness, was used to assess delirium.<sup>18</sup> Delirium is diagnosed

when the first two features and the third or the fourth are present.<sup>18</sup> The psychometric properties of the CAM are good.<sup>19</sup>

### Physical Function

#### *Activities of Daily Living*

The Barthel Index, which evaluates self-care abilities in feeding, bathing, grooming, dressing, bowel, bladder, toilet use, transferring, walking, and using stairs, was used as one measure of activity level. The maximum score is 20, and a score of at least 19 indicates functional independence.<sup>20</sup> When administered in an interview, the Barthel Index has sufficient psychometric properties to provide a valid measure ADLs.<sup>21</sup>

#### *Instrumental Activities of Daily Living*

The Nottingham Extended Activities of Daily Living Scale uses 22 items to evaluate an individual's ability to perform complex levels of functioning, such as cooking, household management, and use of public transportation. Each item is scored from 0 to 3, and the items are summed, with 66 being the highest score. Higher scores indicate greater levels of independence.<sup>22</sup> This index is reliable and valid.<sup>23</sup>

### Cognitive Function

Cognitive function was assessed using the Mini-Mental State Examination (MMSE),<sup>24</sup> which has a range of 0–30 points, with 30 indicating the best cognition. In the Norwegian version, a score of 27 or less indicates poor cognitive function. The MMSE is a valid instrument for assessing global cognitive function.<sup>24</sup>

### Self-Reported Health Status

#### *Medical Outcomes Study 12-Item Short-Form Health Survey*

The Medical Outcomes Study 12-Item Short-Form Health Survey (SF-12) was used to measure subjective general health.<sup>25</sup> It is a generic, self-assessed health index based on 12 items and is combined into two summary scores: the Physical Component Summary (PCS) and the Mental Component Summary (MCS). Scores range from 0 to 100, with higher scores indicating better self-reported health status. The psychometric properties of the SF-12 are good.<sup>25</sup>

### Other Study Variables

#### *Comorbidity*

The Charlson Comorbidity Index, which predicts mortality in individuals with comorbid disorders, was used to quantify comorbidities.<sup>26</sup> It has been shown to have good psychometric properties.<sup>26,27</sup>

#### *Cardiac Operative Risk*

The Logistic European System for Cardiac Operative Risk Evaluation I (Logistic EuroSCORE I), which uses a scoring system that calculates operative mortality for individuals

undergoing cardiac surgery, was used to evaluate mortality risk.<sup>28</sup> The Logistic EuroSCORE I takes into consideration 17 risk variables that predict mortality. Higher scores indicate greater operative mortality risk.<sup>29</sup>

The selection of explanatory variables included in the prediction models for the present study was based on previous research exploring the consequences of delirium after cardiac surgery,<sup>9,11,30,31</sup> taking into account clinical experience and the limited sample size.

## Data Collection

### *Preoperative Data and Postoperative Assessment of Delirium*

A detailed description of preoperative data collection and assessment of delirium was presented in a previous article.<sup>12</sup> Briefly, the day before treatment, ADL and cognitive function were evaluated in individuals fulfilling the inclusion criteria. A self-report form containing IADL and SF-12 questionnaires was given to participants at the end of the inclusion process and collected before surgery. Demographic and clinical data were gathered from medical records or in an interview, as appropriate.

The presence of delirium was measured daily, including weekends, at approximately noon from Postoperative Day 1–5. Research nurses trained in CAM performed clinical assessments at participants' bedsides. Medical, nursing, and physiotherapist reports from the previous 24 hours and meetings with health professionals in charge of the participants were taken into consideration when scoring the CAM.

### *One- and 6-Month Assessments*

Follow-up visits were scheduled at the hospital 1 and 6 months after treatment. Information about ADL function was collected at this time, and self-report forms containing IADL and SF-12 questionnaires were provided. If a participant was unable to attend a follow-up visit, and a new appointment could not be scheduled within a window of 2 weeks, telephone contact was attempted. Information required for the Barthel Index was collected over the telephone, and then self-report forms containing IADL and SF-12 questionnaires were mailed for completion at home. The MMSE was administered after 6 months in participants attending follow-up visits.

## Data Analyses

Data are presented as counts and percentages or means and standard deviations or confidence intervals. Longitudinal linear models were fitted separately, with time, delirium, and the interaction between time and delirium as explanatory factors to estimate mean ADL, IADL, MMSE, SF-12 PCS, and SF-12 MCS scores at baseline and 1- and 6-month follow-up. To estimate how delirium could improve predictions over baseline scores alone or baseline scores and other risk or comorbidity factors, linear longitudinal models for the scores were fitted at 1- and 6-month follow-up using baseline score as an explanatory variable for the unadjusted analysis and baseline score, sex,

Charlson Comorbidity Index, and logistic EuroSCORE I as explanatory variables for the adjusted analysis.

All longitudinal models were fitted separately for each treatment (SAVR, TAVI) using generalized least squares with an unstructured correlation matrix.  $P \leq .05$  was considered statistically significant. Reported  $P$ -values were not adjusted for multiple comparisons. Data management and initial statistical analyses were conducted using SPSS version 22.0 (IBM SPSS Statistics for Windows, Armonk, NY) and R 3.1.1 (R Foundation for Statistical Computing, Vienna, Austria) was used for all reported statistical analyses except those reported in Table 1. The R package "nlme" was used for longitudinal analyses.

## Missing Data

Data were screened and checked for missing units (questionnaires) and loss of single items.<sup>32</sup> Before data collection started, a coding system for missing data was implemented (participant did not answer item, participant withdrew from study, participant died). Participants with incomplete baseline SF-12 units were more likely to be male ( $P = .02$ ). Otherwise, no differences were found at baseline or follow-up in terms of sex, comorbidity, or marital or educational status between participants with complete and incomplete units.

By the time data collection ended, 22 participants were lost-to-follow-up, nine of whom had withdrawn from the study (8 treated with SAVR) and 13 of whom had died (8 treated with TAVI). Including participants who were lost to follow-up, cognitive screening 6 months after treatment was not performed in 45 (31%). Twenty-two of these participants did not attend 6-month follow-up at the hospital. The majority of these nonattendees were living more than 2 hours away from the hospital; five said that the hospital was too far away from their residence to attend the consultation, nine that they were not well enough to travel, and four that they were healthy and did not need further follow-up examination; three did not indicate their reason for not attending the follow-up; and two could not be contacted. Participants who did not attend their 6-month follow-up visit did not differ from those attending in terms of sex ( $P = .27$ ), baseline comorbidities ( $P = .74$ ), or baseline MMSE score ( $P = .83$ ).

## Handling of Missing Data

Because it could not be assumed that data were missing completely at random, a likelihood-based longitudinal model, requiring only the much weaker missing at random assumption, was used. Still, there could be informative censoring that the model did not capture, with, for example, participants showing greater improvements from baseline being more likely to respond to the follow-up questionnaire. A sensitivity analysis for the changes from baseline was therefore performed in which all missing data were replaced with participants' baseline values and the statistical analysis repeated. The results from the sensitivity analysis can be seen in Figure S1.

**Table 1. Characteristics of Individuals Aged 80 and Older Undergoing Transcatheter Aortic Valve Implantation (TAVI) or Surgical Aortic Valve Replacement (SAVR) Who Did and Did Not Develop Delirium (N = 136)**

Characteristic	Total	SAVR			TAVI		
		No Delirium, n = 25	Delirium, n = 48	P- Value	No Delirium, n = 35	Delirium, n = 28	P- Value
Age, mean ± SD	83.5 ± 2.7	81.6 ± 1.4	82.7 ± 2.3	.01	84.7 ± 2.8	84.9 ± 2.8	.74
Female, n (%)	76 (56)	12 (48)	24 (50)	.87	25 (71)	15 (54)	.14
Married, n (%)	73 (54)	16 (64)	27 (56)	.52	15 (43)	15 (54)	.40
Activity of daily living function, mean ± SD (range 0–20)	18.9 ± 1.5	19.5 ± 1.0	18.9 ± 1.5	.06	18.9 ± 1.5	18.5 ± 1.4	.28
Instrumental activity of daily living function, mean ± SD (range 0–66)	54.2 ± 10.1	57.1 ± 8.7	57.5 ± 7.9	.87	52.4 ± 10.9	48.6 ± 11.1	.21
Mini-Mental State Examination score, mean ± SD (range 0–30)	27.2 ± 2.9	27.9 ± 2.2	27.8 ± 2.8	.86	27.4 ± 2.4	25.4 ± 3.6	.01
Medical Outcomes Study 12-Item Short Form Survey score, mean ± SD (range 0–100)							
Physical Component Summary	33.9 ± 10.6	38.4 ± 8.8	36.2 ± 10.4	.40	30.5 ± 10.0	30.9 ± 11.3	.88
Mental Component Summary	48.7 ± 10.8	50.3 ± 10.6	50.1 ± 10.4	.94	47.0 ± 8.3	47.1 ± 14.1	.95
Charlson Comorbidity Index, mean ± SD	2.1 ± 1.2	1.8 ± 1.0	1.8 ± 0.9	.78	2.3 ± 1.3	2.7 ± 1.3	.20
Logistic European System for Cardiac Operative Risk Evaluation I, mean ± SD <sup>a</sup>	14.0 ± 9.2	9.9 ± 3.8	8.8 ± 3.1	.31	19.4 ± 1.0	19.8 ± 11.6	.86
New York Heart Association class							
I + II	47 (35)	13 (54)	24 (54)	.98	6 (19)	4 (18)	.96
III + IV	75 (55)	11 (46)	20 (45)	.98	26 (81)	18 (81)	.96
Left ventricular ejection fraction, %	56.6 ± 10.2	57.2 ± 12.0	57.3 ± 9.4	.97	55.9 ± 10.4	55.6 ± 10.3	.89
Maximum aortic gradient, mmHg	79.5 ± 23.9	86.2 ± 26.7	82.1 ± 23.8	.54	73.4 ± 23.7	76.9 ± 20.9	.54
Mean aortic gradient, mmHg	48.3 ± 16.1	51.6 ± 16.8	50.1 ± 16.2	.72	45.6 ± 16.0	45.9 ± 15.2	.93
Aortic valve area, cm <sup>2</sup> /m <sup>2</sup>	0.4 ± 0.2	0.4 ± 0.1	0.4 ± 0.2	.29	0.4 ± 0.1	0.4 ± 0.07	.40
American Society of Anesthesiologists classification, n (%)							
3	114 (84)	25 (100)	46 (96)	.30	23 (66)	20 (71)	.63
4	22 (16)	0 (0)	2 (4)	.30	12 (34)	8 (29)	.63

SD = standard deviation.

<sup>a</sup>P-value based on log-transformed values.

## Ethical Considerations

This study was conducted in accordance with the Declaration of Helsinki and approved by the Regional Committee for Ethics in Medical Research in Norway (REK Vest 2010/2936–6). Special consideration was given to signs of participant exhaustion during data collection. Whenever these signs were present, data collection was stopped and later resumed.

## RESULTS

### Characteristics of the Study Population

Clinical and sociodemographic characteristics of included participants are presented in Table 1. Fifty-seven percent of the participants were female, and TAVI was performed in 46% of the study population. Participants in the TAVI group were older ( $P < .001$ ) and had more comorbidities ( $P < .001$ ), a higher Logistic EuroSCORE I ( $P < .001$ ), poorer IADL function ( $P < .001$ ), lower MMSE scores ( $P = .007$ ), lower SF-12 PCS scores ( $P = .002$ ), and lower SF-12 MCS scores ( $P = .09$ ).

Participants without delirium were not different from those with delirium in terms of sex ( $P > .14$ ), comorbidity index ( $P > .20$ ), or logistic EuroSCORE ( $P > .31$ ), but participants treated using SAVR developed delirium more often than participants treated with TAVI ( $P = .01$ ).

### Postoperative Delirium

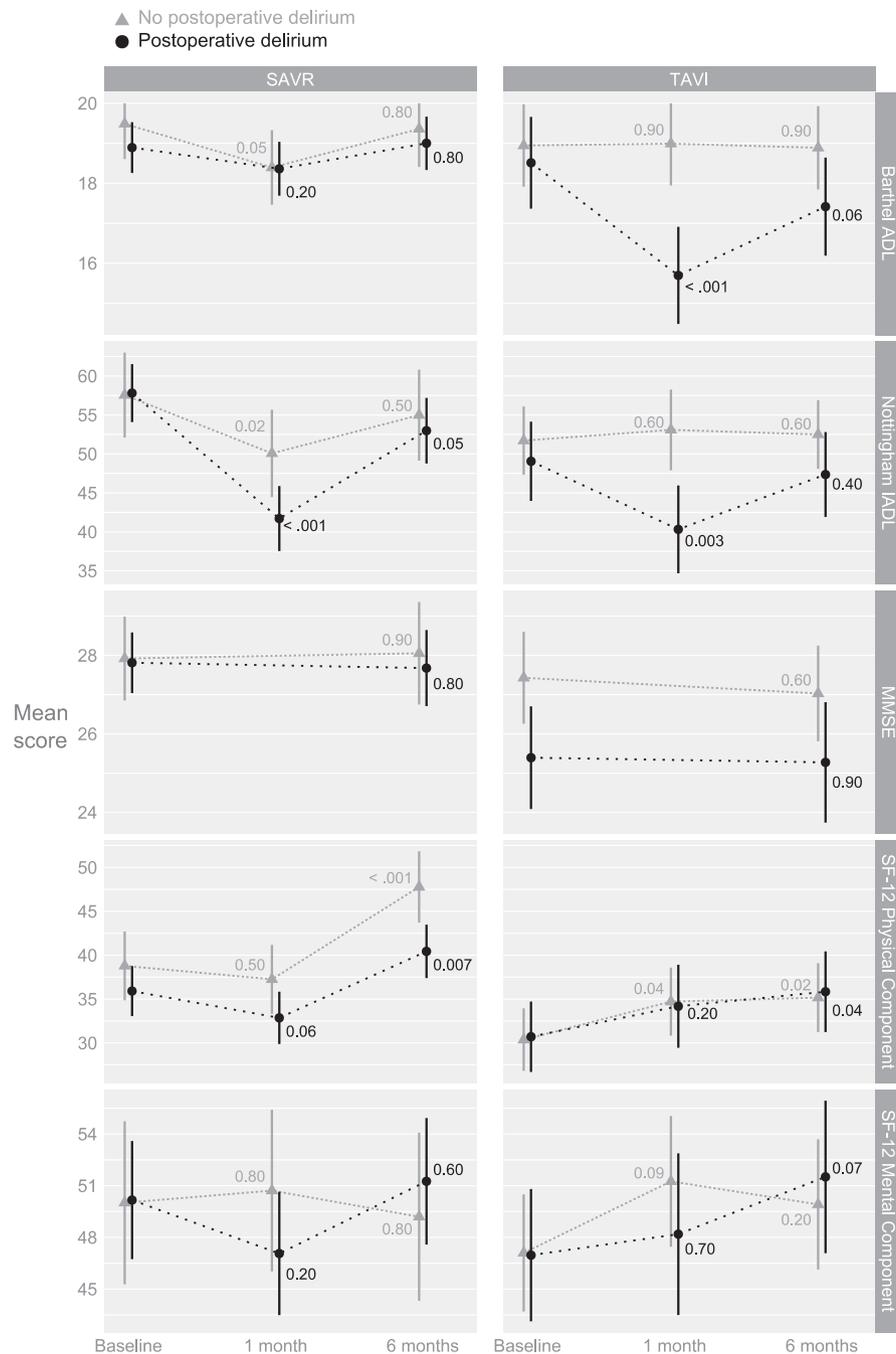
An earlier article<sup>12</sup> presented the incidence of delirium in the studied population. Delirium was identified in 66% of participants in the SAVR group and 44% of those in the TAVI group.<sup>12</sup>

### ADLs–SAVR Group

ADL scores of participants treated with SAVR were similar to baseline scores at 1- and 6-month follow-up regardless of the presence of delirium (all  $P > .05$ ) (Figure 1). Delirium did not predict performance well when adjusted for baseline or baseline and other risk factors (Table 2).

### ADLs–TAVI Group

At 1-month follow-up, participants in the TAVI group with delirium had much worse mean ADL scores than at baseline. After 6 months, ADL scores for the TAVI group with delirium had improved and were no longer statistically significantly different from baseline scores ( $P = .06$ ). The 1- and 6-month follow-up scores of participants undergoing TAVI who did not develop delirium were similar to their baseline scores (Figure 1). The regression models showed that delirium predicted performance well at 1-month follow-up, even when baseline ADL function was included as a linear predictor in the models (Table 2).



**Figure 1.** Model-based estimated means for activities of daily living (ADLs; possible range of scores 0–20), instrumental activities of daily living (IADLs; possible range of scores 0–66), Mini-Mental State Examination (MMSE; possible range of scores 0–30), and Medical Outcomes Study 12-item Short Form Survey scores ((SF-12) possible range of scores 0–100) (with 95% confidence intervals) at baseline and 1- and 6-month follow-up. Organized according to treatment (surgical aortic valve replacement (SAVR), transcatheter aortic valve implantation (TAVI)) and presence or absence of delirium (circles and triangles, respectively) (N = 136). The result of testing for change from baseline, based on longitudinal models, is shown as P-values at each time point. See Table 2 for information on the number of observations used to estimate each outcome.

This analysis also showed that participants who developed delirium had mean baseline-adjusted scores 3.1 points lower (worse) than those who did not ( $P = .002$ ). This effect also persisted when adjusting for other risk and comorbidity factors (sex, Charlson Comorbidity Index, baseline logistic EuroSCORE I) ( $P = .001$ ). At 6-month follow-up, presence of delirium in the first 5 days after surgery no longer predicted ADL performance.

#### IADLs–SAVR Group

IADL scores at 1-month follow-up were lower than at baseline for participants who did not develop delirium ( $P = .02$ ) and even lower for those who did ( $P < .001$ ). There were no or minor differences from baseline at 6-month follow-up ( $P = .50$  for participants without delirium,  $P = .05$  for SAVR participants with delirium). The

**Table 2. Effect of Experiencing Delirium on Physical and Cognitive Function and Self-Reported Health, Adjusted for Baseline Values, at 1- and 6-Month Follow-Up, for Individuals Aged 80 and Older with Severe Aortic Stenosis**

Assessment	Surgical Aortic Valve Replacement						Transcatheter Aortic Valve Implantation					
	n*	Estimated, <sup>c</sup> P-Value					n*	Estimated, <sup>c</sup> P-Value				
		Baseline Adjusted <sup>a</sup>		Baseline and Risk Adjusted <sup>b</sup>				Baseline Adjusted <sup>a</sup>		Baseline and Risk Adjusted <sup>b</sup>		
		1 Month	6 Months	1 Month	6 Months	1 Month		6 Months	1 Month	6 Months		
Activity of daily living function	67	0.3, .60	0.1, .90	0.0, >.99	-0.3, .70	60	-3.1, .002	-1.5, .10	-3.1, .001	-1.6, .10		
Instrumental activity of daily living function	47	-8.1, .07	-1.8, .70	-9.4, .06	-3.0, .60	48	-10.6, .004	-3.0, .40	-10.5, .005	-2.3, .50		
Mini-Mental State Examination	45		-0.3, .70		-0.6, .50	52		-1.1, .40		-1.4, .20		
Medical Outcomes Study 12-Item Short Form Survey												
Physical Component Summary	52	-2.9, .20	-4.1, .10	-4.0, .10	-4.9, .05	44	-0.6, .80	0.9, .80	-0.6, .80	1.1, .70		
Mental Component Summary	52	-5.1, .10	5.1, .10	-6.3, .06	4.3, .20	44	-4.0, .20	2.4, .40	-3.6, .20	3.0, .30		

<sup>a</sup>Adjusted for baseline score.

<sup>b</sup>Adjusted for sex and baseline score, Charlson Comorbidity Index, and Logistic European System for Cardiac Operative Risk Evaluation I.

<sup>c</sup>Estimated difference in mean score between an individual experiencing delirium and an individual not experiencing delirium based on a linear longitudinal model with the mean score of the individual experiencing delirium modeled as a linear function of experiencing delirium and baseline value/baseline value and other risk factors.

\*Number of patients included in the models, i.e., with at least one measurement (baseline, 1 month and/or 6 month).

regression models showed no predictive power of delirium at 6 months but suggest a possible moderate to large effect size at 1 month (not statistically significant) (Table 2).

**IADLs–TAVI Group**

At 1-month follow-up, IADL scores did not differ from baseline in participants who did not develop delirium ( $P = .60$ ) but were lower than at baseline for those who did ( $P = .003$ ). There were no differences in scores from baseline to 6-month follow-up independent of delirium (without delirium,  $P = .60$ ; with delirium,  $P = .40$ ) (Figure 1). The regression models showed that, for participants undergoing TAVI, delirium predicted performance well at 1-month follow-up, even after adjusting for baseline IADL function. According to this analysis, participants who developed delirium had mean baseline-adjusted scores that were approximately 10 points lower (worse) than scores of those who did not ( $P = .005$ ). This was also the case when adjusted for other risk and comorbidity factors (Table 2).

**MMSE–SAVR Group**

There were no differences in cognitive function between baseline and 6-month follow-up in participants who did and did not develop delirium (Figure 1). For participants undergoing SAVR, the regression models showed no significant improvement in prediction when including delirium as a predictor in the analysis (Table 2).

**MMSE–TAVI Group**

Although individuals undergoing TAVI who developed delirium had lower overall scores than those who did not (even at baseline), no differences in cognitive

function were found 6 months after treatment (Table 2). Taking into account baseline MMSE score and other risk factors, including information on the presence or absence of delirium did not improve predictions (Table 2).

**SF-12 PCS–SAVR Group**

There were minor, statistically nonsignificant changes in SF-12 PCS score after 1 month. Participants who did and did not develop delirium had a major increase in scores at 6-month follow-up ( $P \leq .007$ ) (Figure 1). The regression models found no improvements in prediction when taking the presence of delirium into account, except for a significant ( $P = .05$ ) effect after 6 months (Table 2).

**SF-12 PCS–TAVI Group**

At 1-month follow-up, only participants who did not develop delirium had a statistically significant improvement in self-reported physical health ( $P = .04$ ). Six months later, there were improvements in all participants (Figure 1). The regression models showed no improvement in prediction when taking the presence of delirium into account (Table 2).

**SF-12 MCS–SAVR Group**

There were no statistically significant differences on the SF-12 MCS at 1- or 6-month follow-up (Figure 1). The regression model revealed no improvement in prediction when taking the presence of delirium into account (Table 2).

## SF-12 MCS–TAVI Group

No statistically significant changes were found in participants who did or did not develop delirium at 1- or 6-month follow-up (Figure 1). For participants undergoing TAVI, there was no effect of delirium at 1- or at 6-month follow-up (Table 2).

## Sensitivity Analysis

The results from the sensitivity analysis showed only minor changes in the estimated effects, so the findings seem robust. All changes from baseline with  $P \leq .04$  (in Figure 1) remained statistically significant. The results from the sensitivity analysis are presented in Figure S1. This supplement is organized like Figure 1, but all estimates and  $P$ -values are based on the sensitivity analysis model described.

## DISCUSSION

To the best of the knowledge of the authors, this is the first study to examine delirium as a predictor of ADL, IADL, and cognitive function and self-reported health in individuals aged 80 and older after TAVI. This work demonstrates how delirium affects individuals aged 80 and older after SAVR or TAVI, the latter being a less-invasive treatment.

Previous studies found an association between delirium and functional decline after hip fracture<sup>8</sup> and cardiac surgery.<sup>9,11</sup> It has been suggested that functional impairment is an important end point after cardiac surgery in older adults.<sup>33,34</sup> The current study shows that, at 1-month follow-up, participants who underwent TAVI and developed delirium had a major decrease in ADL scores. This effect persisted after adjusting for baseline ADL score and other risk factors. The same level of decrease was not present in individuals aged 80 and older undergoing the more-invasive SAVR. One could argue that individuals aged 80 and older scheduled for TAVI are more vulnerable than those undergoing SAVR. ADL scores in participants undergoing TAVI and not developing delirium remained constant from baseline to follow-up.

IADL function has been linked to cognition.<sup>35</sup> In the current study, participants with delirium scored lower on the IADL scale at 1-month follow-up than those without delirium: 16 points for participants undergoing SAVR and 9 points for participants undergoing TAVI. Diminished IADL performance might be expected, especially after SAVR, which requires full sternotomy, aortic cross-clamping, and extracorporeal bypass circulation. Furthermore, electrocardiography devices, temporal pacemakers, and catheters limit mobility during the immediate postoperative period. After 6 months, the IADL scores of individuals who underwent TAVI and SAVR had increased and did not significantly differ from baseline.

Important differences in cognitive function were identified. MMSE scores at baseline and 6-month follow-up of individuals who underwent TAVI and developed delirium were approximately 2 points lower than scores of participants undergoing TAVI who did not develop delirium, although the cognitive changes from baseline to 6-month

follow-up in all participants treated with TAVI were not significant. No differences were observed in MMSE scores of participants who underwent SAVR, regardless of development of delirium. Even though diminished cognitive function has been reported 6 months after hip fracture in individuals with delirium,<sup>36</sup> and delirium has been shown to be associated with persistent cognitive impairment and prolonged recovery up to 1 year after cardiac surgery,<sup>31</sup> a decrease in cognitive scores 6 months after SAVR or TAVI was not observed. These encouraging results compare favorably with findings from other studies<sup>30</sup> and provide further knowledge in the area of delirium by including individuals undergoing cardiac surgery aged 80 and older treated with a novel aortic valve therapy. The study measured cognitive function only at baseline and 6-month follow-up, and it was not possible to explore possible fluctuations that could have occurred during the intermediate postoperative period. It also cannot be determined whether some participants developed cognitive impairment after 6 months.

The SF-12 has been used to measure self-reported health status after SAVR and TAVI.<sup>37–39</sup> To the authors' knowledge, the self-reported health of individuals aged 80 and older undergoing TAVI who develop delirium has not been established. The PCS score of individuals who underwent SAVR and developed delirium was lower (nonsignificantly) at 1-month follow-up than at baseline but improved significantly at 6 months. The scores of individuals who underwent SAVR and did not develop delirium remained constant at 1-month follow-up and improved greatly after 6 months, supporting observations from the Placement of AoRTic TraNscathetER Valve Trial.<sup>39</sup> In the current study, participants treated with TAVI had the lowest PCS scores at baseline. Differences in scores between the TAVI and SAVR groups became more accentuated 6 months after treatment, suggesting that individuals who underwent TAVI were frail at baseline and remained frail after treatment.

MCS scores of the SAVR and TAVI groups had a different pattern than others have reported.<sup>37,39</sup> There was no statistically significant difference in these scores from baseline to 1- and 6-month follow-up. The utility of the SF-12 for detecting changes over time in individuals with heart failure has been questioned.<sup>40</sup> Similarly, the SF-12 MCS may not be sufficiently sensitive to detect changes in delirium. It is also possible that participants in the SAVR group had higher expectations for the procedure than the frailer group that underwent TAVI and developed delirium. Nevertheless, it is surprising that cognitive, ADL, and IADL function were well preserved in the SAVR cohort, because these participants did not receive as much screening as those in the TAVI group regarding general atherosclerosis and aortic calcification. This indicates that the selection and quality of surgery and perioperative treatment of participants were good, because participants who underwent TAVI were older and had a higher EuroSCORE and more comorbidities. It also shows that SAVR may be performed safely in individuals aged 80 and older with reasonably good physical and mental health. With new technology (widespread use of intraoperative, epi-aortic ultrasound to detect aortic atheroma and thereby avoid cerebral embolization; recently developed rapid

deployment aortic valve prostheses to reduce extracorporeal bypass circulation time in elderly adults undergoing open surgery for aortic stenosis), SAVR may potentially be performed with even less risk of cerebral complications.<sup>41,42</sup>

This study has several strengths, including its prospective design with consecutive inclusion of individuals and its use of valid and reliable instruments. Furthermore, the study hospital performs all TAVI and SAVR in western Norway, allowing the inclusion of a representative group of individuals aged 80 and older with severe aortic stenosis from the entire region. The fact that the participants were more homogeneous in terms of age, diagnosis, and treatment received than in other studies<sup>9,11,30,31</sup> can explain the high incidence of delirium in the current study. Screening with CAM was performed in a thorough manner at bedside for 5 days postoperatively, starting on the first postoperative day. Participants were also assessed on weekends and holidays. Meetings with health professionals in contact with participants and close examination of their reports were performed before the CAM was scored.

A limitation of the study is that it was not designed as a randomized controlled trial. Randomization to compare treatment modalities was not possible, because TAVI and SAVR are used to treat distinctly different target groups.<sup>6</sup> Because of this, the results were analyzed stratified according to treatment. Another limitation was the modest size of the studied cohort. The results warrant future studies with larger samples. There was also the risk of type 1 errors due to use of multiple testing. The high ADL, IADL, and cognitive functioning of the cohort may limit the applicability of the results to other populations and might indicate that subject selection bias was present before participants were referred to the university hospital. It is also a limitation that cognitive function at 6-month follow-up was not measured in the 22 participants who did not attend their consultation, but the consequences of missing MMSE data at 6 months were investigated in a sensitivity analysis and showed only minor changes in the estimated effects. Other tools could have been added to complement the cognitive evaluation done with the MMSE.<sup>43</sup> Six months may be considered a short follow-up period for evaluating the long-term consequences of delirium. This warrants further study with longer follow-up.

In conclusion, delirium is an important predictor of lower ADL and IADL function 1 month after invasive treatment for aortic stenosis, even when gentler techniques such as TAVI are used. Lower ADL and IADL scores at 1-month follow-up (Figure 1) in individuals aged 80 and older with postoperative delirium address the importance of prevention and recognition of the condition. This is probably even more relevant in a population in which functional ability is perhaps more appealing than longevity. Close monitoring of individuals at risk of developing delirium, even after less invasive aortic valve therapy, is therefore recommended. Future studies should focus on the effect of delirium on adverse events demanding acute readmission to hospital and nursing home placement in individuals aged 80 and older after SAVR or TAVI.

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**Author Contributions:** Eide, Ranhoff, Nordrehaug, Norekvål: study concept and design. Eide: data collection. Eide, Hufthammer, Ranhoff, Haaverstad, Kuiper, Nordrehaug, Norekvål: analysis and interpretation of data. Eide, Ranhoff, Fridlund, Norekvål: initial draft of manuscript. Eide, Ranhoff, Fridlund, Haaverstad, Hufthammer, Kuiper, Nordrehaug, Norekvål: critical revision of manuscript.

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## SUPPORTING INFORMATION

Additional Supporting Information may be found in the online version of this article:

**Figure S1.** Sensitivity analysis showing minor changes in estimated effects: activities of daily living (ADLs; possible range of scores 0–20), instrumental activities of daily living (IADLs; possible range of scores 0–66), Mini-Mental State Examination (MMSE; possible range of scores 0–30), and Medical Outcomes Study 12-Item Short Form Survey scores ((SF-12) possible range of scores 0–100) (with 95% confidence intervals) at baseline and 1- and 6-month follow-up.

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