Perspective

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The surgical patient of yesterday, today, and tomorrow—a time-trend analysis based on a cohort of 8.7 million surgical patients

Samuel Knoedler[a,d,*], Dany Y. Matar[d], Sarah Friedrich, PhD[b], Leonard Knoedler[e], Valentin Haug, MD[c,d], Gabriel Hundeshagen, MD, MMS[c], Martin Kauke-Navarro, MD[f], Ulrich Kneser, MD, PhD[c], Bohdan Pomahac, MD[f], Dennis P. Orgill, MD, PhD[d], Adriana C. Panayi, MD, PhD[c,d,*]

Background: Global healthcare delivery is challenged by the aging population and the increase in obesity and type 2 diabetes. The extent to which such trends affect the cohort of patients the authors surgically operate on remains to be elucidated. Comprising of 8.7 million surgical patients, the American College of Surgeons (ACS) National Surgical Quality Improvement Program (NSQIP) database can be analyzed to investigate the echo of general population dynamics and forecast future trends.

Material and methods: The authors reviewed the ACS-NSQIP database (2008–2020) in its entirety, extracting patient age, BMI, and diabetes prevalence. Based on these data, the authors forecasted future trends up to 2030 using a drift model.

Results: During the review period, median age increased by 3 years, and median BMI by 0.9 kg/m^2. The proportion of patients with overweight, obesity class I, and class II rates increased. The prevalence of diabetes rose between 2008 (14.9%) and 2020 (15.3%). The authors forecast the median age in 2030 to reach 61.5 years and median BMI to climb to 29.8 kg/m^2. Concerningly, in 2030, eight of ten surgical patients are projected to have a BMI above normal. Diabetes prevalence is projected to rise to 15.6% over the next decade.

Conclusion: General population trends echo in the field of surgery, with the surgical cohort aging at an alarmingly rapid rate and increasingly suffering from obesity and diabetes. These trends show no sign of abating without dedicated efforts and call for urgent measures and fundamental re-structuring for improved future surgical care.

Keywords: aging, big data, demographics, diabetes mellitus, obesity, surgery

Introduction

Forecasting analysis of a population, as a tool to plan and manage risk, is omnipresent across multiple fields; from governments to public health organizations, predicted scenarios allow for estimation of future need, allocation of resources to the appropriate domains, and implementation of mitigation or prevention strategies. Forecasting uses past and current data to predict future trends; in population health analysis, these data tend to be demographic and comorbidity prevalence trends.

The demographic changes of the general population are well-described: the average life expectancy is increasing with elderly people representing the fastest-growing age group worldwide. Overweight status and obesity are on the rise. The WHO reports the prevalence of obesity has nearly tripled over the past forty years and estimates the current number of obese adults to be as high as 650 million[1]. In the US alone, one in eleven people has a BMI over 40 and severe obesity[2]. At the same time, the percentage of US adults with diabetes has increased from 0.9% in 1959 to 14.7% in 2020[3,4].

[a]Department of Plastic Surgery and Hand Surgery, Klinikum Rechts der Isar, Technical University of Munich, Munich, [b]Department of Mathematical Statistics and Artificial Intelligence in Medicine, University of Augsburg, Augsburg, [c]Department of Hand-, Plastic and Reconstructive Surgery, Burn Center, BG Trauma Center Ludwigshafen, University of Heidelberg, Ludwigshafen, Germany, [d]Division of Plastic Surgery, Department of Surgery, Brigham and Women's Hospital, [e]Division of Plastic and Reconstructive Surgery, Massachusetts General Hospital, Harvard Medical School, Boston, MA, and [f]Division of Plastic Surgery, Department of Surgery, Yale New Haven Hospital, Yale School of Medicine, New Haven, CT, USA

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*Corresponding authors. Address: Department of Plastic Surgery and Hand Surgery, Klinikum Rechts der Isar, Technical University of Munich, Ismaninger Straße 22, 81675 Munich, Germany. Tel.: +49 89 289 01; fax: +49 89 289 22000. E-mail address: samuel.knoedler@tum.de (S. Knoedler); Division of Plastic Surgery Department of Surgery, Brigham and Women's Hospital, Harvard Medical School 75 Francis Street, Boston 02115, MA, USA. Tel.: +1 617 732 7180; fax: +1 617 732 5300. E-mail address: a.panayi@cantab.net (A. C. Panayi).

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Given such population changes, surgical patients today are substantially different from those a decade ago. An age-related and frailty-related decline in health exacerbates surgical vulnerability and predisposes to complications. Frailty is also associated with higher BMI, while overweight and obesity status are independently correlated with worse postoperative outcomes[5–11]. Likewise, diabetes mellitus is a well-documented surgical risk factor[12–15].

The extent to which such trends affect surgery as a multifaceted field rather than individual patient cohorts undergoing specific procedures, at specific locations and points in time, remains to be elucidated. The American College of Surgeons National Surgical Quality Improvement Program (ACS-NSQIP) database collects validated data from more than 700 hospitals. We analyzed this multi-institutional database over the past 13 years, investigating the echo of general population trends in the surgical cohort. We explored whether the surgical population is indeed aging and becoming increasingly prone to obesity and diabetes. Based on these data from more than 8.7 million patients we forecast future developments.

HIGHLIGHTS

- Global healthcare delivery is challenged by our aging population and the increase in obesity and type 2 diabetes mellitus.
- Based on multi-institutional data of 8.7 million surgical patients, we forecasted future trends of the surgical population up to 2030.
- Mean and median age on the rise and will be as high as 57.7 years and 61.5 years, respectively, in 2030. Such a scenario would imply an increase of the mean age by 2.1 years and the median age by 5.5 years within 23 years (2008–2030).
- By 2030, the mean BMI is forecasted to reach 30.4 kg/m^2 and the median BMI to climb to 29.8 kg/m^2. In contrast, in 2008, we calculated a mean BMI of 29.9 kg/m^2 and a median BMI of 28.1 kg/m^2.
- In 2030, 80% of surgical patients are expected to have a BMI above the healthy threshold.
- The diabetes prevalence rose less steeply, yet statistically significantly, between 2008 (14.9%) and 2020 (15.3%). The forecasting model calculated an increase to 15.6% in 2030.
- These trends show no sign of abating and call for a fundamental re-structuring of future surgical care delivery.

Material and methods

Data source

Data were gathered over a 13-year period from 2008 to 2020 using the ACS-NSQIP database. At the time of analysis, more recent data were not available. The 2005–2007 records were excluded due to a divergent data structure and capture system. While being exclusively available to the participating facilities, the ACS-NSQIP represents a multi-institutional and risk-adjusted data collection of surgical patients and procedures. This clinical registry provides information from over 700 hospitals on more than 150 preoperative, perioperative, and postoperative variables for patients undergoing surgery. The annual number of submitted cases and participating hospitals is increasing (Supplementary Table 1, Supplemental Digital Content 1, http://links.lww.com/JS9/A695). Spot audits and peer controls guarantee the quality, reliability, and validity of the database. In addition, trained personnel are delegated to capture the data directly from the medical chart of randomly assigned patients. The records analyzed contain strictly de-identified information.

Patient selection and variable extraction

A single exclusion criterion was applied: after systematic review, no reports of living patients with a BMI less than 7 kg/m^2 or greater than or equal to 250 kg/m^2 were found in the scientific literature. Therefore, cases with a calculated BMI beyond these cut-off points were deemed miscoding and excluded. Otherwise, all patients for whom the necessary information (weight or height) to calculate BMI was available were included. For each year, we collected the following preoperative data: age, diabetes mellitus, and BMI {calculated using the formula [weight (pounds) / height (inches)^2 x 703]}. In order to be able to identify trends in particular age cohorts, we subdivided the entire study population into 5-year age subgroups, following the WHO coding list of age groups[16]. When classifying the BMI values, we adhered to the official thresholds of the National Institute of Health (NIH) and the WHO[17]: (i) underweight was defined with a BMI less than 18.5 kg/m^2, (ii) normal weight with a BMI greater than or equal to 18.5–24.9 kg/m^2, (iii) overweight with a BMI greater than or equal to 25–29.9 kg/m^2, (iv) obesity with a BMI greater than or equal to 30 kg/m^2. We further subclassified the cohort of obese patients, with a BMI of 30–34.9 kg/m^2 indicating obesity class I, a BMI of 35–39.9 kg/m^2 obesity class II, and a BMI $\geq$40 kg/m^2 obesity class III. The diagnosis of diabetes mellitus was further specified based on the medication received, that is oral anti-diabetic drugs versus insulin.

Statistical analysis and forecasting

The raw data of the ACS-NSQIP annual datasets were converted into analyzable Microsoft Excel (Version 16, Microsoft Corporation) files via IBM SPSS Statistics for Windows, version 29 (IBM Corporation). Subsequently, all ACS-NSQIP datasets between 2008 and 2020 were standardized into a consistent format. Data were collected and saved in an electronic laboratory notebook (LabArchives, LLC), and analyzed using R software (version 4.1.2). Categorical data are presented as absolute numbers (n) and percentages (%) and continuous variables as mean ± SD or median [interquartile range (IQR)]. Hypothesis testing was performed as two-sided tests with a *P* value less than 0.05 as the criterion for statistical significance. We compared patient characteristics from 2008 to those obtained in 2020 using t-tests for mean values, Kruskal–Wallis-tests for median values, and Pearson's χ^2 test for categorical variables. All reported *P* values are nominal and have not been adjusted for multiple testing. Forecasts are based on a random walk with drift model (using the rwf-function of the forecast package in R), which models and extrapolates the trend seen in the historical data. The amount of change over time, the drift, is set to equal the average change in the historical data. A straight line is drawn through the first and last observed data point and extrapolated into the future. To quantify the precision of the forecast, all results are equipped with

95% prediction intervals, assuming that the forecast errors are normally distributed. We compared different modelling approaches with respect to prediction accuracy (measured as mean squared error and mean absolute error based on cross-validation). Since our data did not show signs of seasonality, we focused explicitly on modelling the trend seen in the data. In addition to the drift model, we considered Holt's method and a non-seasonal ARIMA model. Since differences between the approaches were minimal and the drift method yielded the most accurate results in most scenarios, we only report results based on this approach. No additional covariates were considered in the forecasts.

Results

Baseline data

The study population comprised 8 782 017 surgical patients over the 13-year review period between 2008 and 2020 (Table 1). The lowest and highest BMI values were 7.3 kg/m^2 and 243.9 kg/m^2, respectively. We excluded 201,753 patients due to incalculable or physiologically impossible BMI values. Supplementary Figure 1, Supplemental Digital Content 1, http://links.lww.com/JS9/A695 provides an outline of the patient identification procedure. Supplementary Table 2, Supplemental Digital Content 1, http://links.lww.com/JS9/A695 provides a statistical comparison of the baseline data between 2008 and 2020. Supplementary Video 1, Supplemental Digital Content 2, http://links.lww.com/JS9/A696, Supplemental Digital Content 1, http://links.lww.com/JS9/A695 is a videographic year-by-year illustration of age and BMI data.

Age

The median age increased significantly by three years during the 13-year study period ($P<0.0001$). In 2008 and 2009, we calculated a median age of 56.0 (IQR: 44–68) years, whereas in 2020 the median age rose to 59.0 years (IQR: 44–70). The mean age fluctuated, with 55.6 ± 17.3 years in 2008 and significantly increased to 56.7 ± 17.3 years in 2020 ($P<0.0001$). The 5-year age subgroup analysis revealed a relatively constant pattern throughout the entire review period (Fig. 1A; Supplementary Table 3, Supplemental Digital Content 1, http://links.lww.com/JS9/A695): the prevalence rate within each age group increased incrementally to a turning point and then decreased. This turning point shifted toward higher thresholds over the 13-year period. While in 2008 patients aged 50–54 years accounted for the largest proportion (10.5%; $n=27\ 716$), the following year, the peak prevalence was measured in the 55–59 years age group (10.7%; $n=35\ 074$). Between 2010 and 2013, the largest proportion was found in the next higher age group (60–64 years); finally, from the year 2015 inclusive and onwards, patients aged 65–69 years represented the largest proportion. Throughout the 13-year period, the majority of surgical patients were older than 55 years (>53%).

Body mass index

In total, 141 839 (1.62%) patients were underweight, while the BMI of 2 054 399 (23.4%) patients fell within the normal reference range. In both these BMI classes, a decreasing trend in prevalence was noted over the 13-year study period. While, in 2008, 2.3% ($n=6046$) and 27.1% ($n=71\ 680$) of the

Table 1

Overview of patient demographics, prevalence of diabetes, and distribution stratified by BMI.

	2008 (n = 264 105)	2009 (n = 327 106)	2010 (n = 355 582)	2011 (n = 175 661)	2012 (n = 532 013)	2013 (n = 637 687)	2014 (n = 735 924)	2015 (n = 868 406)	2016 (n = 980 440)	2017 (n = 1 008 516)	2018 (n = 997 530)	2019 (n = 1 023 932)	2020 (n = 875 116)
Age													
Mean (SD)	55.6 (17.3)	56 (17.0)	56.1 (16.9)	56.7 (16.7)	57 (16.8)	57.1 (16.7)	56.3 (16.9)	56.5 (16.9)	56.6 (16.9)	56.6 (17.0)	56.9 (17.0)	56.9 (17.1)	56.7 (17.3)
Median (IQR)	56 (44–68)	56 (44–68)	57 (44–68)	57 (45–69)	58 (45–69)	58 (45–69)	58 (45–69)	58 (45–69)	58 (45–69)	58 (45–69)	59 (45–69)	59 (45–70)	59 (44–70)
Diabetes													
No (n = 7 425 864)	224 638 (85.1)	276 732 (84.6)	301 387 (84.8)	148 414 (84.5)	450 950 (84.8)	539 255 (84.6)	622 650 (84.6)	733 540 (84.5)	826 289 (84.3)	850 051 (84.3)	842 467 (84.5)	868 130 (84.8)	741 361 (84.7)
Yes (n = 1 356 148)	39 467 (14.9)	50 374 (15.4)	54 193 (15.2)	27 247 (15.5)	81 063 (15.2)	98 430 (15.4)	113 274 (15.4)	134 866 (15.5)	154 150 (15.7)	158 465 (15.7)	155 063 (15.5)	155 802 (15.2)	133 754 (15.3)
Ins. (n = 501 538)	15 695 (6.0)	19 524 (6.0)	20 801 (5.9)	10 635 (6.1)	30 113 (5.7)	37 291 (5.9)	43 398 (5.9)	51 125 (5.9)	56 988 (5.8)	58 176 (5.8)	56 296 (5.6)	53 920 (5.3)	47 576 (5.4)
Oral (n = 854 510)	23 772 (9.0)	30 850 (9.4)	33 392 (9.4%)	16 612 (9.5)	50 950 (9.6)	61 139 (9.6)	69 876 (9.5)	83 741 (9.6)	97 162 (9.9)	100 289 (9.9)	98 767 (9.9)	101 882 (10.0)	86 178 (9.9)
BMI													
Mean (SD)	29.9 (8.4)	30.0 (8.3)	30.0 (8.2)	29.8 (8.1)	30.0 (7.9)	30.1 (7.9)	30.1 (7.7)	30.2 (7.7)	30.3 (7.6)	30.4 (7.6)	30.3 (7.4)	30.3 (7.3)	30.1 (7.3)
Median (IQR)	28.1 (24.1–32.8)	28.3 (24.4–33.8)	28.3 (24.4–33.8)	28.2 (24.3–33.4)	28.5 (24.6–33.7)	28.6 (24.7–33.8)	28.7 (24.9–34.0)	28.9 (24.9–34.0)	29.0 (25.1–34.2)	29.1 (25.1–34.2)	29.1 (25.1–34.1)	29.1 (25.2–34.1)	29.0 (25.1–34.0)
UW (n = 141 839)	6046 (2.3)	6971 (2.1)	7075 (2.0)	3740 (2.1)	9349 (1.8)	10 807 (1.7)	11 915 (1.6)	13 638 (1.6)	14 794 (1.5)	14 769 (1.5)	14 589 (1.5)	14 404 (1.4)	13 742 (1.6)
N (n = 2 054 399)	71 680 (27.1)	85 225 (26.1)	91 860 (25.8)	46 475 (26.5)	132 740 (25.0)	156 462 (24.5)	176 277 (24.0)	203 561 (23.4)	222 474 (22.7)	226 794 (22.5)	221 318 (22.2)	223 195 (21.8)	196 338 (22.4)
OW (n = 2 747 802)	80 697 (30.6)	101 137 (30.9)	109 339 (30.7)	55 020 (31.3)	168 169 (31.6)	199 839 (31.3)	230 723 (31.4)	270 806 (31.2)	306 113 (31.2)	314 025 (31.1)	313 058 (31.4)	323 445 (31.6)	275 431 (31.5)
OB1 (n = 1 921 649)	49 531 (18.8)	63 314 (19.4)	70 365 (19.8)	34 652 (19.7)	109 812 (20.6)	134 537 (21.1)	157 261 (21.4)	189 004 (21.8)	217 958 (22.2)	226 185 (22.4)	228 161 (22.9)	239 193 (23.4)	201 676 (23.0)
OB2 (n = 1 012 040)	25 859 (9.8)	33 290 (10.2)	37 076 (10.4)	17 668 (10.1)	56 914 (10.7)	69 690 (10.9)	82 669 (11.2)	99 883 (11.5)	116 098 (11.8)	120 998 (12.0)	120 388 (12.1)	125 729 (12.3)	105 778 (12.1)
OB3 (n = 904 288)	30 292 (11.5)	37 169 (11.4)	39 867 (11.2)	18 106 (10.3)	55 029 (10.3)	66 352 (10.4)	77 079 (10.5)	91 514 (10.5)	103 003 (10.5)	105 745 (10.5)	100 016 (10.0)	97 966 (9.6)	82 150 (9.4)

Reported as n (%), unless otherwise stated.

UW (BMI: >18.5 kg/m^2); N (BMI: 18.5–24.9 kg/m^2); OW (BMI:25.0–29.9 kg/m^2); OB1 (BMI: 30.0–34.9 kg/m^2); OB2 (BMI: 35.0–39.9 kg/m^2); OB3 (BMI: ≥40 kg/m^2).

Ins, Insulin; IQR, interquartile range; N, normal weight; OB1, obesity class I; OB2, obesity class II; OB3, obesity class III; OW, overweight; UW, underweight.

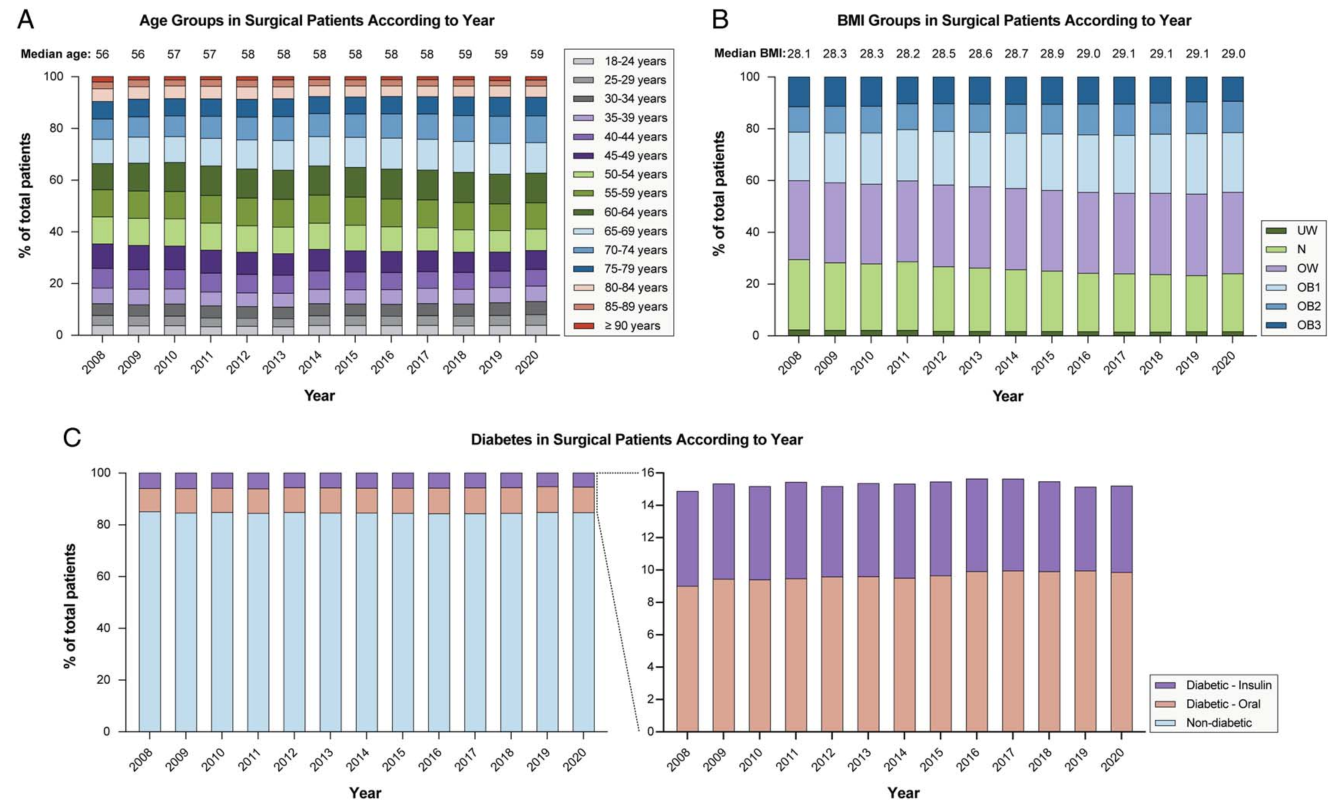

Figure 1. (A) Age groups in surgical patients according to year. Chronological course of annual patient age distribution with age stratified into 5-year groups. The prevalence at the ends of the age spectrum (i.e. 18–24, 25–29, 30–34, and 80–84, 85–89, and 90 + years) remained relatively low, and the majority of patients clustered in the middle core groups. Over the 13-year study period, the prevalence of elderly/geriatric age (i.e. 60 + years) patients grew successively larger. This trend is also reflected in the increase in the median age from 56 years in 2008 to 59 years in 2018, 2019, and 2020. The corresponding numbers are listed in Supplementary Table 3. (B) BMI groups in surgical patients according to year. Year-by-year distribution of the study population stratified by BMI. Throughout the 13-year review period, clear patterns emerged, with a polarization of the study cohort. While the number of patients being underweight and normal weight markedly decreased, the proportion of pathological BMI classes (i.e. overweight, obesity class I, and obesity class II) increased. Interestingly, the percentage of patients with a BMI $\geq$40 kg/m^2 slightly fluctuated—with a lowest in 2020 (9.4%) and a maximum in 2008 (11.5%). (C). Diabetes in surgical patients according to year. Prevalence of diabetes mellitus over the 13-year study period. The ratio of diabetic and non-diabetic patients remained relatively stable from 2008 to 2020. More specifically, diabetes prevalence ranged from 14.9% in 2008 to 15.7% in 2016 and 2017, with an overall mean of 15.4%. When specifying the diagnosis according to the medication required, a distinct tendency was noted. While the percentage of patients taking oral antidiabetic drugs gradually increased from 9.0% in 2008 to 10.0% in 2019, the number of patients on insulin treatment declined (with a peak of 6.1% in 2011 and a trough of 5.3% in 2019). UW (BMI: > 18.5 kg/m^2); N (BMI: 18.5–24.9 kg/m^2); OW (BMI:25.0–29.9 kg/m^2); OB1 (BMI: 30.0–34.9 kg/m^2); OB2 (BMI: 35.0–39.9 kg/m^2); OB3 (BMI: $\geq$40 kg/m^2). N, normal weight; OB1, obesity class I; OB2, obesity class II; OB3, obesity class III; OW, overweight; UW, underweight.

study cohort were underweight and normal weight, respectively, these percentages significantly decreased to 1.6% (n = 13 742) and 22.4% (n = 196 338) in 2020 (P < 0.0001). Accordingly, the number of patients with obesity, in particular obesity class I and II, increased significantly between 2008 and 2020 (P < 0.0001). Overall, the number of overweight patients amounted to 2 747 802 (31.3%), while a total of 1 921 649 (21.9%) and 1 012 040 (11.5%) patients had obesity class I and II, respectively. A cumulative number of 904 288 (10.3%) patients had a BMI greater than or equal to 40 kg/m^2. The annual proportion in this BMI category fluctuated during the 13-year study period, with initial values ranging from 11.5% (n = 30 292) in 2008 through 10.3% (n = 18 106) in 2012 and 10.5% (n = 105 745) in 2017 to 9.4% (n = 82 150) in 2020. Across the 13-year period, the majority of surgical patients were either overweight or obese (>70%). Figure 1B shows the year-by-year patient distribution stratified by BMI.

The median BMI increased significantly by 3.2% over the 13-year study period (P < 0.0001). In 2008, the median BMI was 28.1 (IQR: 24.1–32.8), rising to 28.7 (IQR: 24.9–34.0) in 2014 and appearing to plateau at 29.1 in 2019 (IQR: 25.2–34.1) and 29.0 in 2020 (IQR: 25.1–34.0). The mean BMI also increased significantly, growing from 29.9 ± 8.4 in 2008 to 30.1 ± 7.3 in 2020 (P < 0.0001).

Diabetes

A total of 1 356 148 (15.4%) patients had a preoperative diagnosis of diabetes, with the majority of patients, 7 425 865 (84.6%), not having diabetes (Table 1). This ratio of diabetic-/non-diabetic patients remained relatively constant over the 13-year review period. Yet, the difference between 2008 (14.9% diabetic patients) and 2020 (15.2% diabetic patients) was found to be statistically significant (P < 0.0001). The prevalence of diabetic patients peaked at 15.7% in both 2016 and 2017, with 826 289 and 850 051 diagnosed cases, respectively. The lowest prevalence of diabetes was reported in 2008 (n = 39 467; 14.9%).

When subgrouping the diabetes diagnosis into medication modalities, some variation was noted (Fig. 1C). As the proportion

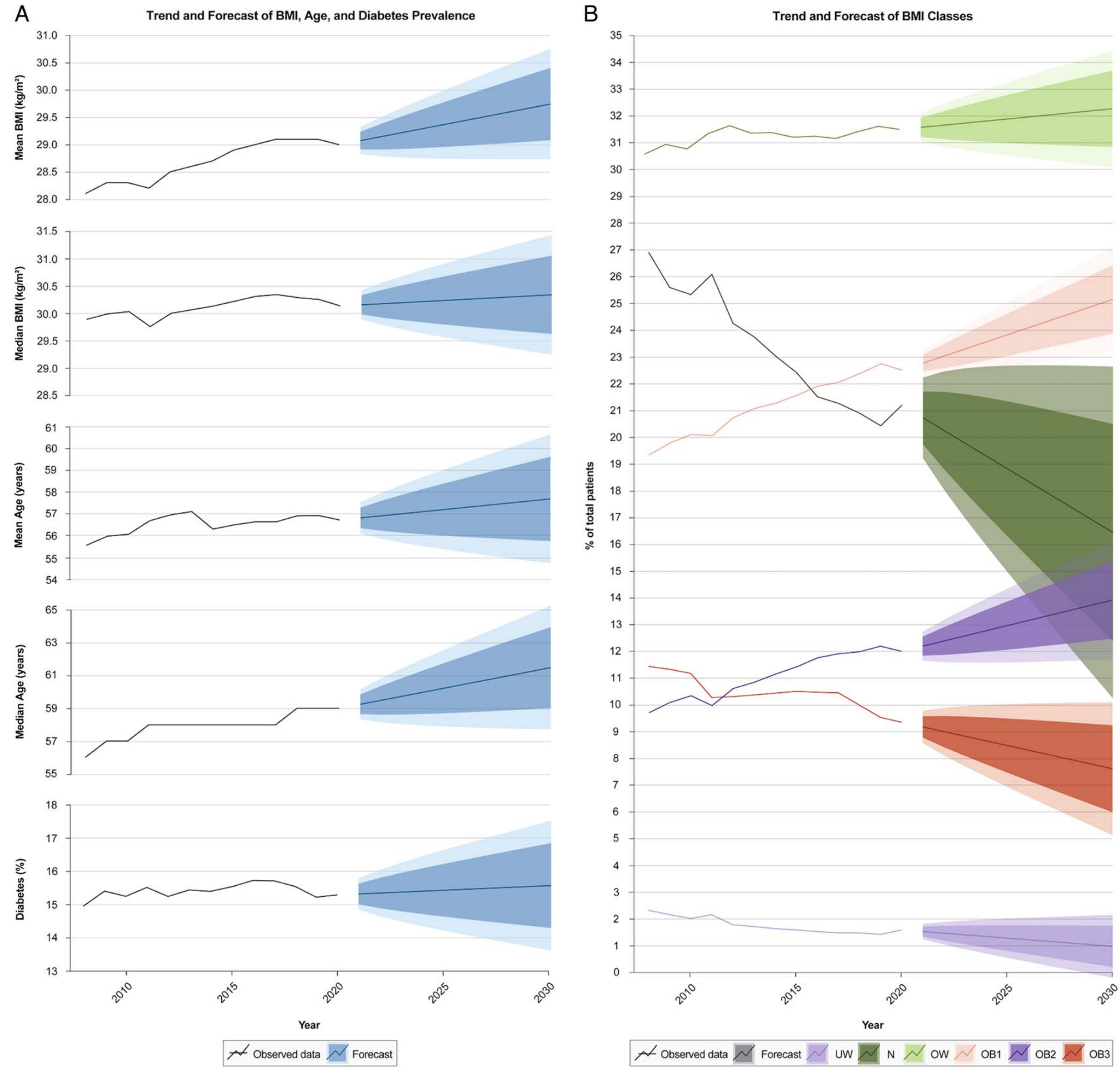

Figure 2. (A) Trend and forecast of BMI, age, and diabetes prevalence. Illustration of BMI, age, and diabetes data throughout the study period (2008–2020) and drift model-based forecasting up to 2030. All parameters (i.e. mean BMI, median BMI, mean age, median age, and diabetes prevalence) increased significantly during the 13-year review period and are projected to further rise over the next decade. More specifically, by 2030, the mean BMI is forecasted to reach 30.4 kg/m^2 and the median BMI to climb to 29.8 kg/m^2. By contrast, in 2008, we calculated a mean BMI of 29.9 kg/m^2 and a median BMI of 28.1 kg/m^2. In addition, the drift model forecasts that the mean and median age in 2030 will be as high as 57.7 years and 61.5 years, respectively. Such a scenario would imply an increase of the mean age by 2.1 years and the median age by 5.5 years within 23 years (2008–2030). The diabetes prevalence rose less steeply, yet statistically significantly, between 2008 (14.9%) and 2020 (15.3%). Accordingly, the forecasting model calculated an increase to 15.6% in 2030. The coloured regions indicate the prediction intervals (dark blue = 80% and light blue = 95%). (B) Trend and forecast of BMI classes. Plot of the trends in the BMI classes during the 13-year study period (2008–2020) and drift model-based forecasting up to 2030. Throughout the entire period from 2008 to 2030, the proportion of patients with underweight (2008: 2.3%; 2020: 1.6%; 2030: 1.0%), normal weight (2008: 27.1%; 2020: 22.4%; 2030: 18.5%), and severe obesity (2008: 11.5%; 2020: 9.4%; 2030: 7.7%) decreased and are projected to drop further. The share of patients overweight (2008: 30.6%; 2020: 31.5%), obesity class I (2008: 18.8%; 2020: 23.0%), and obesity class II (2008: 9.8%; 2020: 12.1%) was on the rise. According to the forecasting model, this upward trend will continue over the next decade, with the percentage of patients with overweight, obesity class I, and obesity class II projected to be as high as 32.2%, 26.6%, and 14.0%, respectively. The coloured regions indicate the prediction intervals (dark colour = 80% and light colour = 95%). UW (BMI: > 18.5 kg/m^2); N (BMI: 18.5–24.9 kg/m^2); OW (BMI:25.0–29.9 kg/m^2); OB1 (BMI: 30.0–34.9 kg/m^2); OB2 (BMI: 35.0–39.9 kg/m^2); OB3 (BMI: ≥ 40 kg/m^2). N, normal weight; OB1, obesity class I; OB2, obesity class II; OB3, obesity class III; OW, overweight; UW, underweight.

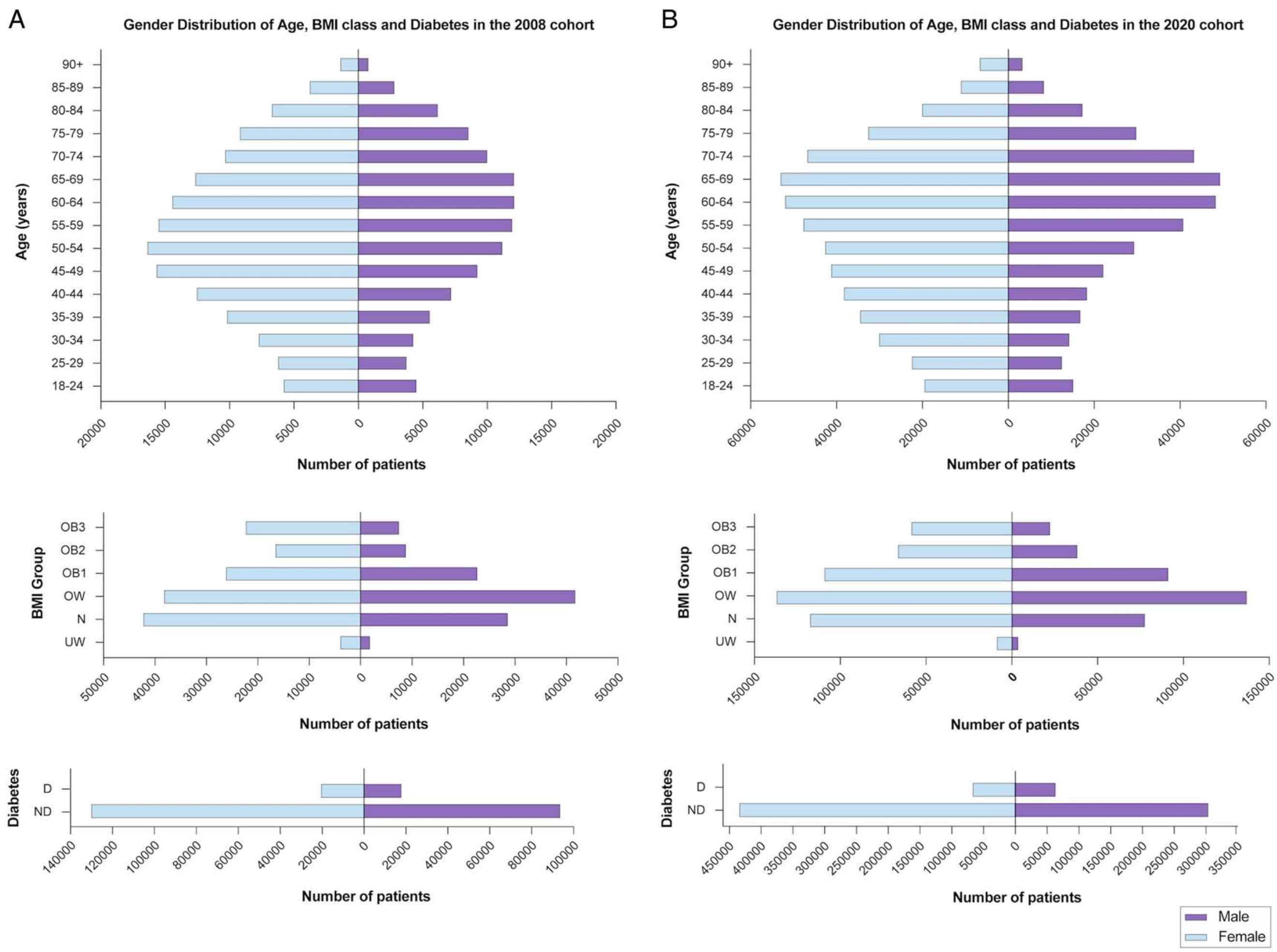

Figure 3. (A) Sex Distribution of age, BMI, and diabetes in the 2008 cohort. (B) Sex distribution of age, BMI, and diabetes in the 2020 cohort. During the 13-year study period, the age pyramid widened at the top, with markedly more sexagenarians and septuagenarians undergoing surgery in 2020. The BMI distribution also shifted: among females, the proportion of patients with overweight and obesity class II increased, whilst in men, the category of obesity class I distinctly grew. Accordingly,—in the comparison of 2008–2020—the share of patients with normal weight decreased in both sexes. In contrast, the prevalence pattern of diabetic and non-diabetic patients appeared consistent in 2008 and 2020.

of patients taking oral antidiabetic drugs gradually increased from 9.0% (n = 23 772) in 2008 to 10.0% (n = 101 882) in 2019, the percentage of patients receiving insulin treatment decreased from peaks in 2008 (5.9%; n = 15 695) and 2011 (6.1%; n = 10 635) to its lowest in 2019 (5.3%; n = 53 920). Across the 13-year period, the majority of surgical patients were non-diabetic (>80%), and, when diabetic, were treated with oral medication (>8%).

Forecasting data age

The drift model forecasted that the surgical patient population will increasingly age during the next decade, reaching a mean age of 57.7 years [95% prediction interval: (54.7, 60.6)] and a median age of 61.5 years [95% prediction interval: (57.7, 65.3)] by 2030 (Fig. 2A).

BMI

According to the drift model, by 2030, the mean BMI and median BMI were forecasted to rise to 30.4 kg/m^2 [95% prediction interval: (29.3, 31.4)] and 29.8 kg/m^2 [95% prediction interval: (28.7, 30.8)], respectively (Fig. 2A).

Within the BMI classes, the drift model forecasted inverse trends until 2030 (Fig. 2B): the proportion of patients with underweight [1%; 95% prediction interval: (– 0.2%, 2.1%)], normal weight [18.5%; 95% prediction interval: (13.4%, 23.6%)], and severe obesity [7.7%; 95% prediction interval: (5.2%, 10.1%)] were projected to decrease. In contrast, the share of patients with overweight [32.2%; 95% prediction interval: (30.1%, 34.4%)], obesity class I [26.6%; 95% prediction interval: (24%, 29.3%)], and obesity class II [14%; 95% prediction interval: (11.8%, 16.2%)] was forecasted to increase over time.

Diabetes mellitus

The prevalence of diabetes mellitus is predicted to remain relatively stable, with a percentage of 15.6% [95% prediction interval: (13.6%, 17.5%)] in 2030 (Fig. 2A). While the proportion of diabetic patients requiring insulin treatment is forecasted to decrease [2030: 5.0%; 95% prediction interval: (3.4%, 6.7%)], the drift

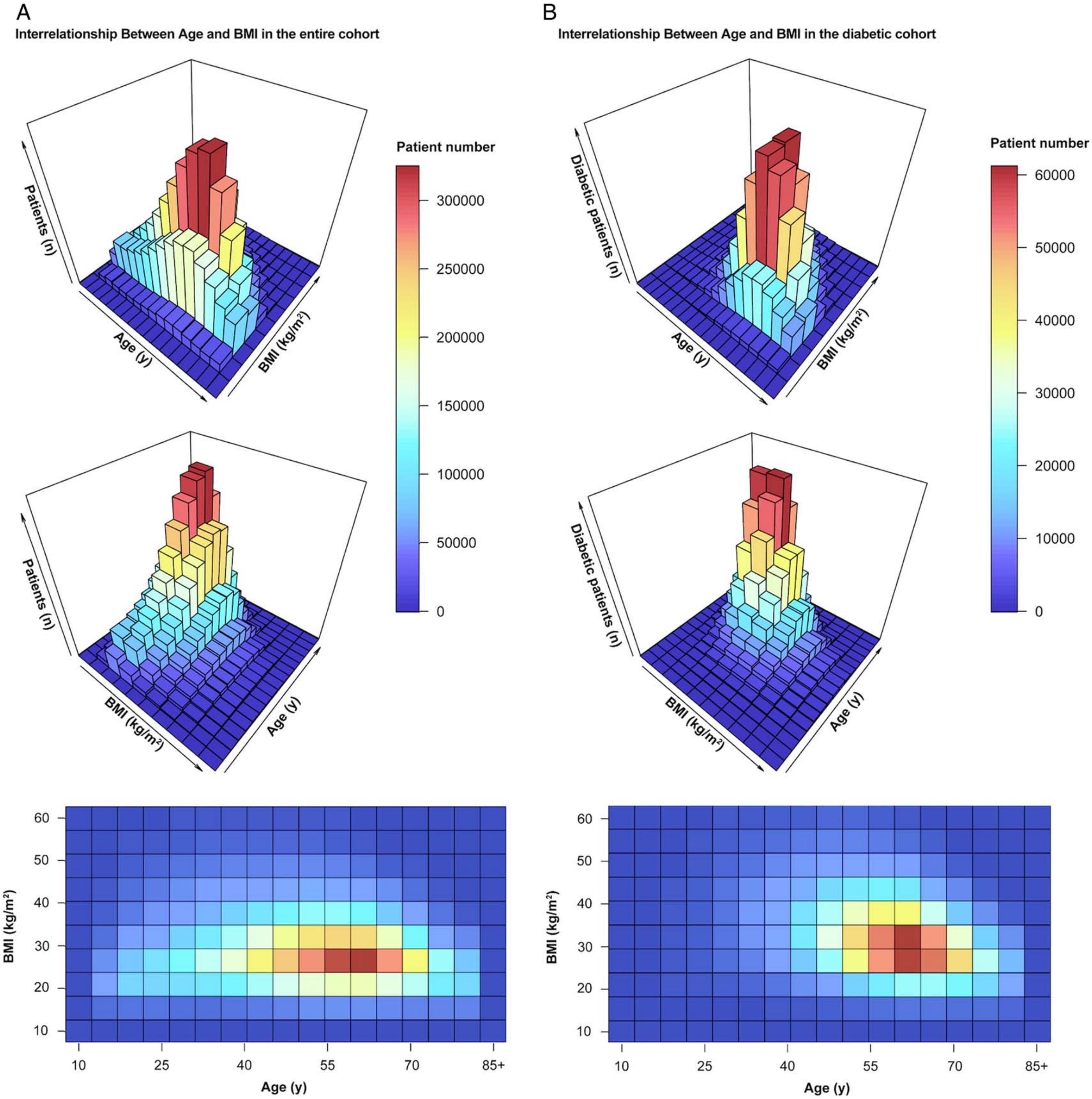

Figure 4. (A) Interrelationship between age and BMI in the entire cohort. 3-D graphs showing the interrelationship between BMI and age in the entire cohort. The peak of the frequency distribution is seen in patients between the age of 65 and 75 years and a BMI of 30–35 kg/m^2. (B) Interrelationship between age and BMI in the diabetic cohort. 3-D graphs showing the interrelationship between BMI and age in the diabetic cohort. The distribution of age and BMI is considerably narrower in the diabetes cohort. In the diabetic population, a peak in frequency is noted in patients between the age of 70 and 75 years and BMI values of 30–40 kg/m^2. On average, diabetic patients had higher BMI levels while being older. Normal BMI values were rarely recorded, with a marked predominance of overweight or obese BMI levels. BMI is measured in kg/m^2 and age is measured in years. 3-D, three dimensional.

model calculated a rising prevalence of orally treated diabetic patients [2030: 10.6%; 95% prediction interval: (9.3%, 11.9%)].

Discussion

This study sheds light on the surgical patient of yesterday, today, and tomorrow, based on data of nearly nine million surgical patients with geographical, institutional, and procedural variance. We investigate the extent to which general demographic shifts and changes in health have affected the surgical population. This insight into the patient cohort that surgeons are currently treating and have treated over the past two decades can help us prepare for the surgical care delivery of tomorrow. Our forecasted future trends demonstrate the need to take action and initiate effective measures—both from a surgeon and from a public health perspective (Fig. 3).

Aging and frailty are interwoven with physical health. Generally, as patients age, their wound healing capacity, cardiovascular stability, and immune system competence decrease. In our analyzed population, advanced age was associated with higher BMI levels (Fig. 4A). Such age-related decline in health aggravates surgical vulnerability and predisposes to perioperative complications. Numerous studies identified age and frailty as surgical risk factors[16–23]. The susceptibility of the surgical geriatric sub-population, therefore, necessitates specialized management. This need for age-appropriate perioperative care is exacerbated in light of the projected future trends: the mean and median age of surgical patients will be as high as 57.7 years and 61.5, respectively. Such a drift model-based scenario would imply that the surgical cohort is aging at a faster rate than the global and the US population. While our model forecasted an increase of the median age by 5.5 years among the surgical population, the United Nations expects the median age to grow by 5.2 years worldwide and by 4.0 years in the US[24]. Our forecasting is in line with studies predicting that the number of elderly (and frail) patients will rise steeply[25–31]. To be able to cope with the increasingly aging surgical population, whilst providing high-quality and safe surgical care, measures are urgently needed—both in the clinical setting as well as at the public health level.

The rapid increase in obesity of the general population is reflected in our surgical population. From 2008 to 2018, we measured an obesity prevalence increase of 4.9%, a number which exceeded the national increase. The proportion of surgical patients with severe obesity—in contrast to the general trend—decreased. The underlying rationale remains to be elucidated; one may hypothesize that the awareness of severe obesity as a surgical risk factor increased, and, therefore, surgeons evaluated the eligibility of patients with severe obesity more critically[32]. The declining numbers in surgical patients with severe obesity may also reflect the advent of new, effective anti-obesity drugs which are prescribed more frequently to patients with a BMI over 40 kg/m²[33,34]. Between 2008 and 2018, the proportion of surgical patients with obesity class I and II also increased, at a rate that outpaced nationwide growth rates and may be explained by two reasons. First, the popularity of bariatric surgery has steadily increased over the past decade, with the number of procedures increasing by 60% between 2011 and 2018[35]. This form of weight-loss surgery is mainly offered to patients with a BMI greater than or equal to 30 kg/m²[36–38]. Second, while patients with severe obesity are known to suffer from the highest postoperative morbidity and mortality, according to Mullen and colleagues "obesity paradox" mild/moderate obesity is associated with better surgical outcomes compared to normal weight[39–43]. Perhaps—given this documented protective effect of obesity—surgeons have become more willing to operate on patients with a higher BMI. Large-scale and long-term studies are required to decipher the ideal body composition of surgical patients and identify the BMI-related trajectories of morbidity and mortality in surgery. Thorough understanding of the impact of overweight and obesity on surgical outcomes is imperative considering our forecast of future trends: in 2030, eight out of ten surgical patients (80.5%) will have a BMI greater than or equal to 25 kg/m², with overweight and obesity rates as high as 32.2% and 48.3%, respectively.

Both at the US national and global levels, the prevalence of diabetes is steadily increasing, with alarming projections for the future[44,45]. Interestingly, these trends were not reflected in our surgical cohort. Based on past trends our forecasting model calculated relatively stable levels over the next decade. This invariability among surgical patients may be due to two reasons: (1) advances in non-surgical treatments for diabetes may increasingly obviate the need for surgery and cushion the growing prevalence; (2) surgical and postoperative care may have reached capacity. Patients with diabetes undergoing surgery require specialized management and interdisciplinary monitoring during hospitalization, which is expensive, time-consuming, and resource-intensive[46], and surgical departments may be unable to handle more diabetic patients. It is essential to highlight that the diabetes prevalence in the surgical population—especially among elderly patients—still exceeds the US and worldwide averages. Diabetes has been linked with a higher risk of postoperative complications and increased morbidity and mortality across different surgical fields[47–53]. Actions are required which will decrease the diabetes prevalence among surgical patients—a turnaround is long overdue and urgently needed.

In conclusion, over the past two decades, the surgical population has been aging and the prevalence of surgical patients who are overweight or have obesity is rising. In the near future, the proportion of patients on which we operate who are elderly and have obesity and diabetes will increase; how these three factors interplay to predispose to complications and poor outcomes remains to be elucidated. As these trends show no signs of abating, measures are needed to maintain safe care for the ever-changing surgical patient. If preventative public health interventions fail to break this trend, surgeons will need to further adjust their perioperative management of associated risk.

Ethical approval

Ethical approval was obtained from our institution (Brigham and Women's Hospital, Boston, MA; Protocol #: 2013P001244).

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Author contribution

S.K.: conceptualization, data collection, methodology, writing—original draft; D.Y.M.: data collection, methodology; S.F.: methodology, statistical analysis, writing—review and editing; L.K.: writing—review and editing; V.H.: writing—review and editing; G.H.: writing—review and editing; M.K.: writing—review and editing; U.K., supervision, writing—review and editing; B.P., supervision, writing—review and editing; D.P.O.: conceptualization, supervision, writing—review and editing; A.C.P.: conceptualization, investigation, methodology, visualization, writing—original draft. All authors read and approved the final manuscript.

Conflicts of interest disclosure

There are no conflicts of interest.

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Presentation

None.

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