Cognitive Functioning after Surgery in Middle-aged and Elderly Danish Twins


Submitted for publication March 8, 2015. Accepted for publication August 6, 2015. From the Unit of Epidemiology, Biostatistics, and Biodemography, and the Danish Aging Research Center, Department of Public Health, University of Southern Denmark, Odense, Denmark; Departments of Anaesthesiology and Intensive Care Medicine (T.G.H.), Clinical Biochemistry and Pharmacology (K.C.), and Clinical Genetics (J.M.-F., K.C.), Odense University Hospital, Odense, Denmark; and Department of Anaesthesia, Centre of Head and Orthopaedics, Rigshospitalet, University of Copenhagen, Copenhagen, Denmark (L.S.R.).

ABSTRACT

Background: Postoperative cognitive dysfunction is common, but it remains unclear whether there are long-term adverse cognitive effects of surgery combined with anesthesia. The authors examined the association between exposure to surgery and level of cognitive functioning in a sample of 8,503 middle-aged and elderly twins.

Methods: Results from five cognitive tests were compared in twins exposed to surgery, classified as major, minor, hip and knee replacement, or other, with those of a reference group without surgery using linear regression adjusted for sex and age. Genetic and shared environmental confounding was addressed in intrapair analyses of 87 monozygotic and 124 dizygotic same-sexed twin pairs in whom one had a history of major surgery and the other did not.

Results: Statistically significantly lower composite cognitive score was found in twins with at least one major surgery compared with the reference group (mean difference, −0.27; 95% CI, −0.48 to −0.06), corresponding to one tenth of an SD, that is, a negligible effect size. In the intrapair analysis, the surgery-exposed co-twin had the lower cognitive score in 49% (95% CI, 42 to 56%) of the pairs. None of the other groups differed from the reference group except the knee and hip replacement group that tended to have higher cognitive scores (mean difference, 0.35; 95% CI, −0.18 to 0.87).

Conclusions: A history of major surgery was associated with a negligibly lower level of cognitive functioning. The supplementary analyses suggest that preoperative cognitive functioning and underlying diseases were more important for cognitive functioning in mid- and late life than surgery and anesthesia. (ANESTHESIOLOGY 2016; 124:312-21)

Cognitive impairment is a well-known complication after surgery with delirium and postoperative cognitive dysfunction (POCD) as the most common disorders.1 Early (7 days) POCD occurs in adult surgical patients of all ages, but elderly patients are at higher risk, and at 3 months after surgery, cognitive impairment is still detectable in patients older than 60 yr.2–5 POCD may be present for longer than 6 months in some patients6 with potential long-term implications for the patient including impaired quality of life,7,8 increased mortality risk,3,9 higher prevalence of time receiving welfare benefits, and increased risk of leaving the labor market prematurely.9

In recent years, POCD has received increasing attention in the literature, and several pathophysiologic factors and pathways have been suggested, including anesthetics and inflammatory response to the surgical trauma.10 Animal
studies suggest that general anesthetics are a possible patho-
genic factor of POCD as brain cell damages, apoptosis, and
decrease in cognitive skills are seen in animals after prolonged
exposure.11–15 On the basis of the evidence from the human
studies, type of surgery is suggested as a risk factor of POCD
as the incidence of early POCD after minor surgery was
significantly lower than after major surgery.16 Several expla-
nations for this finding have been proposed including non-
resolution of the inflammatory response after surgery.10,17
Moreover, the disease prompting the surgery may be respon-
sible for the cognitive impairment as two very common dis-
eses among the elderly, namely cardiac disease and cancer,
are found to be associated with cognitive impairment.18–20
A longitudinal study has shown that patients with coronary
artery disease showed significant declines in different cogni-
tive domains after 6 yr of follow-up, regardless of whether
they had on-pump coronary artery bypass graft surgery, off-
pump coronary artery bypass graft surgery, or no surgery.19
Furthermore, the incidence of cognitive impairment in
colorectal cancer patients before chemotherapy is more than
three times that of aged-matched healthy controls.20 No
differences were found by disease stage or between patients
pre- and postoperatively, indicating that factors other than
surgery and anesthesia were responsible for the higher pro-
portion of cognitive impairment in these patients at baseline.
Mild cognitive impairment with memory deficits has been
shown to associate with subsequent dementia, particularly
Alzheimer’s disease (AD),21 and it has further been suggested
that POCD and dementia share some of the perioperative risk
factors, including anesthetics.22 However, a meta-analysis23
including 15 case–control studies found that a history of expo-
sure to general anesthesia was not associated with an increased
risk of AD, and also in a recent cohort study, it was not possible
to ascertain an association between POCD and dementia.24

Our aim was to examine the association between expo-
sure to surgery and subsequent level of cognitive functioning
in a very large population of middle-aged and elderly twins
with almost complete records of surgeries since 1977, hereby
enabling us to test for more subtle differences in cognitive
functioning. The use of a twin design further enabled us to
tackle the potential confounding from shared environmen-
tal and genetic factors as an approach to adjust for preopera-
tive cognitive functioning.

Materials and Methods

The current study was based on the linkage of the intake exami-
nation data of the Longitudinal Study of Middle-Aged Danish
Twins (MADT) and the Longitudinal Study of Aging Danish
Twins (LSADT) in Copenhagen. Both studies included an assessment
of cognitive functioning and have previously been described in
detail elsewhere.25–27 In brief, participants in the MADT and
the LSADT were ascertained through the Danish Twin Registry
comprising twin pairs born in 1870 to 2004 and considered

representative of the general population in Denmark.28,29 The
MADT represented a random sample of 120 intact twin pairs
from each birth cohort from 1931 to 1952. The LSADT was
initiated in 1995 and included Danish twins aged 75 yr or older
and residing in Denmark by January 1995. Further cohorts
aged at least 70 yr were added in 1997, 1999, and 2001.

The MADT and the LSADT included a questionnaire on
sociodemographic factors, health and diseases, and life style
factors along with physical and cognitive tests. We excluded
patients who had undergone neurosurgery.

Register Linkage

Since 1968, all Danish citizens have been assigned a unique
10-digit identifier, the central personal register number
(the CPR number), which is the key to individual informa-
tion in all official registries covering the Danish population.30
Within Statistics Denmark, the central personal register
enables the linkage between Danish registries, including the
Danish NPR. The Danish NPR comprises data on surgeries
performed in Danish hospitals since 1977 along with data on
diagnoses. Until 1996, the Danish National Board of
Health’s Classification of Surgeries was used to classify sur-
geries, and from 1996, the Nordic Classification of Surgical
Procedures was used. Data on outpatients and emergency
patients were added in 1995.31 Thus, the register has nation-
wide coverage and is considered to have high validity, espe-
cially with regard to surgical procedures.32

Exposure Assessment

The exposure group encompassed twins who had at least one
surgical procedure within 18 to 24 yr before intake cognitive
examination. The exposure group was separated into four
groups by type of surgical procedure taking into account the
severity of the underlying disease: (1) major surgeries, includ-
ing cardiac, thoracic, laparotomy, central and peripheral vascu-
lar, and major fracture surgeries; (2) knee and hip replacement
surgeries; (3) minor surgeries; and (4) other surgeries. Minor
surgeries included all-day only procedures, surgeries followed
by less than 2 days of hospitalization, and, independently of
the first two criteria, surgery codes representing eye, skin,
endoscopic procedures along with biopsies and other small
surgical procedures. The classification was performed by two
experienced anesthesiologists (T.G.H. and L.S.R.), who, inde-
dependently of one another, went through the records of surgery
codes in the study sample for the period from 1977 and until
intake examination (details can be found in the appendix).

Twins who had more than one surgical procedure were
assigned to the groups using the following algorithm: (1) major
surgery if any; (2) knee and hip replacement surgery if any, but
no major surgery; and (3) other surgeries if any, but neither
major nor knee and hip replacement surgery. The reference
group in all analyses comprised twins with no surgical pro-
cedures from 1977 and until intake examination. The expo-
sure was reassessed by using three more narrow time frames
to assess whether time since surgery modified the association
between exposure to surgery and cognitive performance: (1) 2 yr (2) 1 yr, and (3) 3 months preceding intake examination. Also the effect of cumulative exposures was investigated based on the type of surgical procedures carried out from 1977 and until cognitive examination. Five exposure groups were defined according to both the type and number of surgeries performed: (1) minor surgeries, (2) one major/other surgery, (3) two major/other surgeries, (4) three major/other surgeries, and (5) more than three major/other surgeries.

**Outcome Measurement**

The outcome was cognitive functioning assessed by a five-component test battery. The specific tasks included in the test battery were (1) a category fluency task, in which individuals were asked to name as many animals as they could during a 1-min interval, (2) forward and (3) backward digit span, and (4) immediate and (5) delayed recall of a 12-item list. An overall composite measure of cognitive functioning was computed by adding the five standardized scores (using mean and SD from participants aged 45 to 49 yr) of each of the five-component tasks. The composite cognitive score has been used in a series of previous studies. It has been shown to be a valid, reliable, and very age-sensitive measure of cognitive functioning although moderately stable over a 2-yr interval (0.60), and it has a high internal consistency reliability (0.75).

**Covariates**

Potential confounders were identified in other similar studies, including sex, age, and educational attainment. However, as the effect sizes were similar regardless of whether educational attainment was included in the statistical model, this covariate was omitted in the analyses.

**Intrapair Analyses**

To address genetic and shared environmental confounding and to take preoperative cognition into account, intrapair analyses were performed. The 8,503 twins in the study population consisted of 1,065 monozygotic pairs and 1,179 dizygotic, same-sexed twin pairs, as well as 4,015 twin individuals from opposite-sexed pairs and "single twins," that is twins who had a co-twin who was either deceased or a nonparticipant. To avoid confounding by sex, the intrapair analyses only included same-sexed pairs. To obtain the biggest contrast in exposure, the intrapair analyses only included pairs in whom one had a history of major surgery and the other no surgery. Among the 1,065 monozygotic pairs, a total of 87 such pairs were identified, whereas the corresponding number for dizygotic twins was 124 among 1,179 pairs. Consequently, 211 exposure-discordant pairs were included in the intrapair analyses.

**Statistical Analyses**

Descriptive statistics were expressed as means and SDs for continuous variables and as numbers and proportions for categories. The comparisons of composite cognitive scores between twins exposed for at least one surgery (major, minor surgery, knee and hip replacement surgery, and other surgeries) before examination of cognitive functioning and twins not exposed were performed using multivariate linear regression models adjusting for sex and age at examination. The within-pair dependency of twin individuals was considered by estimating the standard errors using the cluster option of STATA (release 13; STATA Corp., USA). Model assumptions were checked by residual plots and quantile-quantile plots of residuals.

In the intrapair analyses, the proportion of pairs in which the co-twin who had been exposed to anesthesia and major surgery also had the lower composite cognitive score was calculated including the 95% CI using the binomial distribution.

**Results**

A total of 8,527 Danish twins with a valid cognitive score were included: 4,309 of 4,314 from the MADT (younger than 70 yr) and 4,218 of 4,731 from the LSADT (70 yr or older).

Of these participants, 65% had at least one surgery preceding intake examination. We excluded 24 twins with neurosurgery from the study: 10 from the MADT and 14 from the LSADT, reducing the sample sizes to 4,299 and 4,204, respectively (table 1).

Major surgery was slightly more common in twins aged 70 yr and older compared with twins younger than 70 yr (20 vs. 17%). The unadjusted mean cognitive scores varied slightly between exposure groups, whereas the cognitive scores were substantially lower for older compared with younger participants, as expected. However, twins aged 70 yr and older with knee and hip replacement surgery had the highest cognitive score (1.68) of surgery groups (ranging from 0.88 to 1.68) and even higher than the reference group (1.24).

Compared with the reference group, twins with major surgery preceding intake examination had slightly lower cognitive scores when adjusted for sex and age (mean difference, −0.27; 95% CI, −0.48 to −0.06) (table 2), which is equivalent to about one tenth of an SD (table 1), that is, negligible effect size.38 In contrast, we found that those with knee and hip replacement surgery had higher cognitive score at intake (mean difference, 0.35; 95% CI, −0.18 to 0.87) although the difference did not reach significance. For twins with minor or other surgical procedures, no differences were found in cognitive score in comparison with the reference group. Analyses stratified on overall age (younger than 70 yr and 70 yr or older) yielded similar estimates.

To further illustrate the effect size associated with major surgery (0.1 SD), we analyzed separately one of the cognitive tests included in the cognitive composite score, namely the animal fluency test (i.e., mention as many animals as possible in 1 min). Here, one tenth of an SD corresponds to 0.7 named animal. In the MADT, the mean number of animals...
In addition, analyses were stratified on the type and number of surgical procedures to investigate the dose–response pattern of cumulative exposure to surgery and anesthesia on cognitive impairment (table 3). We found that exposure to three or more surgeries was associated with significantly lower score, about one fifth of an SD.

The intrapair analysis of twin pairs in whom one had a history of major surgery and the other had no surgery was included to further adjust for genetic and shared environmental factors. In the analysis of all 211 discordant pairs, we found that the surgery-exposed twin had a lower cognitive score than the co-twin in 49% (95% CI, 42 to 56%) of the pairs (fig. 2), suggesting that it was as common to have the higher cognitive score when exposed to surgery as it was to have the lower cognitive score. When twin pairs were restricted according to the magnitude of the intrapair differences in cognitive score to the top 75, 50, and 25%, respectively, the analyses yielded similar results. This was

Table 1. Characteristics and Summary Statistics for Composite Cognitive Scores among Participants from the Study of Middle-aged Danish Twins (< 70 Yr) and the Longitudinal Study of Aging Danish Twins (≥ 70 Yr), in Totals and by Type of Surgical Procedure

<table>
<thead>
<tr>
<th>Surgical Procedure Groups</th>
<th>n (%</th>
<th>Differences in Cognitive Scores (95 % CI)</th>
<th>n (%</th>
<th>Differences in Cognitive Scores (95 % CI)</th>
<th>n (%</th>
<th>Differences in Cognitive Scores (95 % CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Totals</td>
<td>Major Surgery</td>
<td>Minor Surgery</td>
<td>Knee and Hip Replacement</td>
<td>Other Surgery</td>
<td>Without Surgery</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>All</td>
<td>8,503 (100)</td>
<td>1,546 (18)</td>
<td>1,729 (20)</td>
<td>171 (2)</td>
<td>2,092 (25)</td>
<td>2,965 (35)</td>
</tr>
<tr>
<td>&lt; 70 yr</td>
<td>4,299 (100)</td>
<td>732 (17)</td>
<td>1,004 (23)</td>
<td>38 (1)</td>
<td>1,043 (24)</td>
<td>1,482 (35)</td>
</tr>
<tr>
<td>≥ 70 yr</td>
<td>4,204 (100)</td>
<td>814 (20)</td>
<td>725 (17)</td>
<td>133 (3)</td>
<td>1,049 (25)</td>
<td>1,483 (35)</td>
</tr>
<tr>
<td>Female sex, n (%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>All</td>
<td>4,560 (54)</td>
<td>1,011 (65)</td>
<td>837 (48)</td>
<td>112 (66)</td>
<td>1,144 (55)</td>
<td>1,456 (49)</td>
</tr>
<tr>
<td>&lt; 70 yr</td>
<td>2,106 (49)</td>
<td>561 (77)</td>
<td>430 (43)</td>
<td>13 (34)</td>
<td>567 (54)</td>
<td>535 (36)</td>
</tr>
<tr>
<td>≥ 70 yr</td>
<td>2,454 (58)</td>
<td>450 (55)</td>
<td>407 (56)</td>
<td>99 (74)</td>
<td>577 (55)</td>
<td>921 (62)</td>
</tr>
<tr>
<td>Age, yr, mean (SD)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>All</td>
<td>67 (12)</td>
<td>68 (12)</td>
<td>65 (12)</td>
<td>74 (8)</td>
<td>67 (12)</td>
<td>67 (11)</td>
</tr>
<tr>
<td>&lt; 70 yr</td>
<td>57 (6)</td>
<td>57 (6)</td>
<td>57 (6)</td>
<td>61 (5)</td>
<td>56 (6)</td>
<td>57 (6)</td>
</tr>
<tr>
<td>≥ 70 yr</td>
<td>77 (5)</td>
<td>77 (5)</td>
<td>77 (5)</td>
<td>77 (5)</td>
<td>77 (5)</td>
<td>77 (5)</td>
</tr>
<tr>
<td>Cognitive score, mean (SD)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>All</td>
<td>2.89 (3.95)</td>
<td>2.58 (4.02)</td>
<td>3.17 (4.05)</td>
<td>2.26 (3.78)</td>
<td>2.94 (4.01)</td>
<td>2.89 (3.79)</td>
</tr>
<tr>
<td>&lt; 70 yr</td>
<td>4.59 (3.50)</td>
<td>4.47 (3.63)</td>
<td>4.62 (3.70)</td>
<td>4.26 (3.61)</td>
<td>4.73 (3.45)</td>
<td>4.54 (3.33)</td>
</tr>
<tr>
<td>≥ 70 yr</td>
<td>1.15 (3.60)</td>
<td>0.88 (3.58)</td>
<td>1.17 (3.63)</td>
<td>1.68 (3.65)</td>
<td>1.17 (3.74)</td>
<td>1.24 (3.49)</td>
</tr>
</tbody>
</table>

* Including cardiac, thoracic, laparotomy, central and peripheral vascular, and fracture surgeries.

Table 2. Mean Differences in Composite Cognitive Scores between Twins with Major, Minor, Knee and Hip Replacement, or Other Surgical Procedures and the Reference Group

<table>
<thead>
<tr>
<th>Surgical Procedure Groups</th>
<th>n</th>
<th>Differences in Cognitive Scores (95 % CI)*</th>
<th>n</th>
<th>Differences in Cognitive Scores (95 % CI)*</th>
<th>n</th>
<th>Differences in Cognitive Scores (95 % CI)*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Major†</td>
<td>Minor</td>
<td>Knee and hip replacement</td>
<td>Other</td>
<td>Without surgery</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Major†</td>
<td>1,546</td>
<td>−0.27 (−0.48 to −0.06)</td>
<td>732</td>
<td>−0.27 (−0.59 to 0.04)</td>
<td>814</td>
<td>−0.30 (−0.59 to −0.01)</td>
</tr>
<tr>
<td>Minor</td>
<td>1,729</td>
<td>−0.06 (−0.27 to 0.14)</td>
<td>1,004</td>
<td>−0.03 (−0.30 to 0.25)</td>
<td>725</td>
<td>−0.09 (−0.39 to 0.20)</td>
</tr>
<tr>
<td>Knee and hip replacement</td>
<td>171</td>
<td>0.35 (−0.18 to 0.87)</td>
<td>38</td>
<td>0.16 (−1.05 to 1.36)</td>
<td>133</td>
<td>0.35 (−0.23 to 0.92)</td>
</tr>
<tr>
<td>Other</td>
<td>2,092</td>
<td>−0.08 (−0.27 to 0.10)</td>
<td>1,043</td>
<td>−0.06 (−0.33 to 0.20)</td>
<td>1,049</td>
<td>−0.04 (−0.30 to 0.23)</td>
</tr>
<tr>
<td>Without surgery</td>
<td>2,965</td>
<td>Reference</td>
<td>1,482</td>
<td>Reference</td>
<td>1,483</td>
<td>Reference</td>
</tr>
</tbody>
</table>

* Multiple linear regression analysis adjusted for sex and age at intake examination. † Including cardiac, thoracic, laparotomy, central and peripheral vascular, and fracture surgeries.

named in 1 min is 24.2, and this means that a one tenth of an SD lower score corresponds to 23.5, which represents a difference that must be considered clinically unimportant. In comparison, the difference in cognitive score between the group younger than 70 yr and that older than 70 yr is about 0.9 SD (table 1), which in the animal fluency test would correspond to a six-word difference.

We also analyzed the data according to those who had undergone surgery up to 2 yr (n = 1,738), 1 yr (n = 1,109), or 3 months (n = 391), respectively, preceding intake examination (fig. 1). Overall, the mean differences in cognitive scores in the surgery groups compared with those without surgery in the same periods were similar across strata. Although the majority of estimates did not reveal statistical significance, the results indicated no interaction of time since surgery with the association between surgery and cognitive score at intake examination. When we stratified on overall age (younger than 70 yr and 70 yr or older), the analyses yielded similar estimates in each of the age groups.

In addition, analyses were stratified on the type and number of surgical procedures to investigate the dose–response pattern of cumulative exposure to surgery and anesthesia on cognitive impairment (table 3). We found that exposure to three or more surgeries was associated with significantly lower score, about one fifth of an SD.

The intrapair analysis of twin pairs in whom one had a history of major surgery and the other had no surgery was included to further adjust for genetic and shared environmental factors. In the analysis of all 211 discordant pairs, we found that the surgery-exposed twin had a lower cognitive score than the co-twin in 49% (95% CI, 42 to 56%) of the pairs (fig. 2), suggesting that it was as common to have the higher cognitive score when exposed to surgery as it was to have the lower cognitive score. When twin pairs were restricted according to the magnitude of the intrapair differences in cognitive score to the top 75, 50, and 25%, respectively, the analyses yielded similar results. This was
also the case when the twins were stratified by zygosity (data not shown).

**Discussion**

In this study comprising 8,503 twins, major surgery was associated with a negligibly lower level of cognitive functioning. Thus, the study provides evidence against a clinically relevant association between exposure to surgical procedures and anesthesia and subsequent cognition in mid- and late life.

Twins who had undergone major surgery had slightly lower cognitive scores, corresponding to one tenth of an SD, compared with the reference group, but in the intra-pair analysis where genetic and shared environmental factors were adjusted for by design, no association was observed.
Twins who had undergone hip or knee replacement had slightly higher cognitive scores, although not significantly so, whereas no differences were found in the minor or other surgery group when compared with the reference group.

The time interval between surgery and cognitive examination had no impact on effect sizes, and no dose–response pattern for number of surgeries was found although having had three or more major/other surgeries was significantly associated with a lower cognitive score corresponding to one fifth of an SD. Our results are reassuring in relation to long-term adverse cognitive effects of exposure to major surgery and anesthesia in adulthood for two reasons: First, effect sizes of one tenth to one fifth of an SD are very subtle and may be clinically irrelevant; second, our large sample size ensures estimates with high confidence. Cognitive impairment is a feared aspect of aging, and thus, our finding of a subtle yet persistent association with a lower cognitive score corresponding to one fifth of an SD.

There was a tendency to better cognitive scores in the hip and knee replacement group compared with all other groups including the reference group. This is most likely due to the fact that the best functioning individuals are offered hip and knee replacements. Furthermore, it could also be explained by reduction in pain and increased mobility after successful joint replacements and subsequent improvement in level of functioning.

Comparisons with other studies are hampered by differences in methodology, including differences in design, endpoints, and length of follow-up. The current study reports mean differences in composite cognitive score, whereas most other studies report dichotomous outcomes, primarily incidence of POCD. Moreover, the current study has longer follow-up (up to 24 yr) than other studies.

Despite the methodological differences, our findings across surgical procedures and in the intrapair analyses are to a large extent in line with other studies that assessed cognition more than 6 months postoperatively. Still, a recent cohort study (n = 192) found an increased incidence of POCD in surgical patients older than 60 yr compared with age- and sex-matched controls at 1 yr postoperatively, and a meta-analysis of 17 studies concluded that no impairment in cognitive performance could be documented at 3 to 6 months after hip and knee replacement. However, only two small studies that included control groups assessed cognitive functioning at 3 months of follow-up in this meta-analysis and that conclusion may, therefore, not be justified. Another study of 270 elderly patients undergoing elective orthopedic surgery found improvements in some verbal cognitive tasks including immediate and delayed verbal recall and either deterioration or no differences in other tasks at follow-up at approximately 1 yr. Hence, our findings of a tendency to a slightly higher composite cognitive score in the hip or knee replacement group could be considered to be in agreement with these findings. However, caution in this interpretation is warranted as the effect size in our study is small and nonsignificant. In addition, even if surgery successfully treats chronic pain and restores both physical and cognitive functioning in this patient group, the recovery may take time and is only registered by longer follow-up.

Our finding of no effect of time interval between surgery and cognitive examination on effect sizes does not support the current evidence of a gradual resolution of POCD between 3 months and 1 to 2 yr, but the CIs are quite wide. Exposure to three or more surgeries seemed to be a risk factor but may be explained by underlying disease(s) or complications after surgery. Interestingly, a cross-sectional study found no association between number of general anesthetic exposures and cognitive deficits in 606 participants aged 75 yr or older. Likewise, a case–control study of 1,010 participants found no association between cumulative number of exposures of general anesthesia and AD.

Major strengths of the current study are the use of study samples from population-based surveys retrieved from the...
Danish Twin Registry and the completeness of the Danish NPR, which minimized the risk for selection bias. The Danish National Health Care System with no out-of-pocket expenses further minimizes the bias from different access to health care depending on the educational and socioeconomic factors that are known to be strongly associated with cognitive performance. However, the study is performed in a relatively homogeneous Northern European population and thus the results should be replicated in other settings.

The large sample size of more than 8,500 twins is another strength as this enabled us to detect even very subtle cognitive score differences with high accuracy. In the literature, there is a compelling body of evidence that twins are similar to the general population with regard to health and survival and in recent cohorts also with regard to cognitive functioning. An observed, slightly lower cognitive functioning in older cohorts should not affect the associations within twin pairs, especially within monozygotic twins.

The use of the co-twin design has a number of strengths. First, it is statistically powerful, reflected in the narrow CI on the effect measure (proportion of pairs in which the major surgery-exposed twin had the lowest score: 49%; 95% CI, 42 to 56%) despite that only 211 pairs were included. Furthermore, the design controls for childhood socioeconomic status and genetic endowment, both known to be strongly associated with cognitive functioning in mid- and late life. Finally, due to the high correlation in cognitive performance within twin pairs, especially within monozygotic twin pairs, the co-twin is the best matched control.

Even though we argued that the risk of selection bias is small in this study, selection bias due to mortality and nonattendance should be considered when interpreting the results. The nonattendance of 518 twins (6%) in the cognitive examination may be explained by severe cognitive or physical impairments. An explorative data analysis (not shown) revealed that nonattendees had 1.3 times higher odds of having had any surgery than attendees. Hence, it cannot be ruled out that a small fraction of surgery-exposed twins may be particularly susceptible to surgery and anesthesia or disadvantaged in other ways.

The cross-sectional design of this study did not allow us to consider selective mortality, that is, those with cognitive decline may have less chance of surviving to the study intake. Results were similar when restricting the analyses to surgeries performed less than 3 months before intake and hence minimizing the risk of survival bias. We did not assess cognition preceding surgery/anesthesia. However, in the intrapair analysis, preoperative cognition was taken into account to some degree as the intrapair similarity of intelligence is high. Unmeasured comorbidity is likely to represent an important factor for cognitive performance. If the operated participants have less comorbidity than the nonoperated (which may be anticipated among the oldest in the cohort because surgery is often not performed among those who are very frail), the surgery–cognition association will be underestimated. However, if the operated participants have more comorbidity (which may be anticipated among middle-aged and younger elderly), the association will be overestimated. We see no such age dependence in our study (table 2). A limitation of the exposure measure is that information about outpatient procedures performed before 1995 is not available. This could mean inclusion of exposed cohort members in the unexposed group and tend to bias the results toward null. However, major surgery very rarely took place in an outpatient setting before 1995.

Finally, alternative explanations related to the cognitive measure used in this study should be considered in the interpretation of our findings. Low sensitivity may be associated with an inability to detect cognitive deficits that may have been picked up by other cognitive test batteries. It is noteworthy that the composite cognitive score used is shown to be very age sensitive with a difference of 2.5 SD from age 45 to 90 yr. Although the composite cognitive score does not capture exactly the same cognitive domains as the psychometric test batteries used to detect POCD, it reflects elements that are pivotal for daily living, including working memory.

In conclusion, exposure to major surgery and anesthesia was associated with a negligible reduction in cognitive functioning among middle-aged and elderly twins. This finding substantiates the current evidence of no long-term major adverse cognitive effect of surgery and anesthesia as the very large sample size along with the sensitive cognitive measure allow us to detect very subtle effect sizes.

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Competing Interests

The authors declare no competing interests.

Correspondence

Address correspondence to Dr. Dokkedal: Unit of Epidemiology, Biostatistics, and Biodemography, University of Southern Denmark, J.B. Wimslovs Vej 9B, 5000 Odense, Denmark. udokkedal@health.slu.dk. This article may be accessed for personal use at no charge through the Journal Web site, www.anesthesiology.org.
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Surgery Codes That Are Not Included in Major, Minor, or Knee and Hip Replacement Surgery, and Other Surgeries

Danish National Board of Health’s Classification of Surgeries and Treatments and Nordic Classification of Surgical Procedures:

Other surgeries
- Nordic Classification of Surgical Procedures: KFNC05, KFNJ96, KFNB96
- Thoracic surgeries, included codes
  - Danish National Board of Health’s Classification of Surgeries and Treatments: 34100, 34140, 34260, 34420, 34960, 35080, 35160, 35180, 35350, 35340, 35360, 35740, 40540, 40549

Nordic Classification of Surgical Procedures:
- Skin surgeries, included codes 89520–90860
- Endoscopic and biopsy procedures, included codes 90900–93190
- Eye surgeries, included codes 10000–19900

Danish National Board of Health’s Classification of Surgeries and Treatments
- Included all day-only procedures, surgeries followed by less than 2 days of hospitalization,* and irrespective of the first two criteria

Minor surgeries
- Included all day-only procedures, surgeries followed by less than 2 days of hospitalization,* and irrespective of the first two criteria surgery codes that are compatible with eye surgery, endoscopic and biopsy procedures, skin surgery, and other small surgeries.

Danish National Board of Health’s Classification of Surgeries and Treatments and the Nordic Classification of Surgical Procedures That Are Included in the Specified Surgery Groups: Major Surgery, Minor Surgery, Knee and Hip Replacement Surgery, and Other Surgeries

Major surgeries
- Cardiac surgeries, included codes
  - Danish National Board of Health’s Classification of Surgeries and Treatments: 30009, 30019, 30029, 30039, 30049, 30059, 30069, 30079, 30089, 30099, 30119, 30120, 30149, 30200, 30240, 30241, 30350, 30354, 30700, 30780, 31020, 31119, 31130, 31268, 31269, 31699, 32400, 32920, 32940, 32960
- Nordic Classification of Surgical Procedures: KFKD00, KFM000, KFM100, KFNA00, KFNA20, KFNC10, KFNC30, KFNC40, KFNC50, KFNE96, KFNJ96, KFXB96
- Knee and Hip Replacement Surgery, and Other Surgeries

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Appendix: Surgery Codes According to the Danish National Board of Health’s Classification of Surgeries and Treatments and the Nordic Classification of Surgical Procedures

Other surgeries
- Nordic Classification of Surgical Procedures: KNFB30, KNFB40, KNFC01, KNFC12, KNFC20, KNFC21, KNFC40, KNGB13, KNGB20, KNGB30, KNGB40, KNGC13, KNGC21, KNGC43