Is Elective Total Hip Arthroplasty Safe in Nonagenarians?

An Arthroplasty Registry Analysis

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Background: An increasing number of elderly patients are becoming candidates for elective total hip arthroplasty (THA). Conflicting results exist with regard to the safety of THA in nonagenarians. The aims of this study were to evaluate postoperative mortality and morbidity after THA in nonagenarians and underlying risk factors. We hypothesized that nonagenarians undergoing elective THA would show higher morbidity than younger patients and higher mortality than nonagenarians in the general population.

Methods: This was an observational cohort study using data from the German Arthroplasty Registry (Endoprothesenregister Deutschland [EPRD]). Of 323,129 THAs, 263,967 (including 1,859 performed on nonagenarians) were eligible. The mean follow-up (and standard deviation) was 1,070 ± 641 days (range, 0 to 3,060 days). The exclusion criteria were age of <60 years at admission and nonelective THAs or hemiarthroplasties. The cohort was divided into 4 age groups: (1) 60 to 69 years, (2) 70 to 79 years, (3) 80 to 89 years, and (4) ≥90 years. Comorbidities representing independent risk factors for postoperative complications and mortality were identified via a logistic regression model. Mortality rates were compared with those from the general population with data from the Federal Statistical Office. The end points of interest were postoperative major complications, minor complications, and mortality.

Results: Among the greatest risk factors for major and minor complications and mortality were congestive heart failure, pulmonary circulation disorders, insulin-dependent diabetes, renal failure, coagulopathy, and fluid and electrolyte disorders. Compared with younger groups, the risks of major and minor complications and mortality were significantly higher in nonagenarians. Mortality increased when major complications occurred. After 1 year, the survival rate in patients without a major complication was 94.4% compared with 79.8% in patients with a major complication. The mortality rates of nonagenarians in the study population were lower than those in the corresponding age group of the general population. The 1-year mortality rates at 90 years of age were 10.5% for men and 6.4% for women within the study group compared with 18.5% for men and 14.7% for women among the general population.

Conclusions: Comorbidities favor the occurrence of complications after elective THA in nonagenarians and thus increase postoperative morbidity. In the case of complications, mortality is also increased. The fact that mortality is still lower than within the general population shows that this aspect can be controlled by careful patient selection and adequate preparation.

Level of Evidence: Therapeutic Level III. See Instructions for Authors for a complete description of levels of evidence.

Driven by demographic change, most developed countries are facing aging populations. A particularly fast-growing group is the very elderly, including those ≥90 years of age. The absolute number of people within this group in Germany is expected to more than double by 2060[1]. Although overall life expectancy is increasing, individuals are also becoming less willing to accept physical limitations at the same time[2]. As a result, an increasing number of elderly patients with osteoarthritis are becoming candidates for elective total hip arthroplasty (THA)[2].

Disclosure: The **Disclosure of Potential Conflicts of Interest** forms are provided with the online version of the article (http://links.lww.com/JBJS/H587).

Previous studies have suggested that age alone may be an independent risk factor for postoperative mortality and morbidity[3]. Nevertheless, the increased risk of complications and mortality within the elderly population may be confounded by preexisting comorbidities and frailty[4,5].

Although patients in this age group have proven to benefit from THA by experiencing pain reduction and improvement in joint-specific function and quality of life[6,7], conflicting results exist about the independent influence of age with regard to postoperative mortality and morbidity within this patient population. It has previously been reported that THA is a safe procedure for nonagenarians, with no increased rates of complications[8]. In contrast, other studies have shown that the risk of complications increases with age[5,9,10]. These results may be contradictory because most previous studies investigated small patient cohorts and thus were underpowered. Furthermore, the methodologies applied may not have adequately addressed the independent influence of age with regard to confounding comorbidities[7,8,10]. Thus, there has been a paucity of reliable data on the safety of THA in nonagenarians. However, the safety of THA is crucial for its selection by both the treating physician and the patient.

The aims of the present study were to evaluate the safety of THA in nonagenarians on the basis of postoperative mortality and morbidity, and their risk factors, following elective THA using registry data with 100% follow-up. We hypothesized that THA in nonagenarians would be associated with higher morbidity than in younger patient groups and higher mortality rates than in nonagenarians in the general population.

Materials and Methods

Data Source

Data were obtained from the German Arthroplasty Registry (Endoprothesenregister Deutschland [EPRD]). The data collection period started in November 2012 and lasted until December 2021. During this period, the EPRD collected data on almost 2 million endoprosthetic procedures on the hip or knee. At last count, 747 clinics submitted data. The EPRD combines 3 data sources: (1) routine billing reports of German public health funds, (2) a constantly updated product database in collaboration with implant manufacturers, and (3) electronic case reports from participating hospitals. The EPRD records approximately 70% of implanted prostheses in Germany, with 100% follow-up due to incorporated health insurance data with regard to patient mortality or arthroplasty failure. The EPRD received a general institutional review board approval from the University of Kiel (D 473/11). Data from the Federal Statistical Office of Germany were used for a comparison of mortality rates with those in the total population[11].

Patient and End-Point Selection

Of 323,129 THAs in the EPRD, 263,967 were eligible for the final statistical analysis. We included patients who were ≥60 years of age at admission and had undergone elective THA. We excluded patients who were <60 years of age at admission and those who had undergone nonelective THAs or hemiarthroplasties. The end points were major complications, minor complications, and mortality during postoperative follow-up. These end points were not exclusive; that is, 1 patient could have had a major complication and could have died during follow-up. For the end points of major and minor complications, patients were censored if they died during the follow-up. Missing descriptive data did not lead to case exclusion. When data were missing, the proportion of cases with missing data was reported. The mean follow-up (and standard deviation) was 1,070 ± 641 days (range, 0 to 3,060 days). A 0-day follow-up indicated mortality shortly after the surgical procedure, as the registry only reports the month of death and not the exact day of death. These patients were included to allow for accurate identification of mortality in this elderly population. The study group was divided into 4 age groups: (1) 60 to 69 years, (2) 70 to 79 years, (3) 80 to 89 years, and (4) ≥90 years.

The major and minor complications were defined conditions identified by International Classification of Diseases, Tenth Revision (ICD-10) codes. A detailed overview of the included conditions and corresponding codes is given in the. Comorbidities were derived from the modified Elixhauser Comorbidity Index (ECI)[12]. Weight loss was defined as abnormal unintentional weight loss of >10% of body weight within 3 months. Paralysis is an umbrella term defining multiple forms including monoparesis of the upper or lower extremity as well as hemiparesis, tetraparesis, and cauda equine syndrome.

Statistical Analysis

The significance level was set to $p = 0.05$. Descriptive statistics were calculated for the 4 age groups. Continuous variables are reported as the mean and the standard deviation, and categorical variables are reported as the frequency and proportion (as a percentage). Groups were compared with 1-way analysis of variance (ANOVA) for continuous variables and with the chi-square test for categorical variables. Bivariate analyses were performed for the end points of major complications, minor complications, and mortality to identify significant variables to include in the logistic regression analysis. P values were corrected for multiple testing with the Holm method.

Six different logistic regression models were then fitted: 2 for each end point, with age as a continuous variable in one and as a categorical variable in the other. Model fitting began with a full model that included all variables that were significant in the bivariate analyses plus the (continuous or categorical) age variable. Nonsignificant variables were then eliminated in a stepwise backward approach, starting with the variable with the highest p value, until only significant variables remained in the model.

Cumulative incidences for the end point of mortality were then calculated using Kaplan-Meier estimates for the age group of ≥90 years, stratified according to the presence or absence of a major complication and of a minor complication. The log-rank test was used to compare cumulative incidences. Comorbidities were represented by the modified ECI[12,13]. Death of the patient was the only end point for which the time from

TABLE I Patient Characteristics and Comorbidities

	Age Groups			
	60-69 Yr (N = 91,363)	70-79 Yr (N = 117,324)	80-89 Yr (N = 53,421)	≥90 Yr (N = 1,859)
Characteristics				
Age at admission* *(yr)*	64.7 ± 2.86	74.8 ± 2.83	82.7 ± 2.41	91.4 ± 1.69
Sex†				
Female	54,839 (60.0%)	78,456 (66.9%)	37,860 (70.9%)	1,440 (77.5%)
Male	36,524 (40.0%)	38,868 (33.1%)	15,561 (29.1%)	419 (22.5%)
Body mass index†				
Underweight (<18.5 kg/m^2)	330 (0.4%)	490 (0.4%)	354 (0.7%)	32 (1.7%)
Normal weight (18.5 to 24.5 kg/m^2)	12,636 (13.8%)	19,235 (16.4%)	12,300 (23.0%)	603 (32.4%)
Overweight (25 to 29.9 kg/m^2)	21,864 (23.9%)	29,611 (25.2%)	15,438 (28.9%)	487 (26.2%)
Obese class I (30 to 34.9 kg/m^2)	14,773 (16.2%)	15,228 (13.0%)	6,124 (11.5%)	104 (5.6%)
Obese class II (35 to 39.9 kg/m^2)	5,892 (6.4%)	4,560 (3.9%)	1,308 (2.4%)	10 (0.5%)
Obese class III (≥40 kg/m^2)	2,640 (2.9%)	1,377 (1.2%)	267 (0.5%)	1 (0.1%)
Missing data	33,228 (36.4%)	46,823 (39.9%)	17,630 (33.0%)	622 (33.5%)
ECI*	−2.07 ± 5.69	−0.640 ± 6.87	1.48 ± 8.41	4.76 ± 10.1
Length of stay* *(days)*	8.34 ± 6.45	9.29 ± 8.00	10.6 ± 7.60	12.9 ± 7.80
Comorbidities†				
Congestive heart failure	2,242 (2.5%)	6,014 (5.1%)	5,210 (9.8%)	345 (18.6%)
Cardiac arrhythmias	5,859 (6.4%)	16,515 (14.1%)	11,429 (21.4%)	507 (27.3%)
Cardiac valve disease	1,146 (1.3%)	3,434 (2.9%)	2,847 (5.3%)	162 (8.7%)
Pulmonary circulation disorders	180 (0.2%)	625 (0.5%)	609 (1.1%)	47 (2.5%)
Peripheral vascular disorders	2,162 (2.4%)	4,017 (3.4%)	2,340 (4.4%)	90 (4.8%)
Hypertension				
Uncomplicated	51,732 (56.6%)	78,638 (67.0%)	38,474 (72.0%)	1,332 (71.7%)
Complicated	1,251 (1.4%)	3,078 (2.6%)	2,514 (4.7%)	121 (6.5%)
Paralysis	363 (0.4%)	605 (0.5%)	336 (0.6%)	13 (0.7%)
Other neurological disorders	1,197 (1.3%)	2,049 (1.7%)	1,088 (2.0%)	38 (2.0%)
Chronic pulmonary disease	7,465 (8.2%)	9,578 (8.2%)	4,272 (8.0%)	148 (8.0%)
Diabetes				
Uncomplicated	10,953 (12.0%)	16,886 (14.4%)	7,765 (14.5%)	179 (9.6%)
Complicated	1,003 (1.1%)	2,233 (1.9%)	1,428 (2.7%)	60 (3.2%)
Hypothyroidism	16,240 (17.8%)	22,781 (19.4%)	9,779 (18.3%)	324 (17.4%)
Renal failure	3,784 (4.1%)	10,931 (9.3%)	9,050 (16.9%)	510 (27.4%)
Liver disease	842 (0.9%)	832 (0.7%)	354 (0.7%)	12 (0.6%)
Peptic ulcer disease, excluding bleeding	20 (0.0%)	43 (0.0%)	24 (0.0%)	1 (0.1%)
HIV/AIDS‡	2 (0.0%)	3 (0.0%)	0 (0%)	0 (0%)
Lymphoma	92 (0.1%)	169 (0.1%)	81 (0.2%)	1 (0.1%)
Metastatic cancer	123 (0.1%)	194 (0.2%)	97 (0.2%)	6 (0.3%)
Solid tumor, without metastasis	369 (0.4%)	712 (0.6%)	361 (0.7%)	13 (0.7%)
Rheumatoid arthritis and/or collagen vascular disease	2,495 (2.7%)	3,621 (3.1%)	1,583 (3.0%)	36 (1.9%)
Coagulopathy	1,093 (1.2%)	1,764 (1.5%)	1,144 (2.1%)	53 (2.9%)
Obesity	19,522 (21.4%)	17,153 (14.6%)	5,195 (9.7%)	81 (4.4%)
Weight loss	570 (0.6%)	1,079 (0.9%)	960 (1.8%)	73 (3.9%)
Fluid and electrolyte disorders	5,654 (6.2%)	10,959 (9.3%)	8,050 (15.1%)	456 (24.5%)
Deficiency anemia	660 (0.7%)	1,281 (1.1%)	986 (1.8%)	55 (3.0%)
Alcohol abuse	408 (0.4%)	204 (0.2%)	45 (0.1%)	1 (0.1%)
Drug abuse	76 (0.1%)	157 (0.1%)	142 (0.3%)	6 (0.3%)

continued

TABLE I (*continued*)

	Age Groups			
	60-69 Yr (N = 91,363)	70-79 Yr (N = 117,324)	80-89 Yr (N = 53,421)	≥90 Yr (N = 1,859)
Psychoses	210 (0.2%)	150 (0.1%)	51 (0.1%)	1 (0.1%)
Depression	4,353 (4.8%)	4,694 (4.0%)	2,268 (4.2%)	82 (4.4%)
Osteoporosis	2,647 (2.9%)	6,092 (5.2%)	4,487 (8.4%)	211 (11.4%)

*The values are given as the mean and the standard deviation. †The values are given as the number of patients, with the percentage in parentheses. ‡HIV/AIDS = human immunodeficiency virus/acquired immunodeficiency syndrome.

the surgical procedure to the event was available, as follow-up ended with the death of the patient. Lastly, we compared 1-year mortality rates of the study population and the overall population. The starting point of the calculation for the mortality rate was age-specific mortality probabilities. This age-specific probability of mortality is defined as the probability of dying before reaching the next year of life. Statistical analysis was performed with R version 4.0.3 (R Foundation for Statistical Computing).

Source of Funding
No external funding was received for this study.

Results

A total of 1,859 nonagenarians (0.7%) were included in this study. Overall, a significantly higher ECI was noted in nonagenarians (mean ECI, 4.76 ± 10.1; $p < 0.001$), as well as significantly higher incidences of multiple comorbidities such as congestive heart failure, cardiac arrhythmia, renal failure,

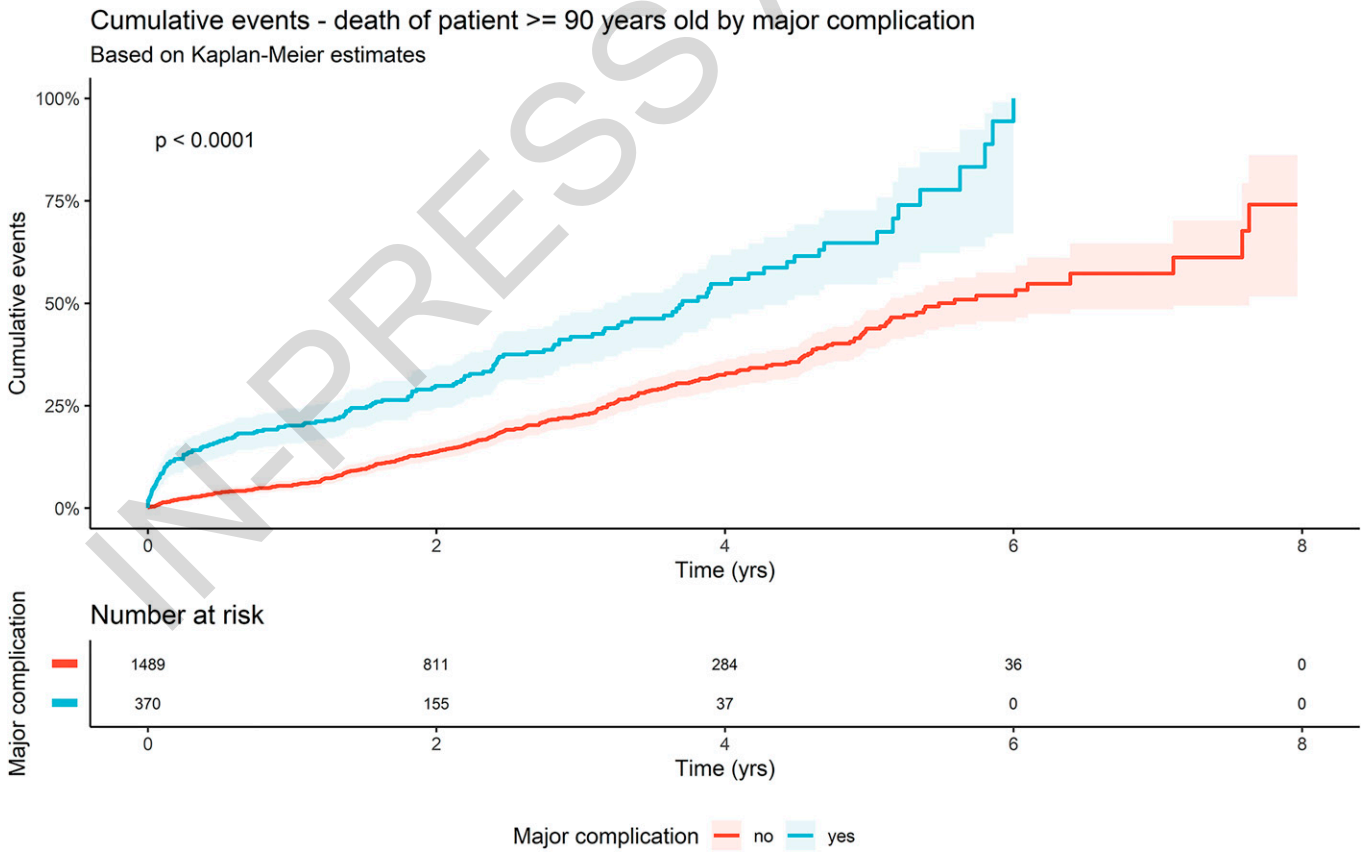

Fig. 1
Cumulative mortality of patients ≥90 years of age who did (blue line) and did not (red line) develop a major complication following THA. A full description of major complications in shown in the Appendix. The shaded areas depict the 95% CIs.

and fluid and electrolyte disorders. The mean postoperative length of stay was significantly increased for nonagenarians compared with younger groups ($p < 0.0001$). Table I provides detailed patient characteristics for the age groups.

Major complications, minor complications, and mortality were more frequent within the nonagenarian age group. Of the major complications reported, there were 370 (a rate of 19.9%) in nonagenarians, 5,709 (10.7%) in the 80 to 89-year-old group, 7,286 (6.2%) in the 70 to 79-year-old group, and 3,419 (3.7%) in the 60 to 69-year-old group. Among the most frequent major complications were acute renal failure, delirium, and coagulopathies. Patient death also occurred more often in the nonagenarian group compared with the younger groups. Overall, of the minor complications reported, there were 1,166 (62.7%) in nonagenarians, 23,068 (43.2%) in the 80 to 89-year-old group, 36,426 (31.0%) in the 70 to 79-year-old group, and 19,632 (21.5%) in the 60 to 69-year-old group. Among the most common minor complications were anemia, bleeding, postoperative exacerbation of chronic kidney disease not requiring dialysis, electrolyte disorders, and respiratory failure. The mortality rate was reported as 26.5% (492 patients) for nonagenarians, 11.8% (6,279 patients) for the 80 to 89-year-old group, 6.0% (7,090 patients) for the 70 to 79-year-old group, and 2.8% (2,589 patients) for the 60 to 69-year-old group. Figure 1 shows mortality as a function of major complications, and Figure 2 shows mortality as a function of minor complications. A detailed overview of postoperative major and minor complications and mortality is shown in Table II.

Among the greatest risk factors for a major complication were coagulopathies (odds ratio [OR], 16.868 [95% confidence interval (CI), 16.523 to 17.219]; $p < 0.001$), paralysis (OR, 9.355 [95% CI, 8.906 to 9.826]; $p < 0.001$), pulmonary circulation disorders (OR, 7.645 [95% CI, 7.224 to 8.090]; $p < 0.001$), weight loss (OR, 3.881 [95% CI, 3.622 to 4.158]; $p < 0.001$), metastatic cancer (OR, 3.761 [95% CI, 3.168 to 4.466]; $p < 0.001$), fluid and electrolyte disorders (OR, 3.680 [95% CI, 3.567 to 3.796]; $p < 0.001$), congestive heart failure (OR, 3.517 [95% CI, 3.388 to 3.650]; $p < 0.001$), alcohol abuse (OR, 3.293 [95% CI, 2.835 to 3.825]; $p < 0.001$), and renal failure (OR, 3.208 [95% CI, 3.105 to 3.314]; $p < 0.001$).

The greatest risk factors for minor complications were renal failure (OR, 3.764 [95% CI, 3.733 to 3.794]; $p < 0.001$), fluid and electrolyte disorders (OR, 3.543 [95% CI, 3.513 to 3.574]; $p < 0.001$), insulin-dependent diabetes (OR, 2.334 [95% CI, 2.288 to 2.381]; $p < 0.001$), weight loss (OR, 2.242 [95% CI, 2.182 to 2.303]; $p < 0.001$), metastatic cancer (OR, 2.141 [95% CI, 1.995 to 2.297]; $p < 0.001$), and coagulopathies (OR, 2.103 [95% CI, 2.052 to 2.155]; $p < 0.001$).

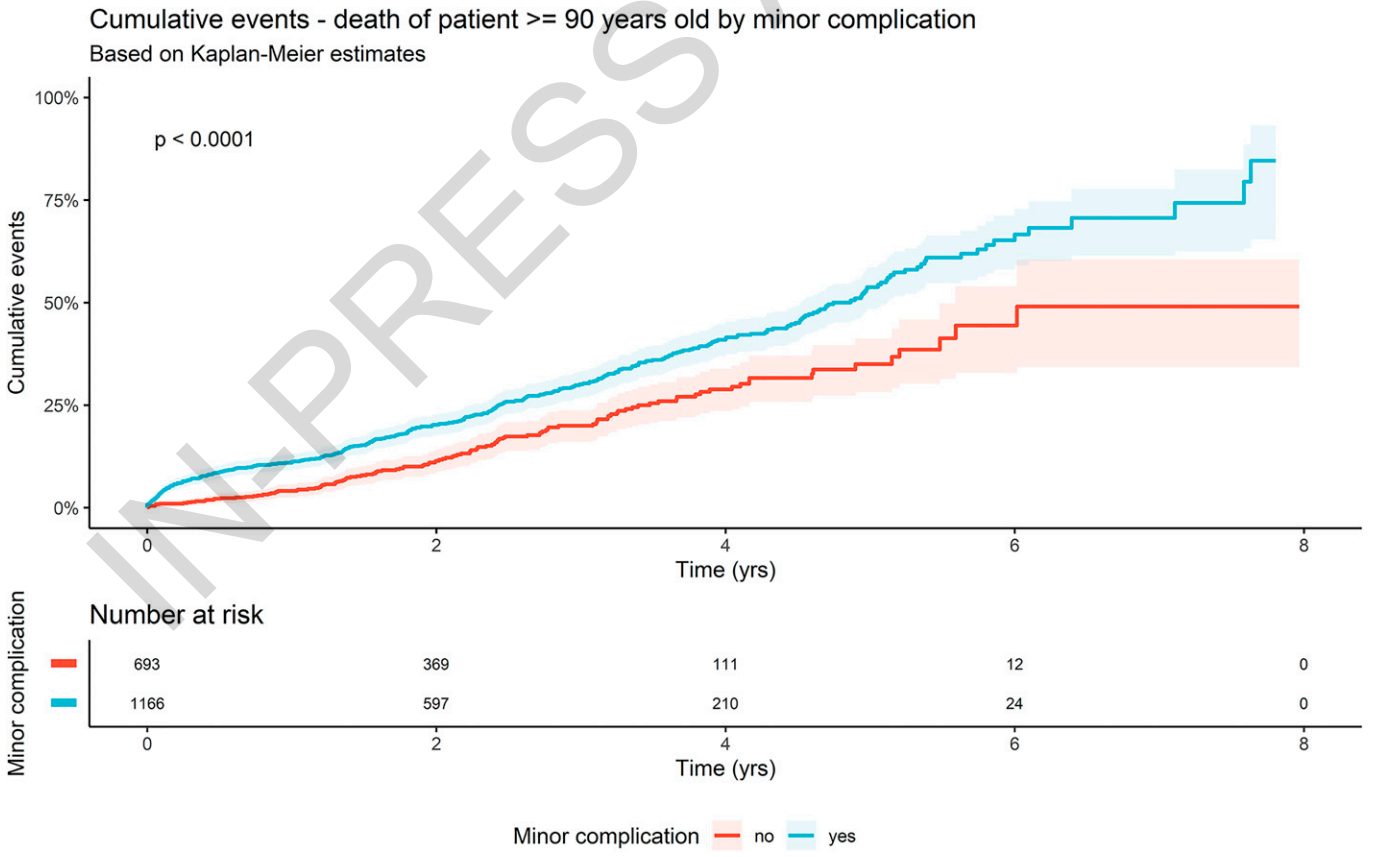

Fig. 2

Cumulative mortality of patients ≥90 years of age who did (blue line) and did not (red line) develop a minor complication following THA. A full description of minor complications is shown in the Appendix. The shaded areas depict the 95% CIs.

TABLE II Frequencies of Postoperative Adverse Events

	60-69 Yr (N = 91,363)	70-79 Yr (N = 117,324)	80-89 Yr (N = 53,421)	≥90 Yr (N = 1,859)	P Value*
Follow-up† *(days)*	1,060 ± 645	1,110 ± 649	969 ± 608	851 ± 591	
Major adverse event‡	3,419 (3.7%)	7,286 (6.2%)	5,709 (10.7%)	370 (19.9%)	<0.0001
Mechanical complication	220 (0.2%)	402 (0.3%)	284 (0.5%)	11 (0.6%)	<0.0001
Stress fracture	10 (0.0%)	24 (0.0%)	20 (0.0%)	1 (0.1%)	0.017
Periprosthetic fracture	746 (0.8%)	1,113 (0.9%)	524 (1.0%)	23 (1.2%)	0.005
Cerebrovascular event	357 (0.4%)	699 (0.6%)	430 (0.8%)	16 (0.9%)	<0.0001
Pulmonary embolism	79 (0.1%)	189 (0.2%)	157 (0.3%)	7 (0.4%)	<0.0001
Myocardial infarction	85 (0.1%)	294 (0.3%)	278 (0.5%)	23 (1.2%)	<0.0001
Sepsis	52 (0.1%)	130 (0.1%)	124 (0.2%)	9 (0.5%)	<0.0001
Acute renal failure	572 (0.6%)	1,871 (1.6%)	1,798 (3.4%)	123 (6.6%)	<0.0001
Periprosthetic joint infection	265 (0.3%)	483 (0.4%)	279 (0.5%)	10 (0.5%)	<0.0001
Shock	145 (0.2%)	186 (0.2%)	119 (0.2%)	6 (0.3%)	0.017
Cardiac arrest	81 (0.1%)	142 (0.1%)	119 (0.2%)	9 (0.5%)	<0.0001
Gastrointestinal bleeding	20 (0.0%)	51 (0.0%)	46 (0.1%)	6 (0.3%)	<0.0001
Delirium	202 (0.2%)	1,256 (1.1%)	1,748 (3.3%)	175 (9.4%)	<0.0001
Nerve lesion	16 (0.0%)	27 (0.0%)	9 (0.0%)	0 (0%)	0.691
Coagulopathy	891 (1.0%)	1,463 (1.2%)	975 (1.8%)	43 (2.3%)	<0.0001
SIRS§	74 (0.1%)	174 (0.1%)	155 (0.3%)	9 (0.5%)	<0.0001
Coagulopathy, acquired	197 (0.2%)	414 (0.4%)	317 (0.6%)	19 (1.0%)	<0.0001
Minor adverse event‡	19,632 (21.5%)	36,426 (31.0%)	23,068 (43.2%)	1,166 (62.7%)	<0.0001
Deep vein thrombosis	165 (0.2%)	355 (0.3%)	219 (0.4%)	11 (0.6%)	<0.0001
Bacterial pneumonia	29 (0.0%)	93 (0.1%)	101 (0.2%)	7 (0.4%)	<0.0001
Other pneumonia	120 (0.1%)	392 (0.3%)	420 (0.8%)	29 (1.6%)	<0.0001
Exacerbation of chronic kidney disease	3,124 (3.4%)	9,362 (8.0%)	7,901 (14.8%)	467 (25.1%)	<0.0001
Anemia	13,341 (14.6%)	24,266 (20.7%)	15,308 (28.7%)	856 (46.0%)	<0.0001
Bleeding	1,212 (1.3%)	2,224 (1.9%)	1,389 (2.6%)	71 (3.8%)	<0.0001
Electrolyte disorder	4,113 (4.5%)	7,563 (6.4%)	5,253 (9.8%)	295 (15.9%)	<0.0001
Respiratory failure	691 (0.8%)	1,388 (1.2%)	1,229 (2.3%)	97 (5.2%)	<0.0001
Gastritis	42 (0.0%)	96 (0.1%)	86 (0.2%)	8 (0.4%)	<0.0001
Mortality‡	2,589 (2.8%)	7,090 (6.0%)	6,279 (11.8%)	492 (26.5%)	<0.0001

*1-way ANOVA was used for continuous variables and the chi-square test was used for categorical variables; these were corrected for multiple testing with the Holm method. †The values are given as the mean and the standard deviation. ‡The values are given as the number of patients, with the percentage in parentheses. §SIRS = systemic inflammatory response syndrome.

Death was more likely if metastatic cancer (OR, 11.063 [95% CI, 10.341 to 11.836]; $p < 0.001$), pulmonary circulation disorders (OR, 3.952 [95% CI, 3.605 to 4.332]; $p < 0.001$), alcohol abuse (OR, 3.286 [95% CI, 2.824 to 3.825]; $p < 0.001$), paralysis (OR, 3.165 [95% CI, 2.834 to 3.536]; $p < 0.001$), or congestive heart failure (OR, 3.13 [95% CI, 3.009 to 3.257]; $p < 0.001$) existed. Table III provides a detailed overview of risk factors for complications and mortality.

Logistic regression analysis revealed a significantly higher risk for nonagenarians with regard to major complications, minor complications, and mortality compared with every other age group. When age was added as a continuous variable, there was a significantly increased risk of major complications for each additional year of life within the nonagenarian group compared with the overall risk within the entire study cohort. For each year of life, the risk of major complications increased by 4.8% (OR, 1.048 [95% CI, 1.044 to 1.051]; $p < 0.0001$) in the entire study cohort. In nonagenarians, the increase in risk was 42.6% (OR, 1.426 [95% CI, 1.208 to 1.684]; $p < 0.0001$) for each year of life. The results of the logistic regression analysis are shown in Table IV.

For each additional year of life, the risk of minor complications increased by 2.5% (OR, 1.025 [95% CI, 1.024 to 1.027]; $p < 0.001$) in the entire study cohort, and by 38.6% (OR, 1.386 [95% CI, 1.204 to 1.596]; $p < 0.001$) in nonagenarians. The detailed results for minor complications, major complications, and mortality are shown in Table III.

TABLE III Risk Factors for Major Complications, Minor Complications, and Mortality

	Major Complications		Minor Complications		Mortality	
	OR*	P Value†	OR*	P Value†	OR*	P Value†
Sex						
Female	1		1		1	
Male	1.226 (1.190 to 1.263)	<0.001	0.833 (0.822 to 0.844)	<0.001	1.479 (1.436 to 1.524)	<0.001
Coagulopathy	16.868 (16.523 to 17.219)	<0.001	2.103 (2.052 to 2.155)	<0.001	2.798 (2.610 to 3.001)	<0.001
Paralysis	9.355 (8.906 to 9.826)	<0.001	1.777 (1.689 to 1.868)	<0.001	3.165 (2.834 to 3.536)	<0.001
Pulmonary circulation disorders	7.645 (7.224 to 8.090)	<0.001	2.374 (2.297 to 2.453)	<0.001	3.952 (3.605 to 4.332)	<0.001
Weight loss	3.881 (3.622 to 4.158)	<0.001	2.242 (2.182 to 2.303)	<0.001	2.528 (2.311 to 2.765)	<0.001
Metastatic cancer	3.761 (3.168 to 4.466)	<0.001	2.141 (1.995 to 2.297)	<0.001	11.063 (10.341 to 11.836)	<0.001
Fluid and electrolyte disorders	3.680 (3.567 to 3.796)	<0.001	3.543 (3.513 to 3.574)	<0.001	2.354 (2.270 to 2.440)	<0.001
Congestive heart failure	3.517 (3.388 to 3.650)	<0.001	2.121 (2.090 to 2.152)	<0.001	3.13 (3.009 to 3.257)	<0.001
Alcohol abuse	3.293 (2.835 to 3.825)	<0.001	1.742 (1.620 to 1.873)	<0.001	3.286 (2.824 to 3.825)	<0.001
Renal failure	3.208 (3.105 to 3.314)	<0.001	3.764 (3.733 to 3.794)	<0.001	2.624 (2.534 to 2.718)	<0.001
Hypertension, complicated	2.985 (2.833 to 3.145)	<0.001	2.065 (2.025 to 2.106)	<0.001	2.394 (2.256 to 2.540)	<0.001
Insulin-dependent diabetes	2.953 (2.774 to 3.143)	<0.001	2.334 (2.288 to 2.381)	<0.001	2.673 (2.500 to 2.857)	<0.001
Cardiac valve disease	2.862 (2.719 to 3.014)	<0.001	1.774 (1.735 to 1.814)	<0.001	2.525 (2.389 to 2.669)	<0.001
Drug abuse	2.856 (2.306 to 3.537)	<0.001	1.961 (1.805 to 2.131)	<0.001	2.872 (2.314 to 3.564)	<0.001
Cardiac arrhythmias	2.619 (2.537 to 2.703)	<0.001	1.632 (1.611 to 1.654)	<0.001	2.301 (2.226 to 2.378)	<0.001
Liver disease	2.472 (2.231 to 2.738)	<0.001	1.562 (1.491 to 1.636)	<0.001	2.296 (2.061 to 2.558)	<0.001
Psychoses	2.257 (1.781 to 2.859)	<0.001	1.613 (1.462 to 1.781)	<0.001	2.263 (1.782 to 2.875)	<0.001
Peripheral vascular disorders	2.036 (1.921 to 2.157)	<0.001	1.545 (1.509 to 1.582)	<0.001	2.248 (2.126 to 2.377)	<0.001

*The values are given as the OR, with the 95% CI in parentheses, and sorted by descending OR for major complications. †Determined with use of the Fisher exact test and adjusted for multiple testing with the Holm method.

The risk of mortality was significantly higher in patients who developed major complications, beginning within the first year after THA compared with patients who did not sustain any complications. Nonagenarians with major complications had higher mortality (OR, 2.514 [95% CI, 1.461 to 4.327]; p = 0.001) than nonagenarians without any complications (OR, 2.048 [95% CI, 1.494 to 2.805]; p < 0.001). Notably, the main increase was observed within the first month after THA, accounting for the largest increase after 1 year. The survival rate at 1 year postoperatively was 94.4% (95% CI, 93.2% to 95.6%; p < 0.001) in patients without any major complication compared with 79.8% (95% CI, 75.8% to 84.1%; p < 0.001) in patients who had a major complication. This effect persisted until 5 years after the THA, at which time the survival rate was 56.2% (95% CI, 51.7% to 61.0%; p < 0.001) for patients without a major complication and 35.3% (95% CI, 27.4% to 45.4%; p < 0.001) for patients with a major complication.

A similar trend shows the risk for mortality if minor complications occur. Likewise, the largest increase was within the first month after THA compared with patients without any complications. Nonagenarians with minor complications had a higher mortality rate (OR, 2.194 [95% CI, 1.584 to 3.04]; p < 0.001) than nonagenarians without any complications (OR, 2.037 [95% CI, 1.241 to 3.343]; p = 0.005). The survival rate at 1 year postoperatively was 95.9% (95% CI, 94.4% to 97.8%; p < 0.001) in patients without any minor complication compared with 88.8% (95% CI, 87.0% to 90.7%; p < 0.001) in patients who had minor complications. At 5 years after THA, the survival rate was 46.2% (95% CI, 41.4% to 51.5%; p < 0.001) for patients with minor complications and 65.0% (95% CI, 58.8% to 71.8%; p < 0.001) for patients without any complications. When comparing mortality rates of nonagenarians within the study population with the corresponding age group in the

TABLE IV Logistic Regression for Major Complications, Minor Complications, and Mortality

	Estimated Log-Odds*	OR†	P Value
Major complication			
Age, continuous, per yr	0.046 ± 0.002 (0.043 to 0.050)	1.048 (1.044 to 1.051)	<0.0001
Age: 60-69 yr	−1.542 ± 0.099 (−1.737 to −1.347)	0.214 (0.176 to 0.260)	<0.0001
Age: 70-79 yr	−1.131 ± 0.098 (−1.322 to −0.939)	0.323 (0.267 to 0.391)	<0.0001
Age: 80-89 yr	−0.754 ± 0.098 (−0.946 to −0.563)	0.470 (0.388 to 0.569)	<0.0001
Reference: ≥90 yr	—	—	
Minor complication			
Age, continuous, per yr	0.025 ± 0.001 (0.023 to 0.027)	1.025 (1.024 to 1.027)	<0.0001
Age: 60-69 yr	−0.943 ± 0.072 (−1.084 to −0.802)	0.389 (0.338 to 0.449)	<0.0001
Age: 70-79 yr	−0.741 ± 0.071 (−0.881 to −0.601)	0.477 (0.414 to 0.548)	<0.0001
Age: 80-89 yr	−0.517 ± 0.072 (−0.657 to −0.377)	0.596 (0.518 to 0.686)	<0.0001
Reference: ≥90 yr	—	—	
Mortality			
Age, continuous, per yr	0.072 ± 0.001 (0.069 to 0.075)	1.075 (1.071 to 1.078)	<0.0001
Age: 60-69 yr	−2.61 ± 0.139 (−2.882 to −2.338)	0.074 (0.056 to 0.097)	<0.0001
Age: 70-79 yr	−2.037 ± 0.138 (−2.308 to −1.767)	0.130 (0.099 to 0.171)	<0.0001
Age: 80-89 yr	−1.440 ± 0.138 (−1.711 to −1.169)	0.237 (0.181 to 0.311)	<0.0001
Reference: ≥90 yr	—	—	

*The values are given as the estimated log-odds and the standard error, with the 95% CI in parentheses. †The values are given as the OR, with the 95% CI in parentheses.

general population, the study population had a lower mortality rate when no complications occurred. In the cases of major or minor complications, mortality rates were significantly higher. Because of the relatively small cohort size, the 1-year mortality rate among 91-year-old and 92-year-old men in our study cohort was 0% (Table V).

Discussion

The indication for THA in elderly patients, especially those ≥90 years of age, is controversial. With the absolute and relative increases in the proportion of this age group in the total population, the consideration of risk factors and the available data are becoming increasingly important for the adequate counseling of patients. The main finding of the present study is that patients ≥90 years of age had a significantly higher risk of postoperative major complications during the inpatient stay and death afterwards compared with younger patients. Also, minor complications occurred significantly more frequently in nonagenarians than in younger age groups. Comorbidities were associated with a higher risk of postoperative major and minor complications as well as death. Nevertheless, the mortality rates of nonagenarians undergoing THA remained lower compared with the general population of nonagenarians.

Preexisting and potentially modifiable comorbidities that were highly associated with postoperative complications or mortality included renal failure and fluid and electrolyte disorders (Table III). Adequate preoperative detection and treatment of chronic renal dysfunction and associated electrolyte imbalance are therefore of particular importance. This can be accomplished by widely available laboratory tests, as previously described in the literature[14]. Once identified, complications can be prevented by appropriate perioperative management, thus improving outcome[15]. Other frequently preexisting risk factors in the study cohort that were associated with complications and mortality were congestive heart failure and coagulopathies (Table III). In addition to optimization of risk factors, patient selection and education with regard to risk factors are paramount. Therefore, it is crucial to identify and address these modifiable comorbidities in order to prevent postoperative complications[16,17].

The most severe complication that can occur after a surgical procedure is the death of the patient. The results of our study show higher mortality rates of patients ≥90 years of age compared with younger patients (Table IV). However, the mortality of the patient cohort did not substantially differ from the mortality in this age group in the general population (Table V).

Naturally, the life expectancy of nonagenarians is limited to a greater extent than that of younger counterparts. In our cohort, the 1-year mortality rate for ≥90-year-old patients was 10.5% for men and 6.4% for women. However, because these mortality rates were noticeably lower than those in the overall population of ≥90-year-old individuals, even ≥90-year-old patients with postoperative complications had a slightly lower mortality rate than the reference group of ≥90-year-old individuals in the general population[11]. We believe that this was most likely because elderly patients who become candidates for elective THA are healthier and biologically younger than the reference group of the general population; the resulting selection bias

TABLE V Comparison of Mortality Rates in the Study Population and the German General Population

	1-Year Mortality Rate Stratified by Complications*	1-Year Mortality Rate of the Overall Population
Men		
70 years of age		2.3%
Major complications	7.9% (4.6% to 12.5%)	
Minor complications only	1.7% (0.9% to 3.1%)	
No complications	0.7% (0.5% to 1.1%)	
80 years of age		5.6%
Major complications	12.1% (8.6% to 15%)	
Minor complications only	4.3% (3.1% to 5.7%)	
No complications	1.8% (1.3% to 2.5%)	
90 years of age		18.5%
Major complications	23.5% (11.6% to 36.8%)	
Minor complications only	5.5% (1.8% to 15.8%)	
No complications	3.8% (0.9% to 14.2%)	
91 years of age		20.2%
Major complications	22.8% (9.3% to 43.5%)	
Minor complications only	9.8% (4% to 21.1%)	
No complications	0% (0% to 0%)	
92 years of age		22.7%
Major complications	27.8% (7% to 71.1%)	
Minor complications only	4.5% (0.7% to 28.1%)	
No complications	0% (0% to 0%)	
93 years of age		24.7%
Major complications	51% (19.9% to 73%)	
Minor complications only	14.8% (3.8% to 46.1%)	
No complications	8.3% (1.2% to 46.1%)	
Women		
70 years of age		1.3%
Major complications	2.8% (1.3% to 5.7%)	
Minor complications only	1.5% (1% to 2.3%)	
No complications	0.5% (0.3% to 0.8%)	
80 years of age		3.6%
Major complications	6.2% (4.4% to 8.2%)	
Minor complications only	1.7% (1.3% to 2.3%)	
No complications	1.1% (0.8% to 1.5%)	
90 years of age		14.7%
Major complications	14.3% (7.6% to 23%)	
Minor complications only	5.8% (3.4% to 9.4%)	
No complications	2.8% (1.2% to 6.5%)	
91 years of age		16.5%
Major complications	16.1% (8.4% to 26.1%)	
Minor complications only	7.2% (3.9% to 12.3%)	
No complications	1.0% (0.1% to 6.7%)	
92 years of age		18.7%
Major complications	32.5% (16.2% to 46%)	
Minor complications only	8.4% (4.1% to 15.7%)	
No complications	7.9% (3.3% to 17.5%)	

continued

TABLE V (*continued*)

	1-Year Mortality Rate Stratified by Complications*	1-Year Mortality Rate of the Overall Population
93 years of age		20.8%
Major complications	17.8% (7.3% to 35.4%)	
Minor complications only	13.3% (6.5% to 23.6%)	
No complications	1.8% (0.2% to 11.8%)	

*The values are shown as the mortality rate within 1 year, assessed using the Kaplan-Meier estimator, with the 95% CI in parentheses.

would be expected to lower the mortality of the nonagenarians in the study cohort. Nevertheless, considerable mortality must be anticipated in nonagenarians regardless of whether or not they undergo THA. Thus, there should be a focus on avoiding complications associated with preexisting comorbidities and frailty. Identifying comorbidities in the best possible way and then optimizing patients preoperatively by prehabilitative measures are therefore of crucial importance. It has been previously shown, in the context of arthroplasty as well as in other surgical fields, that elderly patients benefit from prehabilitation measures, as a better postoperative outcome can be achieved with their implementation[18-21]. Therefore, preoperative optimization should play a central role in the future of orthopaedic surgery.

With rising health-care costs and limited financial resources, the economics of THA in the elderly population have been an increasing focus among science and policymakers[22,23]. Postoperative complications due to preexisting comorbidities have been shown to be associated with longer inpatient stay, higher readmission rates, and, thus, substantial treatment costs, which further emphasizes the importance of detailed preparation of individual patients and, thus, avoidance of postoperative complications[17,24]. This was partially reflected in our data, as older patient groups, who more frequently had comorbidities, had significantly longer inpatient stays than younger patients.

The present study had several limitations. The EPRD collects data from hospitals nationwide and additionally from health insurers. The EPRD collecting data from health insurers ensures consistent recording of mortality and arthroplasty failure among all patients and nearly complete capture of these outcomes. However, the coding of diagnoses for comorbidities and postoperative complications may be subject to human error and bias. This is an inherent problem of registries and must be considered when analyzing their data. Furthermore, only data from insurance records were available after the observation period of the inpatient stay. Therefore, not all complications may have been recorded. However, the mean length of stay in nonagenarians was relatively long, 12.9 ± 7.80 days, compared with data from other national arthroplasty registries[25]. Another limitation was the relatively short follow-up, including patients followed for <2 years. However, considering the life expectancy of very elderly patients, a short-term follow-up with the end point of mortality seems equally important to report.

It must also be taken into account that patients undergoing elective hip surgery at the age of ≥90 years may be healthier than the national mean, which could result in a selection bias. However, the lower mortality rates of the study cohort show that, with good patient selection and preparation, elective THA can be performed safely in very elderly patients. Lastly, it must be noted that the total population used as a comparison group includes individuals who have and have not undergone THA.

In conclusion, comorbidities, which are frequently present in nonagenarians, were associated with a higher prevalence of postoperative complications after elective THA and thus with increased postoperative morbidity. Mortality was also increased in patients who developed complications. However, the fact that mortality was still lower than in the general population shows that this aspect can be controlled by careful patient selection and adequate preparation. Therefore, elective THA can be appropriately considered by surgeons and patients when symptoms of hip osteoarthritis are present in nonagenarians.

Appendix

eA Supporting material provided by the authors is posted with the online version of this article as a data supplement at http://jbjs.org (http://links.lww.com//JBJS/H588). ■

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