



Case series

Characteristics, comorbidity burden and outcomes in centenarians undergoing surgery in a university hospital: A case series

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ABSTRACT

Introduction: As the population ages, so too does the age of those requiring surgery. People over the age of 100, centenarians, often have a greater degree of comorbidity and frailty than their younger counterparts but may also have a greater incidence of events requiring surgical intervention. There is, however, a dearth of literature describing the clinical course and practical considerations for this vulnerable population undergoing surgery. We aimed to describe the demographics of centenarians undergoing surgery, the procedures they receive, their intraoperative anaesthesia management, and their postoperative outcomes.

Presentation of cases: A retrospective cohort study was completed to understand key perioperative and intraoperative variables linked to improved outcomes. Of the 25 patients included in this study, 22 (88%) were female and the median age was 101 years. Emergency cases predominated (72%) and 44% of surgeries occurred after hours. 60% underwent an intermediate risk surgery, and no centenarians underwent high risk surgery in this study period.

Discussion: 64% of patients experienced at least one episode of intraoperative hypotension, with a median 3.5 epochs per patient. 68% of patients experienced postoperative complications and 20% of patients had a complication of Clavien-Dindo severity \geq III. In centenarians, the risk of high severity postoperative complications was independent of the intrinsic procedural risk.

Conclusion: Centenarian patients have an elevated burden of comorbidity, presenting often in the emergent setting. However, age alone should not preclude surgical intervention as expert multidisciplinary care can have acceptable outcomes.

1. Introduction

Centenarians (age \geq 100 years) present a unique intersection of increased vulnerability and comorbid burden with medical concerns. Life expectancy in most developed countries has continued to rise, increasing by 4.8 years for males and 3.2 years for females over the past two decades in Australia [1]. Additionally, the proportion of the over 75-year-old population admitted for surgery has also increased over recent decades [2,3]. Therefore, the number of centenarians who may present for surgery will accelerate. Centenarians are not exempt from medical conditions that require prompt surgical intervention. However, advanced age is strongly associated with numerous physiological derangements, and when combined with a greater comorbid burden, the

reported and estimated mortality rate for any hospitalisation in centenarians is greater than 10% [4,5].

There is a dearth of research describing the characteristics, comorbidity burden and perioperative course for centenarians undergoing surgery, and, consequently, there is little evidence to guide and inform clinical practice and enhanced recovery pathways. In a recent study of centenarians and nonagenarians undergoing hemiarthroplasty a linear association between age and postoperative complications was found, placing centenarians at the highest age-related risk following surgery [6]. The majority of surgical research on centenarians has been in the context of trauma and orthopaedic surgery, and few studies have provided a granular insight into the anaesthesia and perioperative course for these patients [7–9]. Accordingly, this case series aims to provide a

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detailed description of centenarians undergoing minor and major surgery at a single-centre university hospital. Specifically, we aim to describe the demographics of centenarians undergoing surgery, the types of surgical procedures they receive, details of their intraoperative anaesthesia management, and their postoperative outcomes. These details, in turn, may facilitate the identification of centenarians undergoing surgery who are at risk of postoperative deterioration, help guide perioperative management, and allow for a focused allocation of hospital resources. This case series has been reported in line with the SCARE criteria [10], registered with Research Registry (unique identifying number 7305) and reported in line with the PROCESS criteria [11].

2. Methods

After Human Research Ethics Committee approval (no: HREC21/30), we undertook a retrospective cohort study of centenarian patients who had undergone surgery at a single-centre teaching hospital. In accordance with the protocol defined *a priori*, data were collected for centenarian patients who had undergone a surgical procedure over seven years from 1 January 2014 to 31 December 2020. Inclusion criteria were patients aged ≥ 100 years who had undergone any low, intermediate, or high-risk surgical procedure. Patients excluded were those who had undergone superficial skin surgery under local anaesthesia, any radiological intervention not requiring anaesthetist-administered medications, cardiac procedures performed by a cardiologist (insertion of permanent pacemakers, electrical cardioversion, coronary angiograms, or any coronary intervention including transcatheter aortic valve replacements) and cataract extractions under topical, retrobulbar, or peribulbar eye blocks.

2.1. Definitions

The procedural risk was classified as low, intermediate, or high risk, following the American College of Cardiology and American Heart Association guidelines for noncardiac surgery procedural risk stratification [12]. Minor surgery was defined as any colonoscopy, gastroscopy, bronchoscopy, and cystoscopy, or skin lesion (including breast) procedure that required anaesthetist-administered sedation, general, regional, or neuraxial anaesthesia. High-risk surgery included any cardiothoracic surgery, or surgery involving any major blood vessel. All other surgeries were classified as intermediate-risk surgery.

Frailty was defined as a score of five or more on the Canadian Study on Health and Aging (CSHA) clinical frailty scale [13]. The Charlson Comorbidity Index (CCI) [14] was used to quantify comorbid burden. Anaemia was defined using the World Health Organization (WHO) criteria [15]. Duration of admission was considered the time from admission to the time of discharge, as noted in the electronic medical record. Time to surgery was defined as the time from admission to the start of anaesthesia. Complications were defined as any deviation from the expected postoperative course and graded using the Clavien-Dindo classification scale [16]. Readmission and return to theatre were noted if they were not part of the standard postoperative course and occurred within 30 days of the initial procedure. A hypotensive episode was identified as 5 min of systolic or diastolic blood pressure less than 80% of the baseline measurement; severe hypotension was a five-minute recording of blood pressure with at least a 40% reduction from baseline blood pressure.

2.2. Study objectives

The primary objective was to provide a detailed descriptive overview of centenarian patient demographics, including comorbidities, types of surgical procedures performed, intraoperative anaesthesia management and types of anaesthesia, fluid management, and opioid use. Further, the study aimed to provide an overview of the postoperative paradigm, including length of hospital stay, readmissions, development of

postoperative complications, and in-hospital and long-term mortality. The secondary exploratory objectives were to assess any differences in outcomes for patients undergoing low, intermediate, and high-risk surgical procedures.

2.3. Standard perioperative care

All high-risk patients of advanced age (>80 years) who had surgery at our institution were assessed by a multidisciplinary team comprising a surgeon, anaesthetist, physiotherapist and geriatrician. Surgical procedures were performed or supervised by qualified surgeons of the relevant specialty. Where indicated, preoperative investigations included biochemical, haematological and coagulation tests. All patients were optimised from a cardio-respiratory perspective and underwent preoperative haemoglobin and diabetic optimisation, based on the National Blood Authority of Australia's patient blood management initiative [17] and the Diabetes Discovery Initiative [18]. Patients with decision-making capacity were assisted in formulating an advanced care plan, which allowed them to communicate their future preferences relating to medical treatment to their families, friends, and health professionals in advance.

Two independent investigators extracted data from the electronic medical records. Austin Health utilises Cerner® electronic medical records, which allows comprehensive electronic data capture and retrieval of patient health information in the perioperative setting.

2.4. Statistical analysis

Deidentified data were stored electronically in a secure Microsoft Excel spreadsheet. Statistical analyses were then performed using Prism GraphPad software. The data are presented as count (proportion), mean (standard deviation; SD), median (interquartile range; IQR) and range (minimum to maximum values). The analyses included an assessment of normality using the Shapiro-Wilk test. Normally distributed data were further analysed using an unpaired *t*-test, and non-normally distributed data were analysed using the Mann-Whitney *U* test. Proportions were compared using contingency tables with Fisher's exact test. P-values are included and were considered statistically significant with a value of less than 0.05.

3. Results

During the study period, 247,657 patients underwent surgery, of which 25 patients (0.01%) fulfilled the prespecified inclusion criteria. Of these patients, 18 (72%) presented to the emergency department as an acute emergency admission. During the same period, 21 centenarians were admitted to the emergency department with an "acute surgical diagnosis". Of these patients, 15 (71%) underwent conservative treatment, which was consistent with their end-of-life treatment preferences. The other six patients (29%) presented with a life-threatening pathology (acute myocardial infarction, aortic dissection, massive gastrointestinal bleed, intracranial haemorrhage, ischaemic bowel). These patients were extremely frail, with multiple comorbidities and of very poor functional status. Surgery was considered futile, and they were palliated.

Baseline patient characteristics, medications and laboratory results of patients who underwent surgery are summarised in Table 1. A total of 22 (88%) patients were female, the median (IQR; minimum–maximum) age was 101 years (100:102; 100–105), and the mean (SD) body mass index (BMI) was 25.0 kg/m² (3.9). Centenarians presented from home (60%, *n* = 15) and residential care (40%, *n* = 10), and most were frail (76%, *n* = 19) and comorbid with an American Society of Anesthesiologists (ASA) physical status score ≥ 3 in 84% of patients and a median (IQR) CCI of 6 (5:7). Malignancy (32%, *n* = 8), cerebrovascular accidents (28%, *n* = 7), chronic kidney disease (24%, *n* = 6) and dementia (24%, *n* = 6) were the most common comorbidities. Medications on hospital admission included antihypertensives (60% of patients, *n* = 15),

Table 1
Characteristics and preoperative management of centenarian patients undergoing major and minor surgery.

	n = 25
<i>Patient characteristics</i>	
Male	3 (12%)
Female	22 (88%)
Age (years)	101 [100:102] (100–105)
BMI (kg/m ²)	25.0 (3.9)
Active smoking	0 (0%)
<i>Residence</i>	
Home	15 (60%)
Residential care facility	10 (40%)
<i>Frailty (modified CSHA clinical frailty scale)</i>	
Fit, well or vulnerable	6 (24%)
Frail (mild, moderate or severe)	19 (76%)
<i>ASA</i>	
<3	4 (16%)
≥3	21 (84%)
1	0 (0%)
2	4 (16%)
3	15 (60%)
4	6 (24%)
<i>Presentation</i>	
Emergency	18 (72%)
Elective	7 (28%)
<i>Comorbidities</i>	
CCI	6 [5:7]
Malignancy (solid tumours/lymphoma/leukaemia)	8 (32%)
Cerebral vascular accident/transient ischaemic attack	7 (28%)
Chronic kidney disease	6 (24%)
Dementia	6 (24%)
Congestive cardiac failure	3 (12%)
Peptic ulcer disease	3 (12%)
Myocardial infarction	2 (8%)
Peripheral vascular disease	2 (8%)
Diabetes	0 (0%)
Chronic liver disease	0 (0%)
Moderate/severe liver disease	0 (0%)
Metastatic malignancy	0 (0%)
Chronic obstructive pulmonary disease	0 (0%)
Hemiplegia	0 (0%)
<i>Presurgical medications</i>	
Antihypertensives	15 (60%)
Non-opioid analgesics	11 (44%)
Antiplatelet agents	7 (28%)
Diuretics	6 (24%)
Anticoagulants	5 (20%)
Benzodiazepines	5 (20%)
Reflux/peptic ulcer	5 (20%)
Vitamin supplements	5 (20%)
Nitrates	4 (16%)
Opioid analgesics	4 (16%)
Thyroxine	4 (16%)
Antimuscarinic (urinary incontinence)	2 (8%)
Bronchodilators	2 (8%)
Laxatives	2 (8%)
Antibiotics	1 (4%)
Antithyroid	1 (4%)
Dementia	1 (4%)
Osteoporosis medications	1 (4%)
Sleep adjuncts	1 (4%)
Statins	1 (4%)
<i>Preoperative paradigm</i>	
Time from hospital admission to surgery (hours)	25 [4:45]
Albumin (g/L)	32.4 (4.4)
Creatinine (µmol/L)	86 [71.5:105]
Haemoglobin (g/L)	114.6 (16.0)
Anaemic patients (WHO classification)	13 (52%)

Note. Data are presented as number (percentage), mean (SD), median [IQR] and range (minimum–maximum).

non-opioid analgesics (44%, n = 11) and antiplatelet agents (28%, n = 7). The mean (SD) preoperative albumin value was 32.4 g/L (4.4), median (IQR) creatinine 86.0 µmol/L (71.5:105.0) and mean (SD) haemoglobin 114.6 g/L (16.0). There were 13 patients (52%) who were anaemic.

Emergency surgery occurred in 72% of patients (see Table 1). The time from hospital admission to surgery was 25 h (IQR 4:45; see Table 1). Intraoperative data are presented in Table 2; 44% of all surgeries occurred after hours. The most common surgeries included orthopaedic (48%, n = 12), plastic (16%, n = 4), maxillofacial (8%, n = 2) and colorectal surgery (8%, n = 2; see Table 2). The proportion of cases that were low, intermediate and high-risk surgeries were 40% (n = 10), 60% (n = 15) and 0%, respectively. The median (IQR; minimum–maximum) duration of surgery was 61 min (41.5:115.0; 7–170).

Most procedures were conducted under general anaesthesia (56%, n = 14), with 32% (n = 8) of cases under light sedation and 12% (n = 3) of cases under regional block only (see Table 2). For airway management, 40% (n = 10) of cases were managed with an endotracheal tube, and 20% (n = 5) of cases used a supraglottic device. Intraoperative temperature was only measured in 16% (n = 4) of cases, with a median lowest temperature of 36.0 °C. Intraoperative opioids were given to 76% (n = 19) of patients, with a median (IQR; minimum–maximum) intravenous morphine equianalgesic dose of 10.0 mg (3.8:14.0; 1.3–18). The type and amount of opioid analgesia are presented in Table 2.

Haemodynamic variables for centenarian patients are detailed in Table 3. The mean (SD) value for pre-induction mean arterial pressure was 98.2 mm Hg (12.4), with a mean (SD) pre-induction systolic pressure of 147.4 mm Hg (19.2). Continuous arterial blood pressure monitoring was performed for 40% of patients throughout their procedure. Intraoperatively, 64% (n = 16) of patients experienced an episode of hypotension, with a median of 3.5 hypertensive epochs per patient; 16% (n = 4) experienced at least one episode of severe hypotension. Intraoperative fluid was administered to 76% (n = 19) of patients, with a median (IQR) volume of 1000 mL (1000:1000). All patients receiving fluid received crystalloid solutions. Vasoactive medication was given to 15 (60%) of patients intraoperatively; of these, 14 received metaraminol (mean dose 1607 µg; SD 663). In the postoperative care unit, 72% (n = 18) of patients experienced hypotension, with a median of 3.0 hypotensive epochs per patient. One patient received vasopressor support.

Postoperative outcomes are outlined in Table 4. Only 20% (n = 5) of patients received opioid analgesia in the post-anaesthesia care unit. All patients were discharged from this unit to the ward. In the ward, 28% (n = 7) of patients had a medical emergency response team (MER) activation. The most common reason for the MER activation was a reduced Glasgow Coma Scale (GCS) score (16% of all patients, n = 4), tachycardia (8%, n = 2) and hypotension (8%, n = 2). One patient returned twice to theatre in the course of their admission, and two patients were readmitted following discharge.

There were 17 patients (68%) who experienced a postoperative complication. The median (IQR; minimum–maximum) number of complications per patient was 2 (2.0:4.0; 2–7), and 28% (n = 7) of patients experienced four or more complications. The majority of complications were minor, of Clavien-Dindo class I and II severity (80% of patients, n = 20), but 20% (n = 5) of patients developed a Clavien-Dindo class III or greater complication. The most common type of complication was neurological (44% of patients, n = 11), followed by renal and gastrointestinal (32% of patients each, n = 8) and cardiac (28% of patients, n = 7).

The differences observed between centenarians undergoing low and intermediate-risk procedures are presented in Table 5. The median (IQR; minimum–maximum) total length of admission was 7.0 days (2.5:13.0; 1.0–31.0), and the median (IQR; minimum–maximum) postoperative stay was 5.0 days (1.4:12.1; 0.1–25.1). There was no intraoperative mortality. There was one death within 30 days post-procedure; however, this was noted to be secondary to the fall and neck of femur fracture that precipitated the admission rather than a direct surgical complication.

Table 2
Intraoperative variables of centenarian patients undergoing major and minor surgery.

	n = 25
<i>Type of surgical procedures</i>	
Orthopaedics	12 (48%)
Plastics	4 (16%)
Maxillofacial	2 (8%)
Colorectal	2 (8%)
Neurosurgery	1 (4%)
Hepatobiliary	1 (4%)
Gastroenterology	1 (4%)
Vascular	1 (4%)
General medicine	1 (4%)
<i>Specific procedures</i>	
Hip hemiarthroplasty	6 (24%)
Dynamic hip screw	4 (16%)
Hip gamma nail	1 (4%)
Hip intramedullary rod	1 (4%)
Tongue biopsy or excision	2 (8%)
Endoscopic ultrasound and/or colonoscopy	2 (8%)
Right leg laceration, debridement, split skin graft	1 (4%)
Craniotomy for subdural haematoma	1 (4%)
Forehead lesion excision and graft	1 (4%)
Excision of right lower eyelid basal cell carcinoma	1 (4%)
Right open inguinal hernia repair	1 (4%)
Nasal tip lesion excision and graft	1 (4%)
Endoscopic retrograde cholangiopancreatography	2 (8%)
Angiogram and angioplasty	1 (4%)
<i>Procedural risk</i>	
Low-risk procedure	10 (40%)
Intermediate-risk procedure	15 (60%)
High-risk procedure	0 (0%)
<i>Timing of procedure</i>	
After hours surgery (18:00–08:00)	11 (44%)
Duration of surgery (min)	61.0 [41.5:115.0] (7.0–170.0)
<i>Anaesthesia paradigm</i>	
General only	11 (44%)
Total intravenous anaesthesia	3 (12%)
Volatile anaesthesia	8 (32%)
Regional anaesthesia	3 (12%)
Combined regional and general anaesthesia	3 (12%)
Conscious sedation	8 (32%)
<i>Airway management</i>	
Endotracheal tube	10 (40%)
Supraglottic device	5 (20%)
<i>Temperature</i>	
Intraoperative lowest temperature (°C) ^a	36.0 [35.0:37.2]
<i>Opioids</i>	
Patients receiving opioids	19 (76%)
Intravenous morphine equianalgesic dose (mg) ^b	10.0 [3.8:14.0] (1.3–18.0)
Fentanyl	
No. of patients	14 (56%)
Total dose (µg)	115 [50:200]
Alfentanil	
No. of patients	4 (16%)
Total dose (µg)	650 [500:875]
Remifentanil	
No. of patients	1 (4%)
Total dose (µg)	8000 [8000:8000]
<i>Other drugs</i>	
Midazolam	
No. of patients	7 (28%)
Total dose (mg)	1.0 [0.5:1.0]

Note. Data are presented as number (percentage), mean (SD), median [IQR] and range (minimum–maximum).

^a Missing values: only n = 4 cases had intraoperative temperature data.

^b Remifentanil excluded from morphine equianalgesic dose calculation.

Table 3
Haemodynamic variables in centenarian patients undergoing major and minor surgery.

	n = 25
<i>Number of patients</i>	
<i>Pre-induction blood pressure</i>	
Systolic blood pressure (mm Hg)	147.4 (19.2)
Mean arterial pressure (mm Hg)	98.2 (12.4)
Diastolic blood pressure (mm Hg)	73.6 (12.3)
<i>Intraoperative hypotension^a</i>	
No. of patients with hypotension	16 (64%)
No. of intraoperative epochs per patient	3.5 [1.3:7.0]
No. of epochs of systolic hypotension per patient	1.0 [1.0:1.8]
No. of epochs of diastolic hypotension per patient	4.0 [2.0:7.0]
No. of epochs of systolic and diastolic hypotension per patient	2.0 [1.8:5.3]
No. of patients with severe hypotension ^b	4 (16%)
Continuous arterial blood pressure monitoring	10 (40%)
<i>Intraoperative fluid administration</i>	
No. of patients receiving intraoperative fluid	19 (76%)
Total fluids (mL)	1000 [1000:1000] (350–2000)
Crystalloid	
No. of patients receiving	19 (76%)
Volume received (mL)	1000 [1000:1000]
<i>Intraoperative vasoactive medication</i>	
No. of patients receiving a vasoactive medication	15 (60%)
Metaraminol	
No. of patients receiving	14 (56%)
Dose received (µg)	1607 (663)
Ephedrine	
No. of patients receiving	2 (8%)
Dose received (mg)	25.5 [15.0:36.0]
Glycerol trinitrate	
No. of patients receiving	1 (4%)
Dose received (µg)	12.5 [12.5:12.5]
<i>Post-anaesthesia care unit</i>	
No. of patients with hypotension ^a	18 (72%)
No. of hypotensive epochs per patient	3 [2:6]
Epoch of systolic hypotension per patient	1.5 [1.0:2.8]
Epoch of diastolic hypotension per patient	3.0 [2.0:5.0]
Epoch systolic and diastolic hypotension per patient	1.5 [1.0:7.3]
Vasopressor use	1 (4%)

Note. Data are presented as number (percentage), mean (SD), median [IQR] and range (minimum–maximum).

^a Intraoperative and postoperative hypotension defined as 5-minute recordings of blood pressure with at least a 20% reduction from baseline blood pressure.

^b Severe hypotension defined as a 5-minute recording of blood pressure with at least a 40% reduction from baseline blood pressure.

Over a median observation follow-up of 40 months, 11 patients (44%) died. The median (IQR; minimum–maximum) time to death post-procedure was 12.1 months (1.2:23.3; 0.8–24.7).

4. Discussion

4.1. Key findings

In a retrospective analysis of centenarian patients admitted for surgery at a university hospital, the number of centenarians who underwent surgery was extremely low (1 centenarian per 10,000 adult patients undergoing surgery). This patient cohort was frail, with a high pre-morbid burden of disease. One in two patients were anaemic on admission to hospital. Nearly 80% of surgeries were emergent, and almost half took place after hours, but all surgeries were of low or intermediate risk. Almost four in five patients developed at least one perioperative hypotensive episode, and a similar proportion developed at least one postoperative complication; however, most complications were minor, and in-hospital mortality was zero. Almost half of the patients were deceased after a median postoperative follow-up period of

Table 4
Postoperative outcomes in centenarian patients undergoing major and minor surgery.

Number of patients	n = 25
Total length of admission (days), median [IQR] (min–max)	7.0 [2.5:13.0] (1.0–31.0)
Postoperative length of admission (days)	5.0 [1.4:12.1] (0.1–25.1)
Post-anaesthesia care unit temperature	
Patients with temperature < 35.5 (°C)	0 (0%)
Post-anaesthesia care unit analgesia	
Patients receiving analgesia	5 (20%)
Patients receiving opioids	5 (20%)
Intravenous morphine equianalgesic dose (mg)	4.0 [2.7:5.3]
Fentanyl	
No. of patients	2 (8%)
Total dose (µg)	40.0 [30.0:50.0]
Morphine	
No. of patients	1 (4%)
Total dose (mg)	4.0 [4.0:4.0]
Oxycodone	
No. of patients	1 (4%)
Total dose (mg)	4.0 [4.0:4.0]
Tramadol	
No. of patients	0 (0%)
Total dose (mg)	0 [0:0]
Fentanyl patient-controlled analgesia/infusion	
No. of patients	1 (4%)
Cumulative dose (µg)	55.5 [55.5:55.5]
Discharge location	
Ward	21 (84%)
High dependency unit	0 (0%)
Intensive care unit	0 (0%)
Home	4 (16%)
MER activations	
Patients with MER activations	7 (28%)
Number of MER activations per patient	1.0 [1.0:2.0] (1.0–3.0)
Reason for MER activation	
Reduced GCS	4 (16%)
Tachycardia	2 (8%)
Hypotension	2 (8%)
Tachypnoea	1 (4%)
Breathing difficulty	1 (4%)
Clinical concern by nursing or medical staff	1 (4%)
Postoperative complications	
Return to theatre ^a	1 (4%)
Readmission	2 (8%)
Patients with complications	17 (68%)
No. of complications	2 [2.0:4.0] (2–7)
No complications	8 (32%)
One complication	0 (0%)
Two complications	9 (36%)
Three complications	1 (4%)
Four or more complications	7 (28%)
No. of patients with complications, by severity (Clavien-Dindo classification)	
I	13 (52%)
II	13 (52%)
IIIa	1 (4%)
IIIb	2 (8%)
IVa	1 (4%)
IVb	0 (0%)
V	1 (4%)
Worst complication severity	2.0 [1.5:3.0]
Patients with complication severity ≤ II (including nil complications)	20 (80%)
Patients with complication severity ≥ III	5 (20%)
Complications by system	
Cardiac	
No. of patients with complication	7 (28%)
No. of complications (proportion of complications)	9 (17.0%)
Haematological	
No. of patients with complication	4 (16%)
No. of complications (proportion of complications)	5 (9.4%)
Pulmonary	
No. of patients with complication	4 (16%)

Table 4 (continued)

Number of patients	n = 25
No. of complications (proportion of complications)	4 (7.5%)
Gastrointestinal	
No. of patients with complication	8 (32%)
No. of complications (proportion of complications)	8 (15%)
Infective	
No. of patients with complication	0 (0%)
No. of complications (proportion of complications)	0 (0%)
Metabolic	
No. of patients with complication	3 (12%)
No. of complications (proportion of complications)	3 (5.7%)
Neurological	
No. of patients with complication	11 (44%)
No. of complications (proportion of complications)	11 (20.8%)
Renal	
No. of patients with complication	8 (32%)
No. of complications (proportion of complications)	9 (17.0%)
Dermatological	
No. of patients with complication	2 (8%)
No. of complications (proportion of complications)	2 (3.8%)
Endocrine	
No. of patients with complication	0 (0%)
No. of complications (proportion of complications)	0 (0%)
Surgical	
No. of patients with complication	1 (4%)
No. of complications (proportion of complications)	1 (1.9%)
Other	
No. of patients with complication	1 (4%)
No. of complications (proportion of complications)	1 (1.9%)
Mortality	
Intraoperative mortality	0 (0%)
In-hospital mortality	0 (0%)
30-day mortality	1 (4%)
3-year mortality	11 (44%)
Time until death ^b post-procedure (months)	12.1 [1.2:23.3] (0.8–24.7)

Note. Data are presented as number (percentage), mean (SD), median [IQR] and range (minimum–maximum).

^a Unplanned return to theatre within 30 days of initial operation.

^b Median observation period was 40 months.

30 months.

4.2. Study implications

Our findings imply that low to intermediate-risk surgery in centenarians can be feasible and safe, even though this advanced-age patient cohort is frail, comorbid, and has a high rate of emergency surgical procedures. Further, our findings imply that while intraoperative and postoperative hypotension are common in this cohort and most patients develop a postoperative complication, the severity of complications is low, and in-hospital mortality in this study was zero. Further, our findings showed that the most common complications were neurological (delirium, 44%) and gastrointestinal (constipation, 32%). These findings provide opportunities for specific preventative strategies to be implemented.

In our study, patients undergoing intermediate and low risk procedures were managed in a general ward setting and this model of care was safe and effective with this risk profile, given suitable patient selection and effective intraoperative haemodynamic management. This is supported by Demoule et al. [19] who found that age alone is not a relevant criterion for ICU admission in patients 90 years of age or over, and illness severity is a much more relevant predictor.

Approximately half of the centenarians admitted for a procedure underwent intermediate-risk orthopaedic surgery (predominantly for a neck of femur fracture). Similar to other studies [20], our findings imply that the benefits of a robust orthogeriatric model of care cannot be understated. A previous model of interdisciplinary care between geriatricians and orthopaedic surgeons has demonstrated reduced mortality for elderly patients with a hip fracture [20]. Further, a previously validated

Table 5
Preoperative and postoperative measures in centenarian patients undergoing low and intermediate-risk procedures.

	Total patients (n = 25)	Low-risk procedure (n = 10)	Intermediate-risk procedure (n = 15)	P-value
<i>Residence</i>				
Home	15 (60%)	7 (70%)	8 (53%)	0.678
Residential care facility	10 (40%)	3 (30%)	7 (43%)	
<i>Frailty (modified CSHA clinical frailty scale)</i>				
Frail (mild, moderate or severe)	19 (76%)	6 (60%)	13 (87%)	0.175
BMI (kg/m ²)	25.0 (3.9)	26.8 (2.4)	22.8 (4.5)	0.093
CCI	6 [5:7]	5 [4:6.3]	6 [5:7]	0.111
<i>Preoperative blood measurements</i>				
Albumin (g/L)	32.4 (4.4)	35.2 (4.5)	30.3 (3.0)	0.005
Creatinine (μmol/L)	86.0 [71.5:105.0]	101.0 [83.3:107.4]	81.0 [64.0:95.0]	0.093
Haemoglobin (g/L)	114.6 (16.0)	117.8 (17.3)	112.5 (15.4)	0.426
Patients with anaemia	13 (52%)	4 (40%)	9 (60%)	0.428
<i>Emergency or elective</i>				
Emergency	18 (72%)	4 (40%)	14 (93%)	0.006
Elective	7 (28%)	6 (60%)	1 (7%)	
<i>Timing</i>				
Time to theatre (h)	25 [4:45]	3.5 [1.8:32.0]	40 [22.0:47.0]	0.013
Duration of procedure (min)	61.0 [41.5:115.0]	31.0 [22.3:56]	107.0 [75.0:132.0]	<0.0001
Length of admission (days)	7.0 [2.5:13.0]	3.0 [1.0:13.25]	8.0 [6.0:14.0]	0.103
Postoperative length of admission (days)	5.0 [1.4:12.1]	0.7 [0.1:13.0]	6.1 [4.1:12.1]	0.042
<i>Haemodynamics</i>				
Preoperative mean arterial pressure (mm Hg)	98.2 (12.4)	102.4 (13.3)	95.4 (11.3)	0.172
Any intraoperative hypotension	16 (64%)	7 (70%)	9 (60%)	0.691
Any postoperative (post-anaesthesia care unit) hypotension	18 (72%)	7 (70%)	11 (73%)	>0.999
No. of patients with intraoperative vasopressor use	15 (60%)	2 (20%)	13 (87%)	0.002
Patients receiving intraoperative fluids	19 (76%)	5 (50%)	14 (93%)	0.047
Total intraoperative fluid received (mL)	1000 [1000:1000]	1000 [375:1500]	1000 [1000:1000]	0.583
No. of patients receiving intraoperative opioid	19 (76%)	7 (70%)	12 (80%)	0.583
Intraoperative intravenous morphine	10.0 [3.8:14.0]	5.0 [3.3:10.0]	13.3 [5.3:16.0]	0.250

Table 5 (continued)

	Total patients (n = 25)	Low-risk procedure (n = 10)	Intermediate-risk procedure (n = 15)	P-value
<i>equianalgesic dose (mg)</i>				
<i>Discharge location</i>				
Ward	21 (84%)	6 (60%)	15 (100%)	0.016
Intensive care unit	0 (0%)	0 (0%)	0 (0%)	
Home	4 (16%)	4 (40%)	0 (0%)	
<i>Complications</i>				
Patients with at least one complication	17 (68%)	4 (40%)	13 (87%)	0.028
Worst complication severity (Clavien-Dindo classification)	2.0 [1.5:3.0]	2.5 [1.3:3.0]	2.0 [1.5:2.5]	0.717
Patients with complication severity ≤ II (including nil complications)	20 (80%)	8 (80%)	12 (80%)	>0.999
Patients with complication severity ≥ III	5 (20%)	2 (20%)	3 (20%)	
MER activation	7 (28%)	2 (20%)	5 (33%)	0.659
All-cause mortality post-procedure	7 (28%)	4 (40%)	3 (20%)	0.378
Time to death post-procedure (months)	12.1 [1.2:23.3]	12.6 [8.6:20.8]	1.2 [0.8:24.5]	0.628

Note. Data are presented as number (percentage), mean (SD), median [IQR] and range (minimum–maximum).

^aBold values indicate statistical significance where P ≤ 0.05.

comprehensive geriatric assessment and multidisciplinary care model has demonstrated a reduced length of hospital stay [21], and our analogous approach has had acceptable postoperative patient outcomes in this centenarian population. However, little data exist to guide these models in the care of the centenarian population; our findings shed further light on the context of centenarians undergoing major orthopaedic surgery.

Finally, all centenarian surgical procedures identified in our study were of low or intermediate surgical risk as classified by the American College of Cardiology and American Heart Association guidelines for noncardiac surgery procedural risk [12]. Interestingly, while patients undergoing procedures of intermediate risk were understandably more likely to experience a postoperative complication, the majority of their complications were mild and could be managed on the ward. Further the incidence of complications with Clavien-Dindo grade III or greater was similar across the two groups (P > 0.9999), suggesting that severe complications may be more associated with intrinsic risk for the comorbid centenarian population deemed surgically fit than with the risk carried by an intermediate-risk procedure. However, the low incidence of these complications and small sample size necessitates further large trials to achieve an adequately powered result.

4.3. Relationship to the literature

Similar case reports have emphasised the potential for improved quality of life for centenarians undergoing surgery [22]; however, there are conflicting reports on the outcomes. One retrospective analysis of trauma in centenarians described a higher incidence of inpatient (19%) and 30-day mortality (33%) than our study [8]. Another case series of 12 centenarians undergoing surgery for proximal femur fracture reported a higher 1-year mortality rate (88%) [23]. These differences may have

been attributable to their selection of trauma cases—invariably of higher acuity than our lower procedural risk cases—and the inclusion of centenarian trauma patients that were deemed not fit for surgery. When compared to birth-matched counterparts in the general population, one case series found no difference in survival rate of centenarians undergoing surgery [24], reinforcing our data demonstrating the acceptability of outcomes with careful patient selection. This finding is echoed by another study that compared the surgical comorbidity and complexity of centenarians, nonagenarians, and octogenarians undergoing surgical repair of a hip fracture and reported that centenarian patients had the lowest comorbidity prior to surgery with no worse outcomes for mortality [7]. Although our review found that no centenarians underwent high-risk procedures, one study of centenarians and nonagenarians has suggested that vascular procedures are not uniformly unsuitable for the elderly population [25]; however, the lack of specific age data made it difficult to attribute this finding to the centenarian proportion of their participants. While age has traditionally been recognised as a risk factor for perioperative morbidity and mortality [26], among older patients age alone does not predict postoperative complications after elective surgery [27]. Indicators of biological age such as comorbidity burden and frailty may be more important predictors of postoperative outcomes in this population. For example, the CCI has been identified as an independent predictor of mortality in centenarians with hip fracture undergoing surgery, as has the functional ambulation category score [9]. The collection of the functional ambulation category score was not within the scope of our study, although this could be a useful measure in future prospective trials.

4.4. Strengths and limitations

Our findings provide a detailed description of centenarians who have undergone minor and major surgery. We have explored the granular data for preoperative and intraoperative variables and postoperative outcomes for this vulnerable patient group. The study's extended follow-up time frames also allowed us to quantify longer-term mortality accurately. Other studies have provided a similar description of centenarians who have undergone orthopaedic surgery or the general elderly population who have had a broad spectrum of procedures. We can add to the clinical picture with a report of centenarians in the general surgical setting. We acknowledge several limitations of this study. A limitation of our study is that most patients were undergoing low to intermediate risk surgery. Therefore, our findings cannot be generalised to patients undergoing high risk surgery and we cannot make inference about whether patients undergoing higher risk surgical procedures could be as well managed on the ward. Additionally, the small sample size and retrospective design inherently limit the quality of its findings. Specifically, a selection bias is introduced as the centenarians in this study were those already deemed suitable for surgery by their treating team; thus, the conclusions drawn have limited applicability to the broader population of centenarian surgical candidates. Further, this is a single-centre study; therefore, our findings are not generalisable to other hospitals. Given that data were collected retrospectively, the follow-up period varied for patients depending on the year of surgery. This caveat may have affected the long-term mortality data, as, at the time of data collection, patients with more recent surgeries had shorter postoperative time frames. Finally, we did not assess functional or quality of life outcomes, which are arguably more important than objective measures of morbidity and mortality in this centenarian cohort [28]. Future studies may be enhanced by assessing functional outcome measures against metrics such as the WHO Disability Assessment Schedule [29,30]. Further, future studies with a larger centenarian sample population and a prospective study design may facilitate more robust multivariable logistic regression analysis. Despite these limitations, our study provides a unique description of an uncommon presentation and serves as a platform for hypothesis generation for future studies.

5. Conclusion

Appropriate selection of patients and multidisciplinary perioperative care leads to acceptable outcomes in centenarians undergoing low and intermediate-risk surgery. Despite advanced age, increasing comorbid burden and frailty, centenarians should not be denied surgery based on age alone. Further prospective trials are needed to identify risk factors associated with adverse outcomes in centenarians and explore potential prophylactic measures to reduce the probable heightened risk of low severity neurological complications, gastrointestinal complications, and postoperative hypotensive episodes.

Institutional review board statement

The study was reviewed and approved by the Institutional Review Board at Austin Health.

Informed consent statement

The need for informed written consent from participants was waived due to the observational and retrospective nature of the study.

Data sharing statement

The datasets generated and analysed during the study are not publicly available due to individual privacy concerns but are available from the corresponding author on reasonable request.

Provenance and peer review

Not commissioned, externally peer-reviewed.

Ethical approval

The study was reviewed and approved by the Institutional Review Board at Austin Health, Human Research Ethics Committee approval number HREC21/30.

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A/Prof Laurence Weinberg is the guarantor.

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CRediT authorship contribution statement

Dr Jayden MacDowall: responsible for data collection, statistical analysis, data interpretation and curation, literature review, writing the original draft of the paper, and revision prior to publication.

Dr Patrick Tully: responsible for data collection, literature review, and writing of the paper.

Dr Ranj Guha, Dr Marissa Ferguson, Dr Chong Tan: all assisted with the literature review, data interpretation, and revision of the paper.

A/Prof Laurence Weinberg: responsible for study concept, study methodology, data interpretation, supervision, project administration, and review and editing of the paper.

All authors have read the final manuscript and approved it for

submission.

Declaration of competing interest

None.

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