Patient-factor stratification and its application in operative theatre management

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List of contents

Introduction 4
Aims 6
Materials and Methods 6
Results 12
Phase 1; Trauma and orthopaedic (General survey) 12
Procedure benchmarking 12
Surgeon experience benchmarking 15
Risk factor cohorting 16
Phase 2 results: Total Knee Arthroplasty (High volume surgery) 17
Patient comorbidities 18
Degree of Osteoarthritis 21
Patient Risk Stratification 29
BMI as an index for patient factor stratification? 27
Special cases and considerations; Osteoporosis 31
Discussion 35
General Consideration 35
Acute Trauma-related surgeries 35
High Volume Surgery 35
The reliability of BMI as an index? 37
Understanding the correlation between BMI and FW 38
Role of Osteoporosis in consideration of reoperation / Revision 39
Managing the operating theater with stratified patient factors 41
Implications in surgical planning 42
Implication in device registration and others 42
Limitations and Future Prospects 43
Conclusion 45
Disclosures 46
Ethical Statement **46**
Acknowledgements **46**

List of publications

1. Kurokawa T., Kaneko Y., Mammen A.V., Walls V., Queiros I., Azaizah M., Bacon M., Török L., Varga E., **CASEMIX study: Assessment of patient factors influencing the subprocedure duration of trauma/orthopaedic surgeries** doi;https://www.injuryjournal.com/article/S0020-1383(24)00215-8/abstract
   Q1, IF; 2.2

2. Kurokawa Y, Kurokawa T, Fujii M, Tanifuji M, Nakajin T, Sato T, Machida I. **Proposal for a Simple Equation for Limb Muscle Weight Calculation.** Med Sci Monit. 2023 Feb 28;29:e938606. doi: 10.12659/MSM.938606. PMID: 36851828; PMCID: PMC9985304.
   Q2, IF; 2.2

3. Kurokawa T., Varga E. **Successful treatment of a challenging periprosthetic femoral fracture on a premenopausal patient with a long history of immunosuppression, MATROKPLAST,** 67. Edition, 2024. May. https://doi.org/10.21755/MTO.2024.067.0001.005

Abbreviations

ACL; Anterior Cruciate Ligament

AP: Anterior Posterior

ASA: American Society of Anesthesiologists

BMI: Body Mass Index

BW: Body Weight

CI; Confidence Interval

DM: Diabetes Mellitus

DXA: dual-energy X-ray absorptiometry

FW: total fat weight obtained by dual-energy X-ray absorptiometry

LMW: limb muscle weight obtained by DXA

HT: Hypertension

IOD: Intraoperative Duration

IQR; Interquartile Range

JLCA: Joint Line Convergence Angle

JRA: Juvenile Rheumatoid Arthritis

JSW: Joint Space Width

KL Classification: Kellgren-Lawrence Classification

LCP: Locking Compression Plate

LMWH: Low Molecular Weight Heparin

NOAC: New Oral Anticoagulants

OA: Osteoarthritis

ORIF:Open Reduction and Internal Fixation

PA: Posterior Anterior

PFHL: Proximal Femoral Hook Plate

RA: Rheumatoid Arthritis

SD: Standard Deviation

TAI: Thrombocyte Aggregation Inhibitor

TKA: Total Knee Arthroplasty

THA: Total Hip Arthroplasty

Introduction

"How long will my surgery take?" The best answer a surgeon can currently give is from a historical mean average for a particular procedure, considering how long surgery took for all patients, regardless of disparate diagnostic codes, demographics, surgeon experiences, comorbidities, and other risk factors. With so much diversity in procedure complexity, operation duration becomes inherently variable and inhibits robust and predictable planning. For example, publications describe an inverse relationship between the experience of the operating surgeon and operation duration.[1]

The lack of productivity that follows is a significant barrier to the effectiveness of public healthcare systems in Europe. As surgical service delivery organisations fail to deliver surgery in an efficient and predictable way, therefore increasing surgery volume, millions of people languish on waiting lists. This is found not just in Hungary[2] but in the United Kingdom[3], Austria,[4] and more. This attracts social burdens that remain a major problem for modern society: without their required surgery, pain continues, functional ability worsens, and symptoms progress, even requiring attendance in emergency wards. Patient experience is poor with repeated cancellations and long waits. The morale of clinicians falls, both being overworked due to late finishing surgeries and the direct impact seen on their patients. Experienced surgeons are left feeling underutilised where lists are underbooked. With the impact of COVID-19, it is estimated to take a typical country nearly one year (45 weeks) to clear their elective surgery backlog even with a 20% increase in surgical activity over their baseline.[5]

Not only this, but operating theatres are cost intensive assets (both in terms of capital cost and operational costs), demanding efficient use. The mean cost of operating room (OR) time is $36 to $37 per minute, according to financial data from California's short-term general and specialty hospitals in the fiscal year of 2014.[6] The means to improve revenue is improved productivity, currently out of reach due to unpredictability.

Our study is divided into two phases: phase 1, the surveying of general trauma and orthopaedic cases, and phase two; examining high volume surgeries, Total Knee Arthroplasties. By examining these two phases we aim to identify the factors determining the intraoperative duration, while stratifying the patients' characteristics that may affect the intraoperative duration.

Chronic knee osteoarthritis (OA) is a common disease that affects over 650 million people in the world. Total Knee Arthroplasty (TKA) is one of the definitive treatments for OA, and its demand is increasing year by year. With the aging population, the demand for high-quality TKA-associated intervention and care has grown exponentially, and efforts to increase productivity have been a major focus. [7,8] Although multiple studies exist concerning intraoperative times, the focus has been more on the patient's biometry and subjective complaints, as well as the composition of the surgical team. The physical, psychological and financial burden is catastrophic, and the development of swift countermeasures are essential.

If these hurdles do not pose enough challenges, the increases in energy costs and continuing concern for carbon emissions have been a relatively new field of interest.[9] Where energy costs have exponentially increased as well, health care providers are keen on decreasing the amount of non-productive energy usage without compromising quality care.[10] The same could be said in orthopaedic surgeries.

An important factor in understanding the patient's basic biometry, or rather its basics, is Body Mass Index (BMI). Despite the fact that methods of diagnosis vary from measuring walking speeds and grip strength to radiological investigations, the majority of them have faced difficulties due to the myriad of tests or parameters required. [11,12] Diminished muscle volume can be diagnosed easily by radiological modalities such as computed tomography, magnetic resonance imaging, and/or dual-energy X-ray absorptiometry (DXA). These methods are practically not available in the majority of smaller clinics, and the demand for a swift and simple method to understand the patients biometric characteristics is high. Not every clinic or hospital has the capacity to add another round of complicated diagnostics prior to surgery, and a primary breakdown of the patient is challenging.

In orthopaedic surgery, quality of the bone is another factor that influences the outcome of the surgery and its postoperative outcome. Revision surgery is time-consuming and financially burdening as well, even in simple cases, but more so in complex cases.[13] While it still provides the necessary care to a patient in a cost-effectiveness perspective, it is still a rapidly burdening problem that must be addressed. [14,15] A better understanding of the status of the bony physiology can be further applied in surgery; operating osteoporotic patients have challenges that require extensive preparation and treatment strategy to avoid multiple revisions.

Aims

The aim of this series of research is to provide a better understanding of factors that affect the surgical duration, especially those that are brought in by the patients. Those such as surgical instruments, surgeon experience and surgical complexities have been known to prolong the duration of surgery, but a better understanding of patient factors definitely is required for efficient surgical suitemanagement. management.

We aimed to evaluate the relationships between patient characteristics and comorbidities, as well as surgeon experience and its relationship to intraoperative subprocedure duration. With a better understanding of these influential factors, our goal is to be able to identify the factors that largely influence surgical duration in certain surgical subprocedures.

Additionally, we assessed the statistical correlations between biometric values such as weight, height, upper arm subcutaneous fat thickness and circumference and find a correlation with the values obtained by the patients' DXA scans such as total Fat Weight (FW) and Limb Muscle Weight (LMW).

Materials and methods

Data for this monocentric study were prospectively acquired via real-time surveys from September 2020 to October 2022, in which TCC-CASEMIX® was utilized. TCC-CASEMIX® was deployed remotely in September 2020 to a touch screen interface and tablets in five theaters at the Szent-Györgyi Albert Clinic of Traumatology and Orthopaedics from the University of Szeged as a data cleansing and acquisition tool.

Every procedure, sub-procedure and risk factor was recorded according to its SNOMED CT definition and duration measured using TCC-CASEMIX®. This ensured consistency of clinical coding and high data usability. Pearson’s correlation tests were performed to evaluate the parametric values, whereas the means and standard deviations were examined in non-parametric values. Data analysis was performed in *MATLAB R2021a*, delivered as part of the TCC-CASEMIX® system.

Pre-operative data from 167 patients were acquired. Patients were excluded according to our exclusion criteria, a lack of complete preoperative data sets, and failure of measurement. In phase 1, we examined general trauma and orthopaedic patients to find correlations between data from pre-operative assessment with intraoperative duration. Preoperative assessments included; age, height, weight, body mass index, and comorbidities. (Table 1) In phase 2 of the study we examined patients who received Knee Arthroplasties(TKA), focusing on high volume surgeries in depth. (Figure 1)

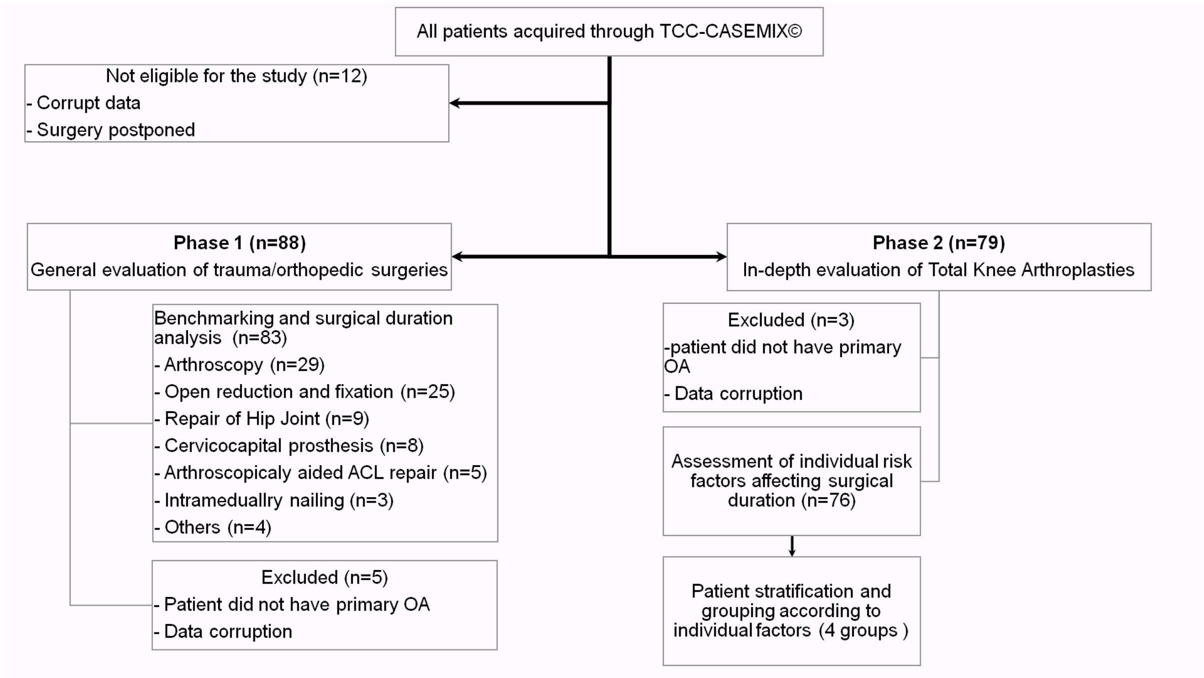

Figure 1. A flowchart representing the study process acquired via real-time surveys from September 2020 to October 2022.

Phase 1: wide spectrum survey of multiple surgeries.

The data acquisition tool acquired data for the study in two steps: Pre-operative Assessment (POAP) and peri/intraoperative measurement in a surgery data acquisition process (SDAP). In POAP, a 3rd party volunteer captures information about the patient (including age, sex, body mass index, and ethnicity), and enters each child sub-procedure (such as skin incision, reduction, and fixation). Independent clinical surveyors participated in the measurements of the surgeries.

User acceptance testing took place in October 2020 for a trial cohort of surgeries. Patient data such as age, weight, height, Body Mass Index (BMI) and most importantly past histories of disease were double checked through interviews with the patient and from nursing documents, and finally with the help of E-MedSolutions, the native administrative system equipped in the University of Szeged. Presence of DM and use of anticoagulants were additionally recorded through patient interview and prior discharge papers, with the consent of the patients. This cross referencing allowed us to minimize bias on patient comorbidities during POAP. Throughout the study, patient specific data was not exported to third parties.

- ASA classification:
  ASA1: Normal Healthy
  ASA2: Patient with mild systemic disease
  ASA3: Patient with severe systemic disease
  ASA4: Patient with severe systemic disease that is a threat to constant life
- Previous surgery:
  Abdomen
  Head and Neck
  Lower Extremity
  Thorax
  Upper Extremity
- Acute Myocardial Infarction
- Age
- Anticoagulant therapy
  Current
  Personal history
- Asthma
- Body mass index
- Blood pressure
- COPD
- Cerebrovascular diseases
- COVID-19:
  Class 1: Previous history of COVID-19
  Class 2: No history of COVID-19
- Congestive Cardiac Failure
- Diabetes Mellitus
- Epilepsy
- Ethnicity
- Gender
- Ischaemic heart disease
- Living alone

- Peptic ulcer
- Renal failure
- Rheumatoid arthritis
- Smoker
- Tendency to fall due to old age or other unclear health problems

Table 1. A list of comorbidities acquired in the preoperative assessment.

Phase 2: Total Knee Arthroplasty

We largely grouped the detailed subprocedures into 3 major steps; 1. Skin incision to joint exposure, 2. Prosthetic implantation, 3. Wound Closure. Detailed subprocedures steps are described in the following:

1. Skin incision to joint exposure
   - 1.1. Skin, subcutaneous layer and muscle layers incision
   - 1.2. Exposing the bony surface of the distal femoral joint

2. Prosthetic implantation
   - 2.1. Intramedullary drilling of the femur for navigator placement, insertion of navigator
   - 2.2. Placement of the resection block on the intramedullary navigator
   - 2.3. Resection of the distal femoral surface
   - 2.4. Placement of the 4 in 1 resector templates
   - 2.5. Resection of the distal femoral surface according to the 4 in 1 templates
   - 2.6. Placement of the external rotational template on resected surface
   - 2.7. Tibial navigator placement
   - 2.8. Tibial block placement bony surface
   - 2.9. Tibial bony resection
   - 2.10. Confirmation of the resection using the tibial templates
   - 2.11. Insertion of trial spacer on the tibial component
   - 2.12. Confirmation of joint components using trial templates
   - 2.13. Preparation for placement of tibial component and its insertion
   - 2.14. Placement and fixation of final tibial spacer

2.15. Fixation of femoral component

3. Wound Closure
   3.1. Muscle, subcutaneous layer and skin closure
   3.2. Sterile bandage application

Table 2. A list of subprocedure steps utilized in the data acquisition for TKA.

While examined detailed subprocedure steps and its durations, we created macroscopic groups of the detailed subprocedures, facilitating the relationships between cohesive steps of TKA. (Figure 2) Joint Line Congruence Angle (JLCA) and medial and lateral Joint Space Width (JSW) were examined, and patients were categorized according to the Kellgren-Lawrence classification (from Grade 0 to Grade 4).

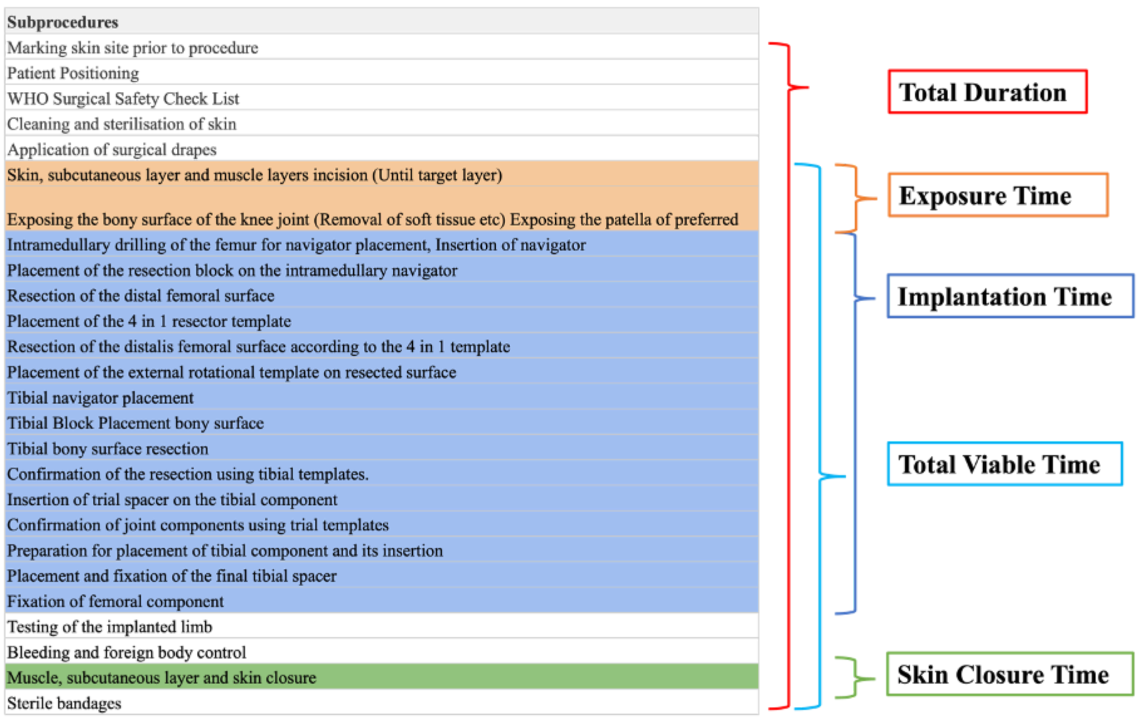

Figure 2. A sample of the grouped subprocedure steps surveyed in real time.

This study was conducted in accordance with the principles of the Helsinki Declaration. The protocol was approved by the Ethics Review Board of Ebetsu Tanifuji Hospital. (Ethical Number R2-0910)

One-hundred and nine patients were retrospectively examined for 33 months from July 2019 to April 2022. All patients were given informed consent and the study has been approved by the hospital's ethical council. Data from 95 patients were utilized to discuss the correlation between physical parameters and the available values examined by DXA. Most common causes of admission were fractures of the extremities, fractures of the vertebrae, and pneumonia, as is summarized in Table 1.

Measured physical parameters were body weight (kg), height (cm), upper arm subcutaneous fat thickness (mm) and upper arm circumference (cm) by a nutritionist by use of caliper tools. Biometric data were measured according to protocols from the National Institute for Health Research to minimize personal bias.[16] The general patient status was examined by the NST. The NST consists of 10 members such as medical doctors, registered nutritionists, nurses, laboratory technicians, pharmacists, speech therapists, physical trainers, and administrative staff. All new inpatients were screened for signs of malnutrition such as recent weight loss, loss of appetite, and low values of serum sodium and albumin levels as well.

FW and LMW of all four limbs were measured by DXA using Lunar iDXA PRODIG (GE Healthcare, U.S.A.)[17] Statistical analysis was performed using JSTAT: Ver. 22.0E.[18] The Pearson's correlation coefficient and probability values were examined among physical parameters and the values obtained by the DXA. Probability less than 0.01 was regarded as significant.

Results

Phase 1 results: Trauma and Orthopaedic (General survey)

83 patients were examined in phase 1. Cases are described in Table 2.

Procedural Intervention		*n*	Elapsed		Productive		Non-productive	
			Mean	SD	Mean	SD	Mean	SD
-	All	83	76.77	46.10	52.92	35.28	23.86	19.73
13714004	Arthroscopy	29	37.23	12.02	25.29	8.51	11.94	6.99
16210001	Resection of clavicle	1	83.32	-	60.59	-	22.73	-
31757006	Osteotomy of tibia	1	108.13	-	80.85	-	27.28	-
47458005	Repair of hip joint	9	130.07	37.75	90.31	27.94	39.77	17.03
55244002	Arthroscopically aided anterior cruciate ligament repair	5	64.47	28.30	39.19	15.56	25.27	14.06
72010008	Removal of internal fixation device	2	41.72	11.68	28.65	14.62	13.07	2.93
133861000	Open reduction and fixation	25	95.98	43.58	73.59	38.93	22.39	10.60
278728008	Cervicocapital prosthesis	8	95.12	43.25	53.90	31.01	41.22	38.61
734271006	Intermedullary nail screw-alignment insert	3	121.35	43.72	60.04	22.22	61.31	22.24

Table 2. Procedure benchmarks for TCC-CASEMIX® data collected at University Clinic of Traumatology of Szeged.

Procedure benchmarking

For each procedure in the TCC-CASEMIX® database, a benchmark of elapsed time broken down into productive and non-productive durations is provided. Productive time was defined as the viable time that was measured according to the designated subprocedure. Non-productive time was defined as the time in which time elapsed which had nothing to do with the subprocedure (waiting for implants, equipment malfunction, etc) In the majority of surgeries a significant amount of non-productive time was measured.(Figure 3)

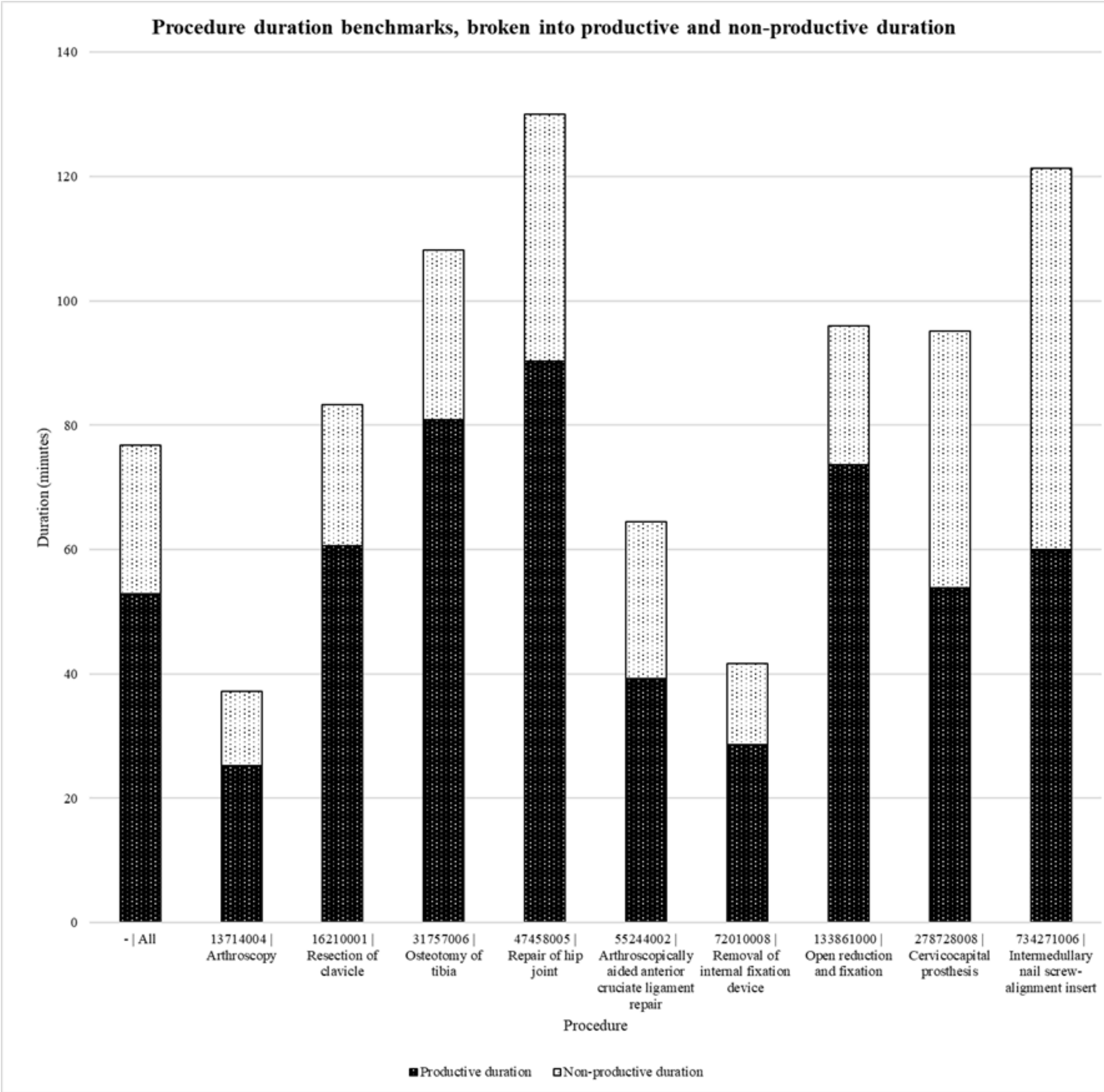

Figure 3: Procedure benchmarks for TCC-CASEMIX® data collected at University Clinic of Traumatology of Szeged

For all procedures, 31.1% of operation duration was non-productive. The procedure with the highest amount of non-productive time was intramedullary nail screw-alignment insert (*n* = 3) with 50.5% non-productive. The lowest was 23.3% for open reduction and fixation (*n* = 25). Twenty-two sub-procedures had collected sufficient data to be statistically reliable (threshold: thirty sub-procedures). During the preoperative assessment, surgeons were asked to estimate the duration of sub-procedures. Generally, sub-procedure durations were overestimated by the operating team. (Figure 4)

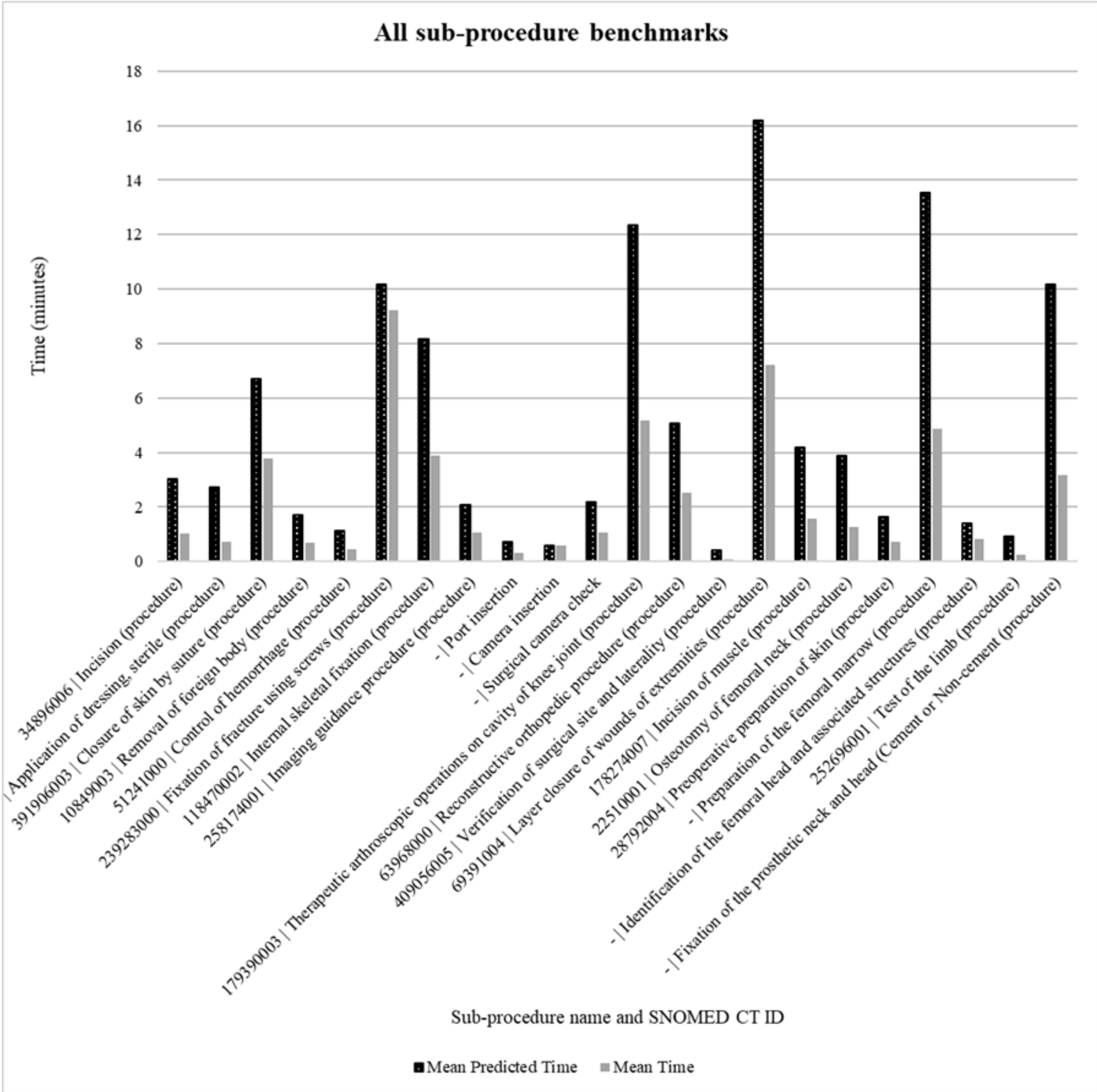

Figure 4: Sub-procedure duration benchmarks

Some sub-procedures were highly predictable: for example, the *application of dressing* (n = 165) had a standard deviation of 0.79 minutes, possibly explained by the simple nature of this procedure.

Others were far less predictable, for example *fixation of fracture using screws* (n = 64) had a standard deviation of 12.14 minutes, likely as this is a complex procedure whose duration depends on the classification and severity of the fracture.

Sub-procedure benchmarking was also completed for sub-procedures related to patient preparation. (Figure 3) Just as with sub-procedures, the length of patient preparation activities was being overestimated significantly by the team. Each sub-procedure had a degree of variability, ranging from a standard deviation of 2.48 minutes for the *WHO Surgical Safety Checklist* (n = 171) to 1.36 minutes for *Application of Surgical Drapes* (n = 174).

Surgeon experience benchmarking

The statistical analysis explored the relationship between surgeon experience and operation duration of *arthroscopy* (n = 29), finding a small deviation in elapsed time. For surgeons recorded with 8 – 9 years of experience, arthroscopies took an average of 37.75 minutes (n = 4) while for those with more than ten years of experience, arthroscopies took an average of 35.62 minutes (n = 19). (Figure 5)

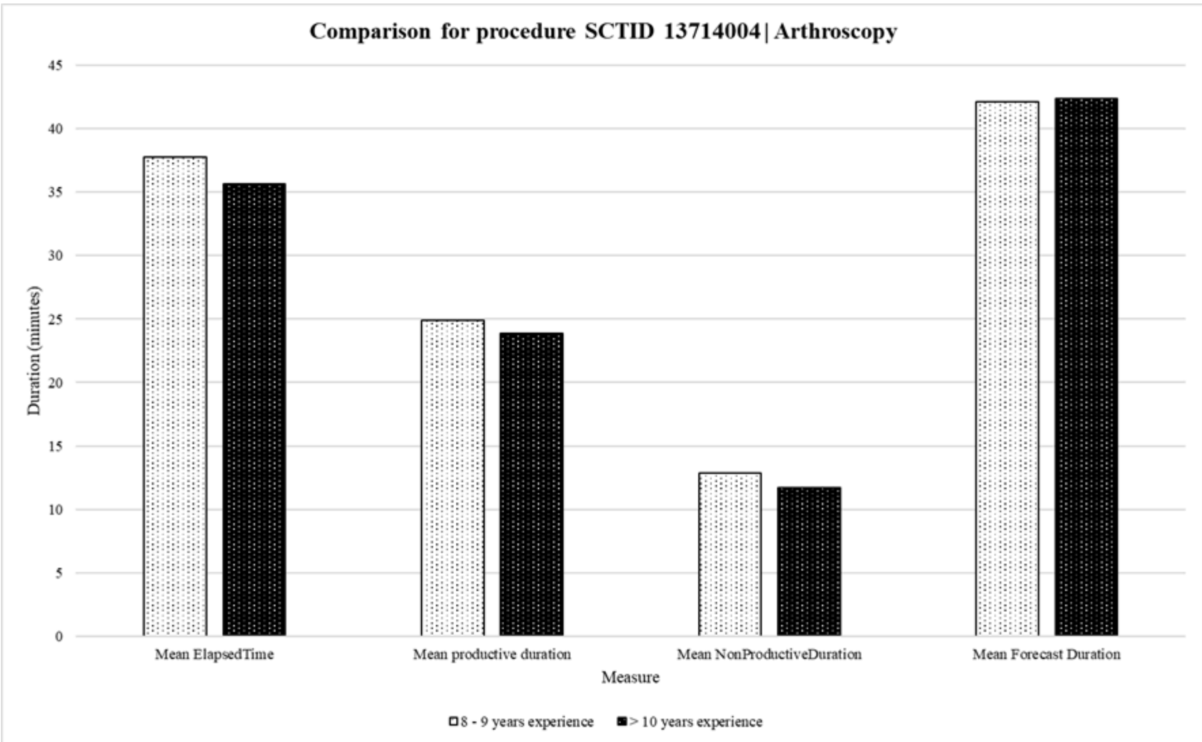

Figure 5: Comparison of intraoperative procedure duration for arthroscopy

The amount of non-productive time was also affected, at 34.1% for the 8 – 9 years of experience group and 32.9% for the 10+ years of experience group. (Figure 6)

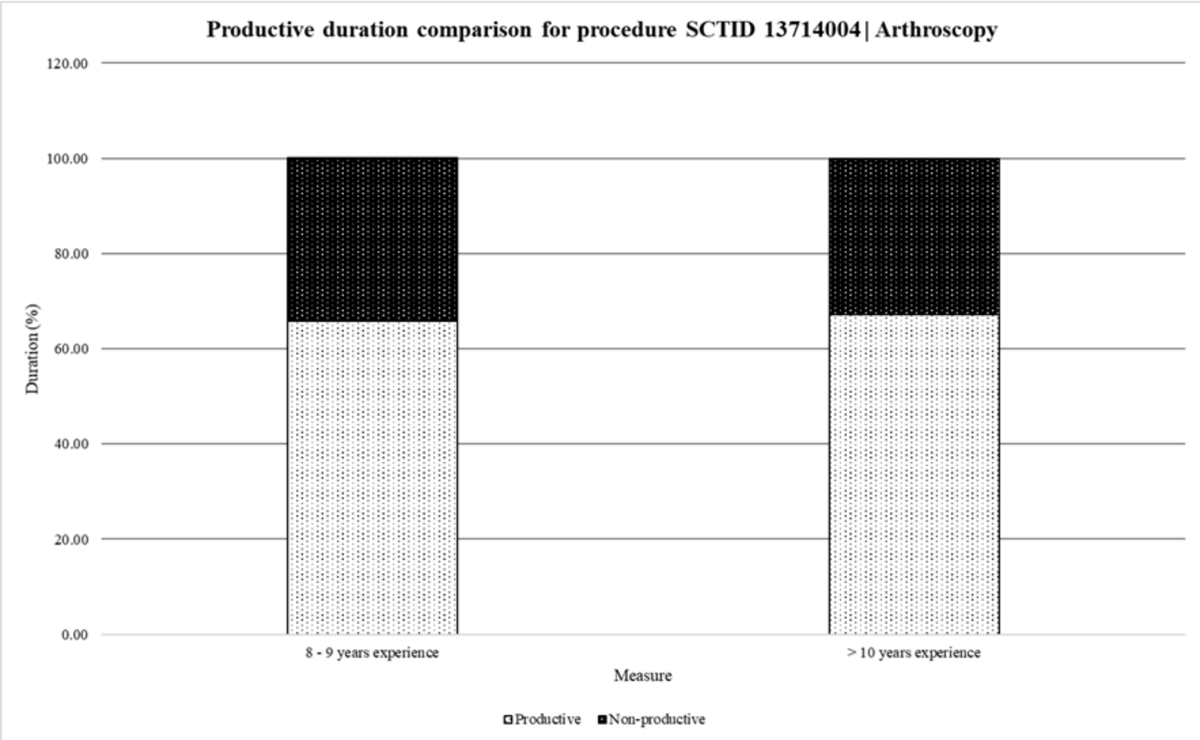

Figure 6: Productivity benchmarks for surgeon experience for arthroscopy

Risk factor cohorting

Using statistical analysis to correlate risk factors with operation duration, it was possible to create cohorts of comparable patients with similar degrees of procedure complexity and operation duration. Compared to procedure benchmarks, each risk factor cohort sees reduced variability measured by standard deviation. Examples can be seen in arthroscopic procedure data. (Table 4)

Snomed ID	Name	Mean Time	Δ	Std. Dev.	n	Surgeon Experience	Method	Patient Age	Risks-2 present
13714004	Arthroscopy	28.12	2.83	4.54	7	> 10 years	Excision	32	RISK - Blood Pressure
13714004	Arthroscopy	27.31	2.02	4.79	8	> 10 years	Excision	32	RISK - Age
13714004	Arthroscopy	27.31	2.02	4.79	8	> 10 years	Excision	32	RISK - BMI
13714004	Arthroscopy	26.71	1.42	4.84	5	> 10 years	Excision	32	RISK - ASA1: Normal Healthy
13714004	Arthroscopy	23.89	-1.40	6.58	6	> 10 years	Excision	22	RISK - Age
13714004	Arthroscopy	23.89	-1.40	6.58	6	> 10 years	Excision	22	RISK - BMI
13714004	Arthroscopy	28.63	3.34	7.08	7	> 10 years	Excision	42	RISK - Age
13714004	Arthroscopy	28.63	3.34	7.08	7	> 10 years	Excision	42	RISK - BMI
13714004	Arthroscopy	28.63	3.34	7.08	7	> 10 years	Excision	42	RISK - Blood Pressure
13714004	Arthroscopy	28.63	3.34	7.08	7	> 10 years	Excision	42	RISK - Ethnicity

Table 4: Arthroscopic procedures cross referenced with surgeon experience, age and other risks.

Phase 2 results: Total Knee Arthroplasty (High Volume Surgery)

A total of 79 were studied and surveyed into TCC-CASEMIX©. Surgical steps were broken down into detailed subprocedures (Table 2) and also largely grouped into three major steps; skin incision to joint exposure (Exposure Time), prosthetic implantation (Implantation Time), and closure (Skin Closure Time). Total Duration (The time from when a patient arrives at the operation room until the end of the procedure) and Total Viable Time (the sum of each subprocedures in TKA). Individual factors were first assessed, followed by patient stratification, allowing us to find a pattern that contributes to better predicting intraoperative duration.

Patient Biometry (Age, Weight, Height, BMI)

The mean age of the patient cohort was 67±17 years old. The correlation between age and Total Duration, Total Viable Time, Exposure Time, Implantation Time, and Skin Closure Time was examined. (Table 5) No significant correlation was found between age and IOD in each subprocedure.

76 patients' data were obtained out of 79 patients. The remaining 3 patients could not be evaluated due to missing patient data. The height of patients ranged from 146 cm to 190 cm, with the mean of 165.8 cm and the median of 165 cm. The weight of patients ranged from 47 kg to 126 kg, with the mean of 88.8 kg and the median of 88.0 kg. The BMI of patients ranged from 19.6 to 43.9, with the mean BMI of 32.3 and the median of 32.0. The BMI ranges were divided into 5 groups: less than 25 (n=9), 25 to 30 (n=12), 30 to 35 (n=31), 35 to 40 (n=18), and more than 40 (n=6).

The correlation between height, weight, BMI, and the grouped sub procedures (Total Duration, Total Viable Time, Exposure Time, Implantation time, and Skin Closure Time) was examined. No significant correlation was observed between age and height and each subprocedure, whereas weight and BMI were minimally correlated.

	Total Duration	Total Viable Time	Exposure Time	Implantation Time	Skin Closure Time
Correlation with Age (r)	-0.081	0.005	-0.055	-0.027	-0.027
Correlation with Weight (r)	0.238	0.148	0.177	0.096	0.034
Correlation with Height (r)	0.124	-0.015	0.038	0.033	0.006
Correlation with BMI (r)	0.183	0.180	0.170	0.079	0.012

Table 5. Correlations observed between subprocedure duration and age, weight, height and BMI.

Patient Comorbidities

1. Anticoagulation

We categorized patients into 5 groups, those who take Aspirin (n=12), Coumarin (n=4), Thrombocyte Aggregation Inhibitor (TAI) (n=2), New Oral Anticoagulant (NOAC) (n=4) and those who do not take any of anticoagulants (n=55). We measured the mean of Total Duration, Total Viable Time, Exposure Time, Implantation Time, Skin Closure Time, and time of Hemorrhage control during the operation for each group. The results can be observed on Table 6.

	Total Viable Time		Exposure Time		Implantation Time		Skin closure Time		Hemorrhage Control (min)		Total Duration	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Aspirin	71.9	15.9	7.0	1.7	38.2	13.8	20.5	5.4	2.8	1.6	104.4	19.0
None	70.5	14.8	6.2	1.7	36.1	8.7	22.5	6.0	4.0	2.7	98.3	21.2
NOAC	61.1	24.5	5.9	1.7	33.3	11.1	24.6	9.5	2.8	0.4	84.3	13.7
TAI	82.7	15.3	9.4	2.1	30.7	15.1	31.8	4.5	6.8	2.7	118.0	12.7
Coumarin	73.4	23.1	6.3	1.0	39.6	15.0	20.7	5.9	3.3	2.9	106.5	26.1

Table 6. Mean values and Standard Deviation of patients taking anticoagulatory medication.

TAI had the most prolonged effect on total duration (118 min) and hemorrhage control (6.8 min), while compared to patients taking other anticoagulant therapy. However, according to our pre-operative protocol, all of our elective patients' anticoagulant therapies were converted to subcutaneous injections of Low Molecular Weight Heparin (LMWH) 2 days prior to the surgery; we find this result to be inconclusive.

2. Hypertension

There were 61 patients with hypertension and 18 patients without hypertension. Hypertension was defined as the following; patients who were previously diagnosed with hypertension, and those who were taking antihypertensive medication. The presence of hypertension did not seem to drastically prolong the IOD. On the contrary, values were shortened minimally in the majority of subprocedures, except for Implantation Time. Since the differences were minimal, this also concludes to be a factor that does not influence IOD, these findings are demonstrated in Table 7 below.

A possible explanation might be attributed to patient adherence and compliance to their therapeutic regime leading to their blood pressure normalizing, which subsequently resulted in minimal influence intraoperatively.

	Total Viable Time		Exposure Time		Implantation Time		Skin Closure Time		Total Duration	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Without HT	70.0	19.1	6.2	2.3	36.3	10.2	22.2	5.5	98.6	25.1
With HT	70.7	14.0	6.6	1.6	35.8	10.0	22.0	6.1	99.2	19.7

Table 7. Mean subprocedure duration times in patients with / without hypertension as well as their Standard Deviation.

The presence of hypertension did not significantly prolong IOD. On the contrary, we found that values were slightly smaller in the majority of subprocedures except for Implantation Time, concluding this to be a factor that does not influence IOD. This could be explained by the fact that because patients were taking their medication and their blood pressure was normalized, minimal influence was seen intraoperatively.

3. Diabetes Mellitus

19 diabetic patients and 60 non-diabetics were examined. Patients who were previously diagnosed with DM type 1 and 2, and those taking anti-diabetic therapy were included. Findings are demonstrated in Table 8.

	Total Viable Time		Exposure Time		Implantation Time		Skin Closure Time		Total Duration	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Without DM	70.5	15.6	6.4	1.8	35.4	10.0	22.6	5.8	100.5	21.8
With DM	70.6	14.2	6.8	1.6	37.4	10.3	20.1	6.4	94.5	17.2

Table 8. Correlation of Diabetes Mellitus with evaluated surgical parameters

To our surprise, patients with DM results in shorter Total Duration than non-diabetics (94.5 min and 100.5 min respectively), however the sample size for diabetics were significantly fewer, thus these results are inconclusive.

4. Smoking

7 patients declared themselves as smokers, and 72 patients were non-smokers. Interestingly, non-smokers tended to have longer IOD in all subprocedure groups except in Skin Closure Time. Exposure Time and Skin Closure Times of the two groups were similar, and large differences were observed in the Implantation Times (Table 9). There is evidence that supports that smoking negatively impacts the duration of procedure, which our study does not highlight. It is important to note that the sample is skewed towards non-smokers, which may in part be due to the binary nature of this inquiry. Therefore, an index could reveal a more complex relationship between smoking and procedure duration.

	Total Viable Time		Exposure Time		Implantation Time		Skin Closure Time		Total Duration	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Non-smoker	70.7	15.7	6.55	1.8	36.1	10.3	21.8	6.1	99.1	21.3
Smoker	68.4	8.5	6.3	1.2	34.1	6.6	24.3	3.0	98.6	17.4

Table 9. Data found regarding smoking habits in correlation with evaluated parameters

Degree of Osteoarthritis

1. Kellgren Lawrence classification

We utilized the Kellgren Lawrence classification to evaluate the severity of osteoarthritis using five grades, Grade 0 to 4. There were zero patients with Grade 0 and 1. There were 3 patients with Grade 2, 17 patients with Grade 3, and 53 patients with Grade 4 (Total n=73). Of 79 patients, 6 patients' X- ray were not available. Results are presented in Table 10.

	Total Viable Time		Exposure Time		Implantation Time		Skin Closure Time		Total Duration	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
GRADE 2 + 3	69.1	13.7	6.3	1.5	35.1	7.9	22.4	7.0	98.8	22.1
GRADE 4	71.7	16.3	6.6	2.0	36.4	11.1	22.2	5.7	100.0	21.1

Table 10. Mean subprocedure duration times of grade 2,3 and grade 4 OA according to the Kellgren - Lawrence classification.

Patients with more severe OA (Grade 4) had prolonged mean IOD. This suggests that the severity of OA has a minimal but prolonging impact on IOD in all patient groups. While Exposure Times and Skin Closure Times remained similar, Implantation Time slightly increased and therefore the Total Viable Time as well. (Figure 7)

Moderate but steady prolongation of mean IODs was observed in patients with KL Grade 4 OA. This suggests that the severity of OA has a minimal but prolonging impact on IOD in all patient groups. While exposure times and skin closure times remained similar, implantation time slightly increased, and consequently the total valid time as well.

2. Joint space width (JSW), Joint Line Convergence Angle (JLCA)

73 patients were examined with the KL classification as well as the JSW and JLCA, by knee AP/PA radiographs, to assess progression of knee osteoarthritis.

To measure the JSW, we measured the distance between the medial point of medial femoral condyle and articular surface of medial tibial condyle (M2), and the distance between the medial point of lateral femoral condyle and articularv surface of lateral tibial condyle (L1)

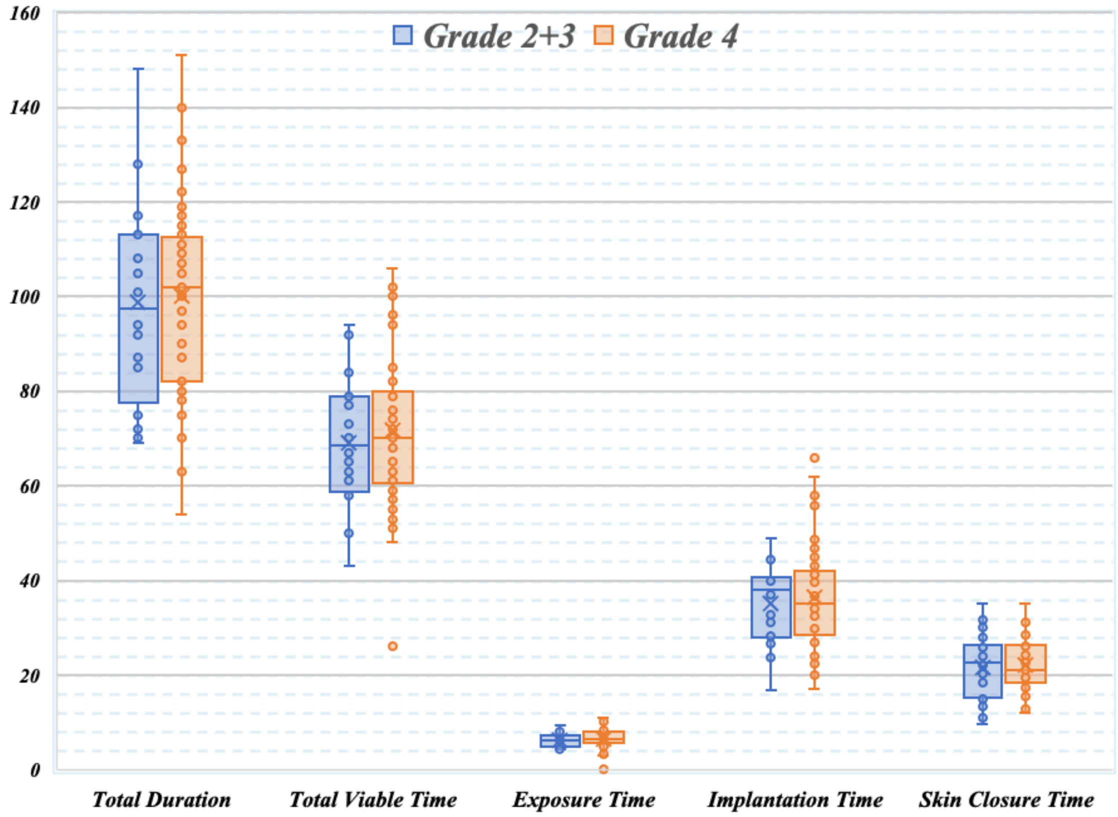

Figure 7. A representation of the steady but unignorable increase in IOD in patients with KL grade 4 OA when compared with grades 2 and 3.

The distance of Medial and Lateral JSW ranged from 0 cm to 11.1 cm and from 1.4 cm to 13.5 cm, with the mean of 4.6±2.1 cm and 6.0±2.4 cm, respectively. To measure the JLCA, we measured the angle formed between two tangential lines at the distal femoral and proximal tibial articular surfaces. The JLCA of patients ranged from 0.7 degree to 20.4

degree with the mean of 5.4±3.6 degree. The correlations between Medial and Lateral JWS, JLCA, and Total Viable Time, Exposure Time, Implantation Time, and Skin Closure Time, and Total Duration were examined. (Table 11)

	Total Viable Time	Exposure Time	Implantation Time	Skin Closure Time	Total Duration
Correlation with Medial JSW (r)	0.090	-0.025	0.043	0.197	0.239
Correlation with Lateral JSW (r)	0.406	0.014	0.400	0.222	0.232
Correlation with JLCA (r)	-0.186	-0.019	-0.151	-0.235	-0.048

Table 11. Joint Space Width and Joint Line Convergence Angle correlations with study parameters

Correlations between the Total Viable Time, Implantation Time and the lateral JSW were moderate, where JLCA, and mJSW did not show significant correlation in any of the subprocedures.

The differences between the different devices were also examined. 6 patients received Columbus (Aesculap, B. Braun), 39 patients received P.F.C. SIGMA (Johnson and Johnson), 34 patients received LEGION (Smith and Nephew) trays. Only Cruciate Retaining types were included for a unison comparison. The mean Total Viable Time of Aesculap was 73.4±14.3 minutes. The mean Total Viable Time for SIGMA was 69.3±13.0 minutes. The mean Total Viable Time for LEGION was 71.4±17.8 minutes. Comparison of Total Viable Time according to the used devices is presented further below (Figure 8).

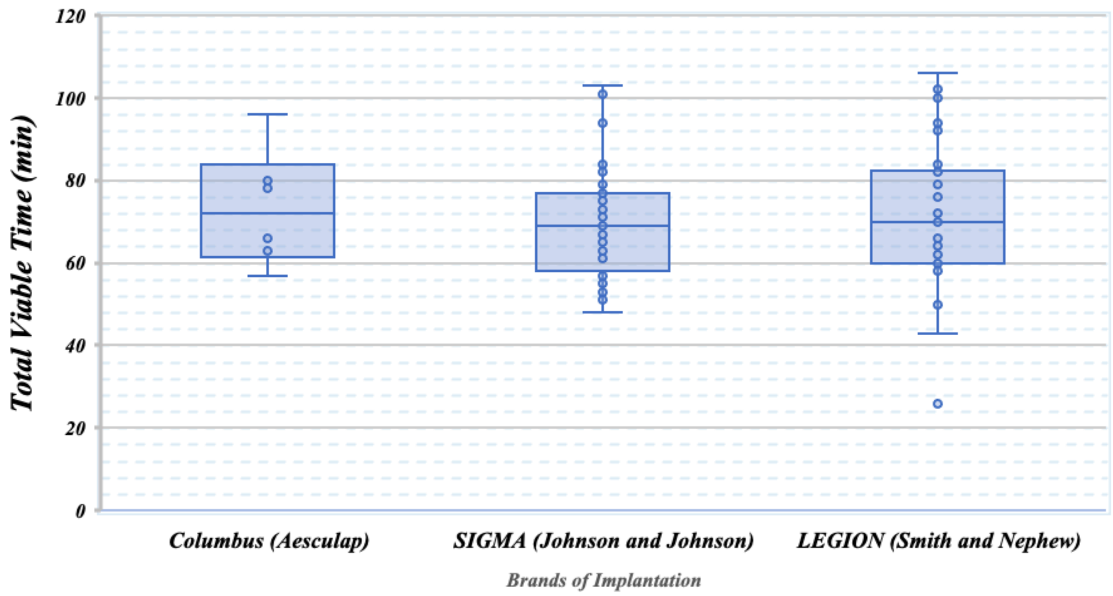

Figure 8. Comparison of Total Viable Time according to three different manufacturers in operating TKAs.

Implantation Time was also examined (Figure 9), where Columbus took 37.9±15.2 minutes, LEGION coming in second at 35.9±11.5 minutes, and SIGMA at 35.6±7.7 minutes. In terms of Total Viable Time, Aesculap devices generally lead to the longest duration, whereas SIGMA from Johnson and Johnson the shortest. However, in the Implantation Time subgroup SIGMA from Johnson and Johnson seemed to bring the most consistent Implantation Time with small variance. Aesculap on the other hand, had the longest Implantation Time, with a high variance in the 4th quartile.

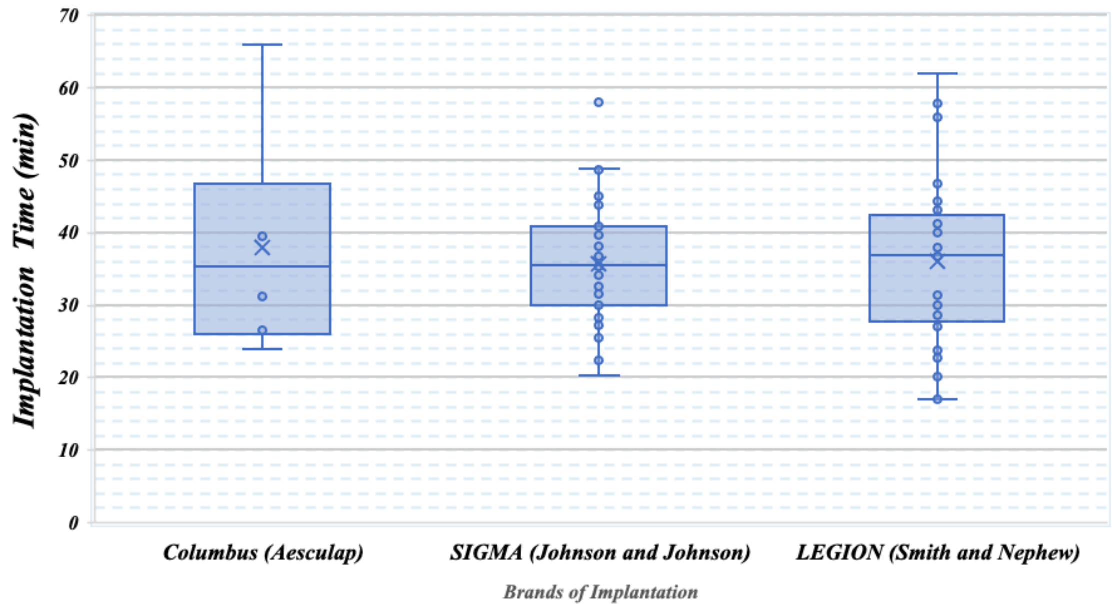

Figure 9. Implantation Time in relation with the three different manufacturers in operating TKAs.

Patient Risk Stratification

By better understanding the impact of individual risk factors, we identified two major factors that affect surgical durations: BMI and surgeon experience. We organized different cohorts from 1 to 4 according to surgeons with less than 5 years of experience, and more than 10 years of experience, grouped with patients with BMIs of below or over 25, and 30. (Table 12)

Cohort Number	1	2	3	4
ASA Rating	2	2	2	2
Surgeon Experience	<5	<5	>10	>10
BMI	<=25	>25	<=30	>30
Risk Level	Low	High	Mid-Low	Mid-High

Information on the distribution of each group is as follows:

Cohort	1	2	3	4
Sample Number	5	9	18	27
Median	79	114	83.5	107
IQR	[65.3 83.3]	[101.5 126.0]	[70.0 106.5]	[88.8 111.8]
Mean	**73.8**	**115.3**	**85.38**	**104.15**
Standard Deviation	**14.17**	**18.35**	**20.92**	**19.83**
95% CI	[61.4 86.2]	[103.3 127.3]	[73.8 93.2]	[96.7 111.6]
90% CI	[63.4 84.2]	[105.2 125.4]	[75.4 91.6]	[97.9 110.4]
75% CI	[66.5 81.1]	[108.3 122.3]	[77.8 89.2]	[99.8 108.5]
50% CI	[69.5 78.1]	[111.2 119.4]	[80.2 86.8]	[101.6 106.7]

Table 12. Patient stratification according to the most influential individual factors. The mean time and its respective SD can be seen in Cohort 1 to Cohort 4.

The mean Total Viable time for cohort 1 was 73.8±14.17 minutes, when in cohort 2 the mean increased to 115.3±18.35 minutes. Also, while comparing cohort 3 and 4, the mean time prolonged from 85.38 minutes to 104.15 minutes, indicating that while all surgeon groups were affected by the higher BMI of the patients, surgeons with less experience were affected even more, showing a significant role of BMI in prolonging IOD.

According to our risk stratification cohorts, we generated a data chart in which predicted times can be calculated according to the mean times and SDs of subprocedure times, as can be seen in table 13.

Procedure Name	Mean	Standard Deviation	CI 95% Low	CI 95% High	CI 90% Low	CI 90% High	CI 75% Low	CI 75% High	CI 50% Low	CI 50% High
Total Procedure Time	73,8	14,2	61,4	86,2	63,4	84,2	66,5	81,1	69,5	78,1
Marking skin site prior to procedure	1,3	0,6	0,7	2,0	0,8	1,9	0,9	1,7	1,1	1,6
Marking skin site prior to procedure(actual)	0,8	0,7	0,2	1,4	0,3	1,3	0,5	1,2	0,6	1,0
Patient Positioning	2,0	1,4	0,8	3,2	1,0	3,0	1,3	2,7	1,6	2,4
Patient Positioning(actual)	1,4	1,4	0,2	2,6	0,4	2,4	0,7	2,1	1,0	1,8
WHO Surgical Safety Check List	5,3	1,7	3,6	6,9	3,8	6,7	4,3	6,2	4,7	5,8
WHO Surgical Safety Check List(actual)	4,1	2,6	1,8	6,4	2,2	6,0	2,8	5,4	3,3	4,9
Cleaning and sterilisation of skin	2,6	0,9	1,8	3,4	1,9	3,3	2,1	3,1	2,3	2,9
Cleaning and sterilisation of skin(actual)	2,5	0,8	1,9	3,2	2,0	3,1	2,1	2,9	2,3	2,7
Application of surgical drapes	3,0	0,8	2,2	3,8	2,3	3,7	2,5	3,5	2,7	3,3
Application of surgical drapes(actual)	2,5	0,8	1,7	3,3	1,9	3,1	2,0	3,0	2,2	2,8
Skin, subcutaneous layer and muscle layers incision (Until target layer)	2,0	0,0	2,0	2,0	2,0	2,0	2,0	2,0	2,0	2,0
Skin, subcutaneous layer and muscle layers incision (Until target layer)(actual)	1,8	0,5	1,3	2,3	1,3	2,2	1,5	2,1	1,6	2,0
Exposing the bony surface of the distal femoral joint (Removal of soft tissue etc)	4,3	0,6	3,7	5,0	3,8	4,9	3,9	4,7	4,1	4,6
Exposing the bony surface of the distal femoral joint (Removal of soft tissue etc)(actual)	4,0	0,9	3,2	4,9	3,3	4,7	3,5	4,5	3,7	4,3
Intramedullary drilling of the femur for navigator placement, Insertion of navigator	1,5	0,7	0,5	2,5	0,7	2,3	0,9	2,1	1,2	1,8
Intramedullary drilling of the femur for navigator placement, Insertion of navigator(actual)	0,8	1,0	-0,3	2,0	-0,1	1,8	0,2	1,5	0,4	1,2
Placement of the resection block on the intramedullary navigator	1,0	0,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0
Placement of the resection block on the intramedullary navigator(actual)	0,5	0,6	-0,2	1,2	-0,1	1,1	0,1	0,9	0,2	0,7
Resection of the distal femoral surface	1,3	0,6	0,7	2,0	0,8	1,9	0,9	1,7	1,1	1,6
Resection of the distal femoral surface(actual)	1,3	0,6	0,6	2,0	0,7	1,8	0,9	1,7	1,0	1,5
Placement of the external rotational template on resected surface?	1,0	0,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0
Placement of the external rotational template on resected surface?(actual)	0,8	0,7	0,1	1,6	0,2	1,4	0,4	1,3	0,6	1,1
Placement of the 4 in 1 resector template	2,3	0,6	1,7	3,0	1,8	2,9	1,9	2,7	2,1	2,6
Placement of the 4 in 1 resector template(actual)	1,9	0,6	1,2	2,5	1,3	2,4	1,5	2,3	1,6	2,1
Resection of the distalis femoral surface according to the 4 in 1 template	1,3	0,6	0,7	2,0	0,8	1,9	0,9	1,7	1,1	1,6
Resection of the distalis femoral surface according to the 4 in 1 template(actual)	1,6	1,0	0,5	2,8	0,7	2,6	1,0	2,3	1,2	2,0
Placement of PS resector template, and resection accordingly										
Placement of PS resector template, and resection accordingly(actual)										
Preparation for placement of tibial component and its insertion	5,3	1,5	3,6	7,1	3,9	6,8	4,3	6,3	4,7	5,9
Preparation for placement of tibial component and its insertion(actual)	5,7	1,7	3,8	7,7	4,1	7,4	4,6	6,9	5,1	6,4
Tibial navigator placement	1,0	0,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0
Tibial navigator placement(actual)	0,5	0,5	-0,1	1,0	0,0	0,9	0,2	0,8	0,3	0,6
Tibial Block Placement bony surface	1,0	0,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0
Tibial Block Placement bony surface(actual)	0,6	0,4	0,2	1,0	0,3	1,0	0,4	0,9	0,5	0,8
Tibial bony surface resection	1,7	1,2	0,4	3,0	0,6	2,8	0,9	2,4	1,2	2,1
Tibial bony surface resection(actual)	1,7	1,0	0,6	2,7	0,8	2,6	1,0	2,3	1,3	2,0
Confirmation of the resection using tibial templates.	2,3	1,5	0,6	4,1	0,9	3,8	1,3	3,3	1,7	2,9
Confirmation of the resection using tibial templates.(actual)	2,3	1,6	0,5	4,2	0,8	3,9	1,2	3,4	1,7	3,0
Confirmation of joint components using trial templates	1,0	0,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0
Confirmation of joint components using trial templates(actual)	1,0	0,1	0,8	1,1	0,9	1,1	0,9	1,1	0,9	1,0
Insertion of trial spacer on the tibial component	1,0	0,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0
Insertion of trial spacer on the tibial component(actual)	1,0	0,7	0,2	1,8	0,4	1,7	0,6	1,5	0,8	1,3
Placement and fixation of the final tibial spacer	1,0	0,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0
Placement and fixation of the final tibial spacer(actual)	0,4	0,3	0,1	0,8	0,1	0,7	0,2	0,6	0,3	0,5
Fixation of femoral component	1,5	0,7	0,5	2,5	0,7	2,3	0,9	2,1	1,2	1,8
Fixation of femoral component(actual)	0,9	0,6	0,3	1,6	0,4	1,5	0,6	1,3	0,7	1,1
Testing of the implanted limb	1,0	0,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0
Testing of the implanted limb(actual)	0,7	0,3	0,4	1,0	0,4	1,0	0,5	0,9	0,6	0,8
Bleeding and foreign body control	4,7	2,3	2,1	7,3	2,5	6,9	3,1	6,2	3,8	5,6
Bleeding and foreign body control(actual)	11,5	13,3	-1,6	24,6	0,6	22,5	3,9	19,2	7,0	16,0
Muscle, subcutaneous layer and skin closure	20,0	2,8	16,1	23,9	16,7	23,3	17,7	22,3	18,7	21,3
Muscle, subcutaneous layer and skin closure(actual)	14,3	10,5	2,4	26,1	4,3	24,2	7,3	21,2	10,2	18,3
Steril bandages	2,0	1,0	0,9	3,1	1,1	2,9	1,3	2,7	1,6	2,4
Steril bandages(actual)	1,7	0,7	0,9	2,6	1,0	2,4	1,3	2,2	1,5	2,0
Preparation for placement of tibial component and its insertion	5,3	1,5	3,6	7,1	3,9	6,8	4,3	6,3	4,7	5,9
Preparation for placement of tibial component and its insertion(actual)	5,7	1,7	3,8	7,7	4,1	7,4	4,6	6,9	5,1	6,4

Table 13. An example of predictive mean values and its SD for cohort 1 with respective Confidence Intervals created according to the database gathered through the real-time surveys.

BMI as an index for patient factor stratification?

Patient Background and Measured Parameters

The gender distribution in the 95 cases was 27:68 for Men:Women, respectively. BMI, upper arm subcutaneous fat thickness, upper arm circumference etc was measured (Table 2) (mean ± standard deviation). Age ranged 47-102 years old (85 ± 8.3). Body weight (BW) ranged 26.8-64.0 kg (43.1 ± 8.17). Height ranged 134-175 cm (153 ± 8.85). Then BMI ranged 11.6-28.1 kg/m^2 (18.4 ± 3.18). Upper arm subcutaneous fat thickness was 0.6-18 mm (7.9 ± 4.0). Upper arm circumference was 12-27 cm (20 ± 3.0).

Measured parameters by DXA were as follows; FW was 3563-25823 g (11823 ± 5203.9) and LMW was 6951-17595 g (10772 ± 2388.2).

Upper arm subcutaneous fat thickness had significant correlations with BMI ($P < 0.001$) and FW ($P < 0.001$). Upper arm circumference also had significant correlations with BMI ($P < 0.001$) and FW ($P < 0.001$). On the contrary, upper arm subcutaneous fat thickness had no correlation with LMW ($P = 0.163$) Upper arm circumference showed correlation with LMW but with low r (0.458).

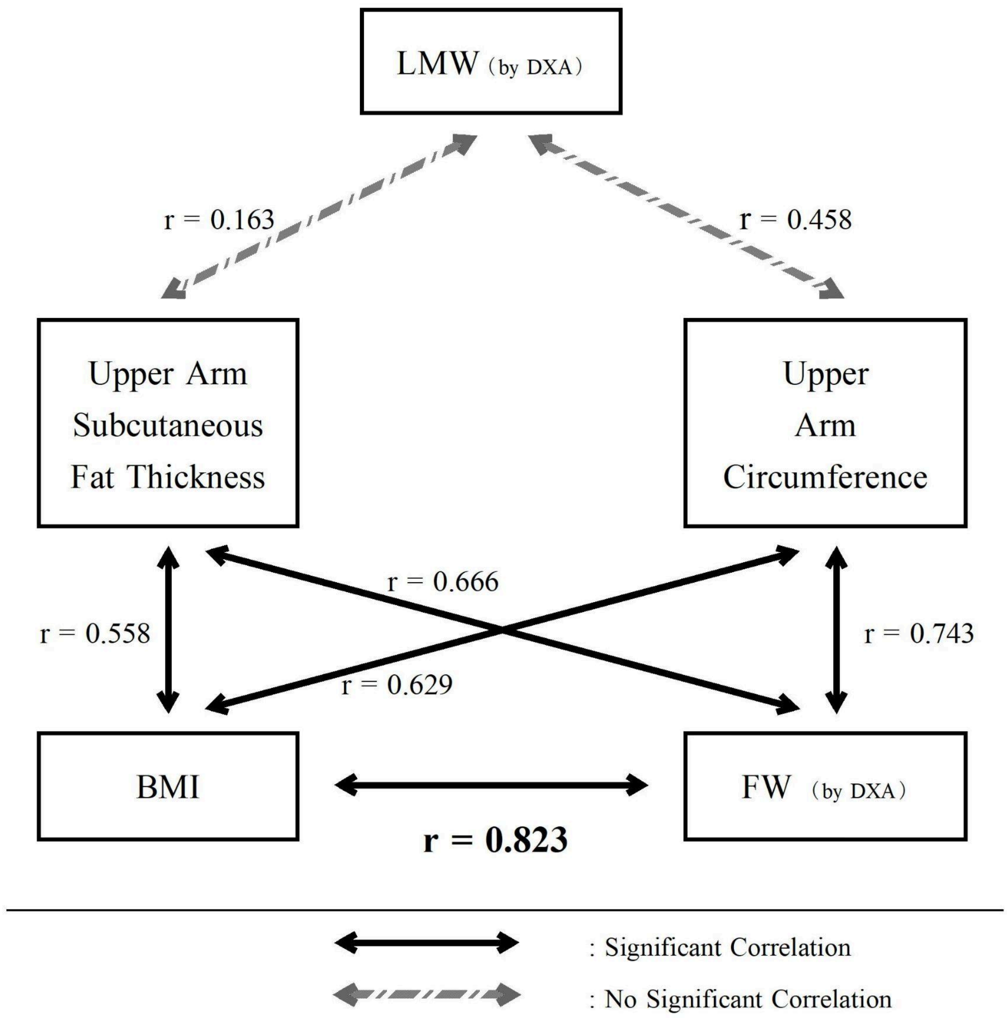

Figure 10. Statistical analysis for each Correlations, that Total Fat Weight (FW) obtained by DXA strongly correlated with BMI.

Since upper arm subcutaneous fat thickness and circumference did not significantly correlate with LMW but do with FW, we tested the correlation between BMI and FW. Then we found that BMI significantly correlates with FW ($r = 0.823$, $P < 0.001$) as can be seen in Fig. 11. The linear correlation suggests that BMI can mathematically substitute FW. Therefore, we additionally hypothesized that there may be a correlation between LMW and the difference of BW and BMI (BW - BMI) . As a result, LMW significantly correlated with BW – BMI ($r = 0.719$, $P < 0.001$). Consequently, we can regard BW - BMI as muscle mass which might help to presume harboring muscle mass (Fig. 12).

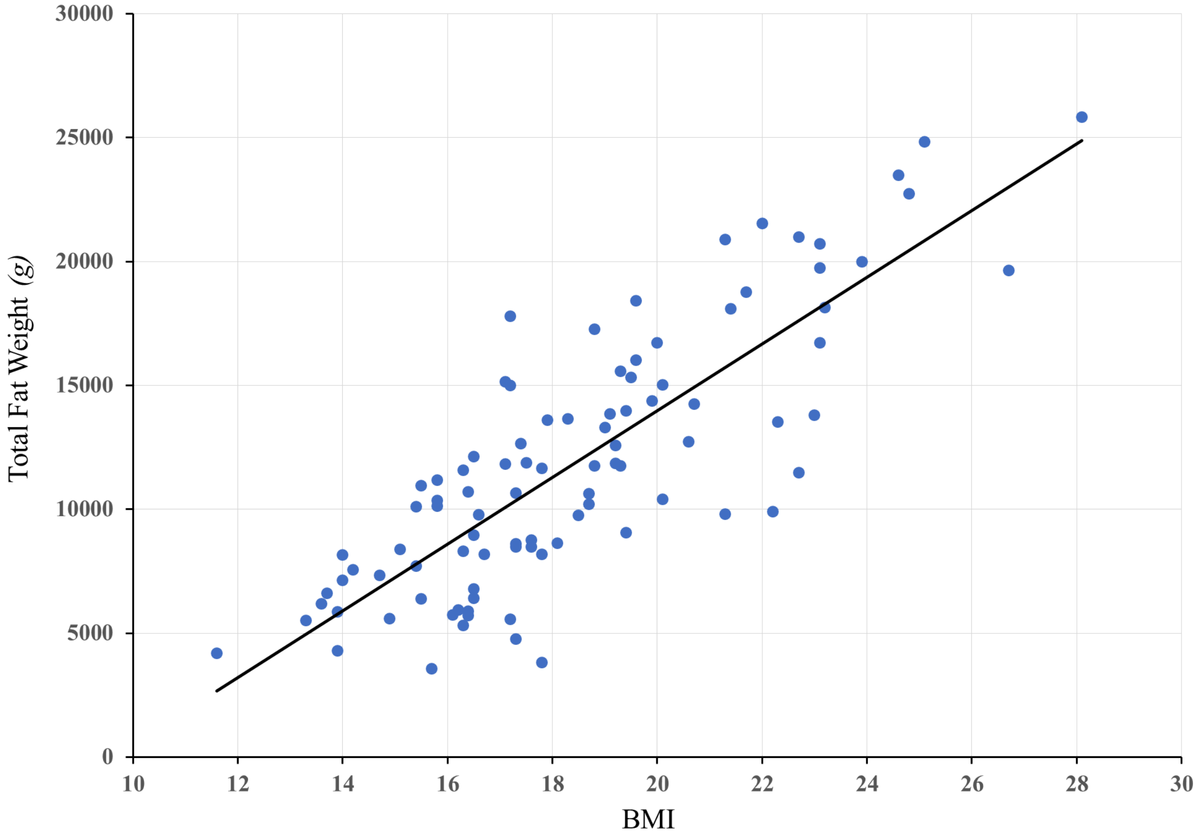

Figure 11. Plot diagram showing a significant correlation (r=0.823) between BMI and Total fat weight (g)

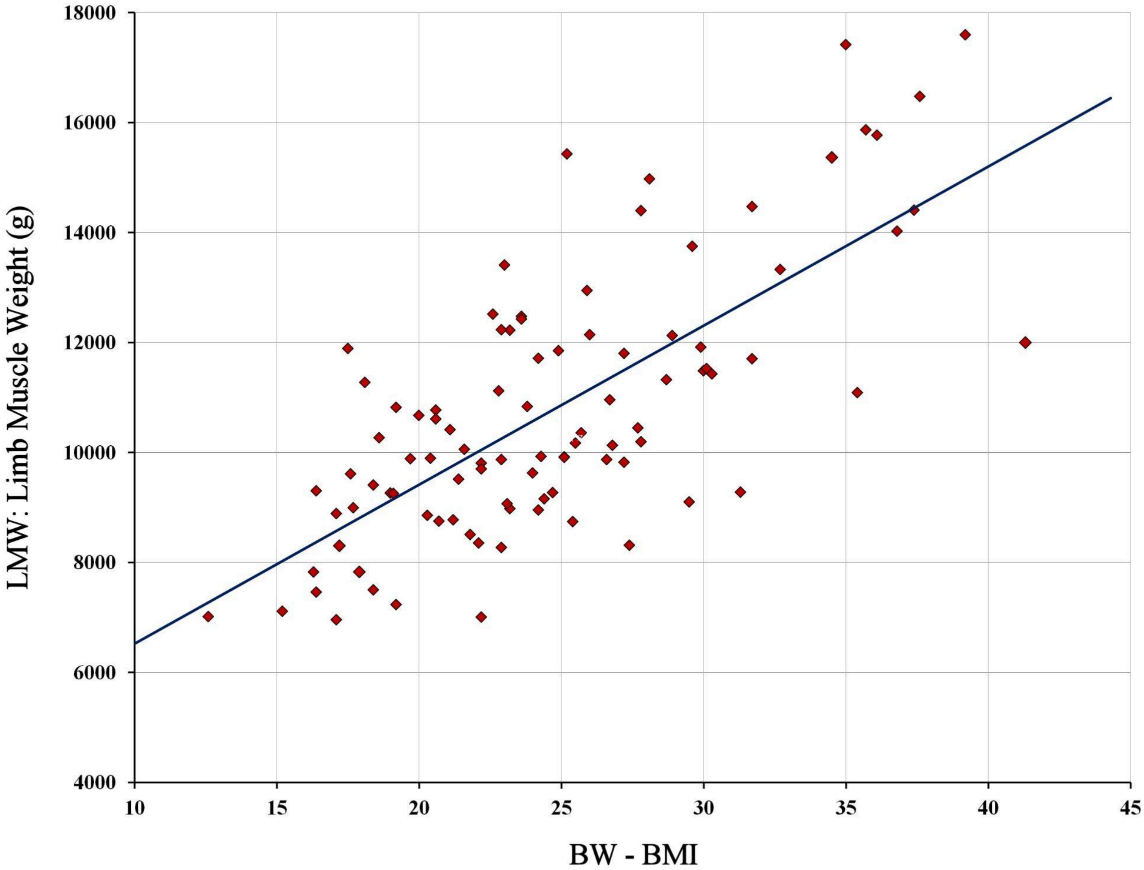

Figure 12. Scatter diagram and regression line on the Limb Muscle Weight (LMW) and the difference of BW and BMI. A strong linear correlation between LMW and BW-BWI can be seen (r = 0.719, P <0.001, y = 289.2 x + 3631) . This enable us to presume harbouring muscle mass calculated only by using BW and height.

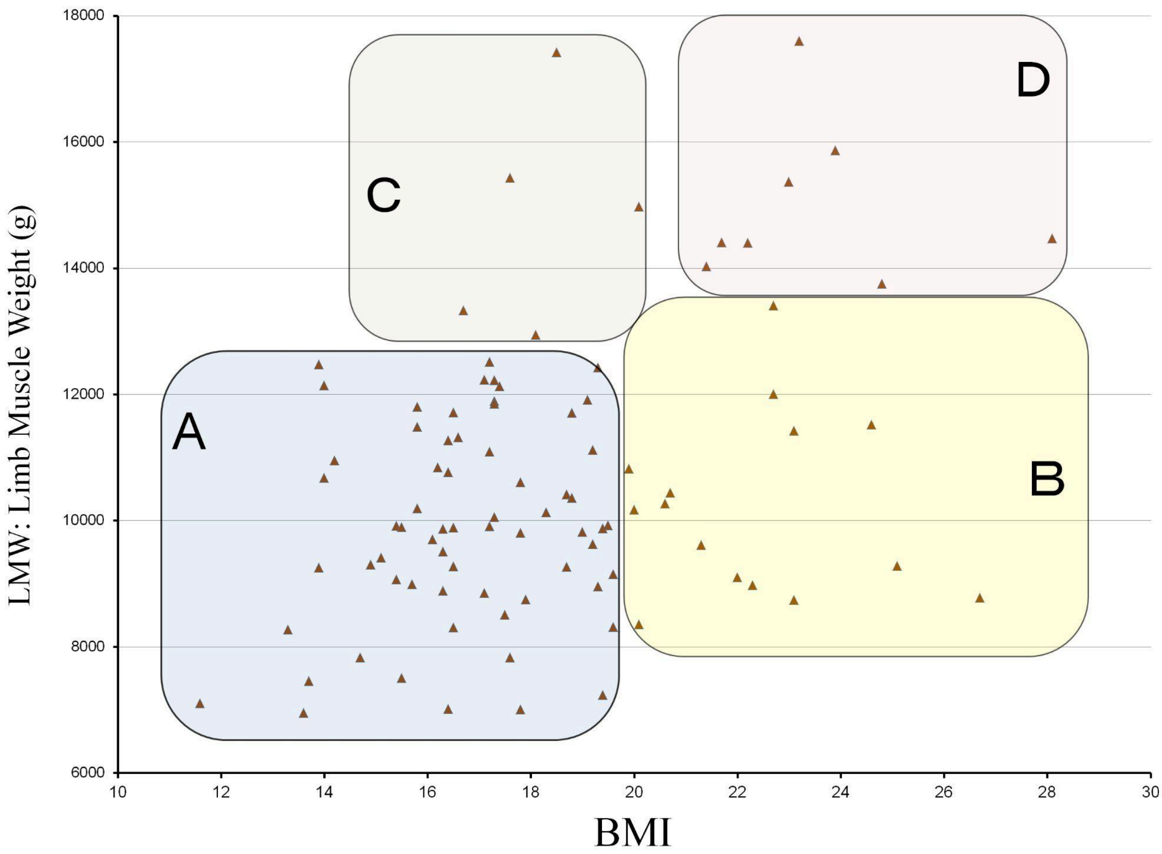

Figure 13. Distribution of Limb Muscle Weight (LMW) in 95 cases.

Special cases and considerations; Osteoporosis

Osteoporotic patients pose a particular difficulty when brought into the operating theater. Not only do the quality affect the biomechanics of the surgery, but the follow ups, post-operative rehabilitation programs may also differ when compared with a non-osteoporotic patient. Moreover, the risk of revision surgery may also burden the patient and the surgical team with additional costs and IOD.

Here we present a case of a 39 year old female patient with a 30 year history of immunosuppression (4mg of methylprednisolone) due to Juvenile Rheumatoid Arthritis (JRA) from the age of 8. She had been prescribed and had been continuously using Methylprednisolone, Methotrexate (22.5mg once a day), and Leflunomide. The patient gave birth in her mid 30s. She had been taking other osteoporotic medication from a young age as well, alongside her prosthetic surgeries; calcium, vitamin D (6000 International Units), Alendroate. For her advanced JRA, she later received tofacitinib therapy as well. She developed allergic reactions to numerous substances, such as phenobarbiturates, Iodine, metal, diclofenac, etc. No known rheumatoid arthritis was reported in her family. The patient was extremely cooperative and compliant, and all medical treatment and rehabilitation instructions were followed.

The patient was originally diagnosed with rheumatoid arthritis at age 7, and has been receiving high dose immunosuppressive medication (Methylprednisone, Methotrexate, Leflunomide. Biological therapy every 6 weeks) ever since. All immunosuppressive medication had been halted during the acute perioperative phase. By the time of admission at our clinic, the patient had already undergone right side Total Hip Arthroplasty (THP) in 2010, left side total knee arthroplasty (TKE) in 2011 and right side THP in 2013. Her acute postoperative course was uneventful.

In June 2019, the patient presented with pain and discomfort in her right thigh during physiotherapy. She was admitted to her local Traumatology department and was diagnosed with a right side femoral shaft fracture of which was surgically reduced by Open Reduction and Internal Fixation (ORIF) with plates.

In October 2019, the patient again presented with spontaneous pain in her right thigh. She was then diagnosed with a Vancouver C type periprosthetic fracture on the right femur, and was referred and admitted to our level one Trauma center in Szeged, Hungary. The patient received a Locking Compression Plate (LCP) type Proximal Femoral Hook Plate (PFHP) with attachments and a bone autograft to reinforce stability and neutralize stress on the fractured area.(Figure 14) Unfortunately the patient suffered from left side brachial artery thrombosis on the first postoperative day. A Fogarty thrombectomy was performed immediately with successful revascularization. The patient was discharged 15 days later with no further complications.

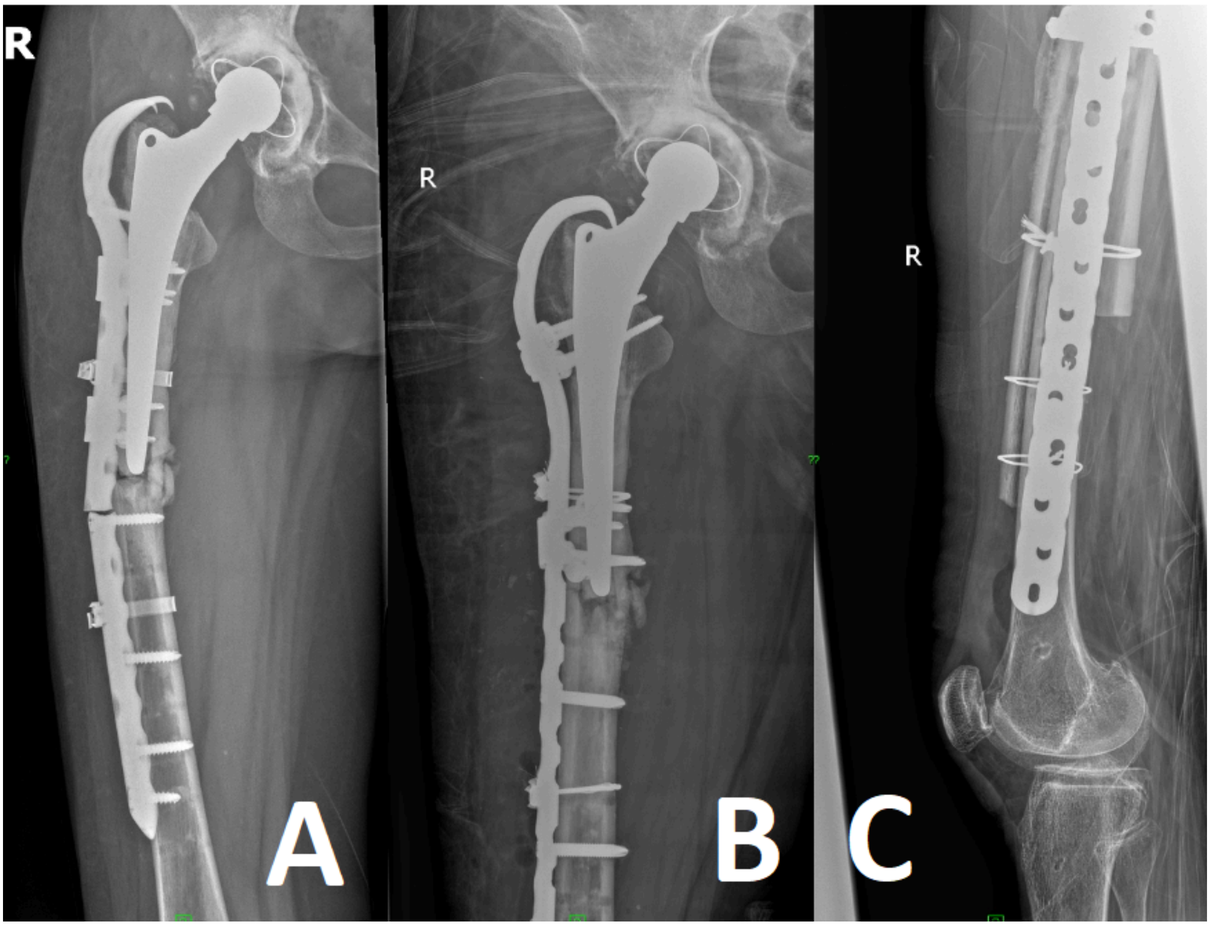

Figure 13. A: an AP preoperative x-ray showing the broken plate. B, C: Two directional postoperative X ray of a Locking Compression Plate (LCP) type Proximal Femoral Hook Plate (PFHP) with attachments and a bone autograft to reinforce stability and neutralize stress on the fractured area

The patient received Teriparatide therapy (Parathyroid hormone analogue) from her local hospital in November, 2019. The patient presented to our outpatient clinic for post-operative radiographic revision on the 6th week (41th postoperative days), and was instructed to commence partial weight bearing from 20kg, up to 7 kg per week. She later presented to the outpatient clinic on the 55th postoperative day due to local pain on the operated limb during weight bearing, and was thus instructed to practice lighter partial weight bearing (10 kg, with a 5 kg increase in weight bearing every week). No radiographic anomalies were found and progressive ossifications were noticeable. By 2020.02.04 (111th postoperative day), the patient was able to complete weight bearing on the operated limb.

On 2020.06.25. the patient presented again to our outpatient clinic with pain in her operated right hip, while playing with her children. Radiology revealed that the right LCP-PFHP component had been fractured. We surgically exchanged the LCP-PFHP and further added a cadaver allograft component to the fractured area in hope of increased ossification.Cable fixation was utilized the stabilization of the allograft, as well as the distal end of the LCP-PFHP, and completed a allograft strut osteosynthesis, The patient was observed post-operatively on our ward, with no unusual findings radiographically.

During 2020 September the patient presented with tachycardic episodes, hypertensive attacks, polyuria, and diarrhea. The patient was referred to an endocrinological institution in suspicion of pheochromocytoma. After no further improvement, approximately 3 months later evidence of pheochromocytoma had not been established. After careful deduction, parathyroid hormone therapy was halted. The patient's condition had improved, and had only presented with fewer random tachycardic episodes due to this day.

After the suture removal on the 10th postoperative day, the patient was discharged and has been presenting to our outpatient clinic for follow-ups. In our most recent revision (15 months post FHL implantation, 10 months after arthrodesis), the patient presented with full ambulatory function and with no complications neither on the femoral components.

Discussion

General considerations

Discussing procedure benchmarks in further detail, the results are plausible and verify the relationships between risk factors, procedure complexity and operation duration found in literature.[19] Arthroscopies are typically a short, high-volume procedure performed by a surgeon, but there was a large difference between the surgeon's own estimates and the actual operation duration. In a survey, it can be difficult for a single surgeon to estimate the time required for a partial or full surgical procedure.[20] Likewise, risk factor analysis demonstrated that operation duration variability was greatly reduced when estimations were taken from cohorts of patients with similar degrees of procedure complexity, as identified by the algorithm. Compared to the surgeons' own estimates of operation duration which overestimated significantly, more reliable prediction was possible for arthroscopy using the algorithm. In fact, there are similar studies for using machine learning approach to predict IOD, which resulted in the higher predictive capability compared to surgeons' own estimation. [21]

Acute Trauma-related Surgeries

On the other hand, open reductions and fixation procedures depended heavily on the presentation and classification of the fracture. Indeed, the operation duration depends more on the fracture being treated than patient risk factors, even where disparate, as evidenced by their being no clear correlations in the risk factors unlike for other procedures. Hence, as the surgeon has received an X-ray and other diagnostics of the fracture by the time of preoperative assessment, an accurate estimation of duration should be possible, but without controlling for fracture presentation in the study, meant that the risk factor cohorts found for arthroscopies were not observable for this procedure.

High Volume Surgery

Total Knee Arthroplasty is a common procedure, which has been successful and developed through many studies around the world for over 50 years.[22] The investigation and pursuing the productivity for TKA have been greatly focused because the demand and high quality of TKA related care and intervention has increased drastically due to the aging population.[23]

In this prospective real time analysis of high volume TKA surgeries, we discovered that the IOD was impacted by more than one individual factor, namely BMI, Degree of OA, and experience of the operating surgeon. These factors, though individual only moderately correlated to the prolonging of IOD; prolonging IOD in subprocedure steps such as prosthetic implantation and skin closure, therefore prolonging the duration of the entire surgery. The IOD of younger surgeons with less than 5 years of experience were drastically affected by the patients BMI, showing over 20 minutes of extra time in stratified groups, which could lead not just to the delay of the surgical program, but the increase in post operational infections.[24] While an increase in surgical time of only 15 min leads to 13% higher chances of surgical site infection, most orthopedic prosthetic implantation surgeries last for more than an hour.[25] It also known that prolonged operative duration leads to more complications and the reduction of IOD is of crucial importance especially in high volume surgeries and should be a "Universal Goal".[26]

In contrast to some opinions saying that surgeries are highly unpredictable, the use of machine learning models and predictive models have brought fruitful results in predicting total surgical duration.[27] Information on pre-operative assessment and its effects on detailed subprocedure duration is sparse, and through our study we have well understood that certain factors such as BMI and surgeon experience impact subprocedures like prosthetic implantation stage dramatically. We also claim that in high volume surgeries, predictability can be refined, and should be encouraged to be used in regular operating theater planning.

From our analysis, the average total time of surgery was 71 minutes, with a SD of 14 minutes. However by better understanding the factors that impact IOD, we concluded that BMI and surgeon experience immensely influences the duration of surgery. A surgeon with less than 10 years of surgical experience takes an average of 86-87 minutes to perform a TKA, where those with more than 10 years of experience complete the intervention in around 65 minutes, showing a difference of more than 20 minutes. The complete breakdown of subprocedures show that the younger surgeons tend to have major problems in the prosthetic implantation steps, and tend to be slower in wound closures. The differences between younger surgeons and experienced surgeons considering the skin incision until joint exposure step was minimal. This seems to be a partially contradictory finding, where other studies have claimed that surgical exposure times differed significantly in non-high volume patients, especially in patients with high BMI.[28] While examining the correlation between the individual steps and BMI, we found moderate correlation. When we included the surgeon's experience to the analysis, we suspected that the IOD of younger surgeons who operated on higher BMI patients were significantly prolonged, by over 42 minutes on average. This pattern was similarly observed in experienced surgeons, where the mean duration was prolonged by 19 minutes. Since patients usually present with KL grade 3 or 4 arthritis for a TKA procedure, minimal correlation was observed while considering the degree of OA and IOT. Other studies also indicated BMI and ASA may contribute to surgical duration prolongation, its conclusions widely vary. [29] The use of BMI seems to be questionable, and though it seems to add some insight its use alone should not be encouraged, but should always be part stratified cohort, for it to be a reliable predictor.

Radiological evaluation of OA, while an essential step in preoperative planning, seems to have minimal to moderate correlation with IOD, even with symptomatic relief and functional improvement.[30] The JLCA, which provides information of the degree of varus deformities, had no significant correlation during the prosthetic implantation step, which was a contradictory finding to some studies.[31] While the Lateral JWS seemed to impact the implantation time, its correlation seemed minimal ($p=0.313$) The correlation between mJWS and the intraoperative durations were practically non-existing, which could be due to the fact in progressive osteoarthritis, the mJSW is non-existent because of the bony surfaces contacting on each other.

The reliability of BMI as an index?

BMI was originally considered to define the "l'homme moyen=average person or ordinary man" by Lambert Adolphe Jacques Quételet.[32] The human body consists of many different constituents such as hard and heavy minerals, water-rich muscle, and relatively light but large amounts of fat, making it rather heterogeneous. Ancel Keys et al. had provided an idea that the amount of harboring body fat could be correlated with the patient's BMI.[33] In contrast to its wide use, BMI has been criticized for not containing relevant information about the patient, such as fat mass and others BMI also does not take into consideration a wide variety of factors such as ethnicity, sex, and age, giving only a poor idea of the individual’s body composition, and with it, the underlying comorbidities.[34, 35]

The motor unit of a body is composed of muscle, fat, connective tissue and bone. We hypothesize that BMI does not reflect the ratio of constituents, and may lead to a misunderstanding of the patients biological capabilities.

While the gold standard of diagnosing muscle mass seems to be unchallenged, emerging modalities have been identified to be useful in the identification of muscle mass, but with certain difficulties.[36] Although ethnical and disease-specific modifications apply, the accuracy of DXA have been backed by numerous literature.[37]

The radiological measurement to obtain accurate values requires special equipment and qualifications, rather than cheaper and lighter devices such as impedance adipometry [14] and ultrasonic measurement of muscle thickness.[38, 39]

The lack of availability to measure muscle mass has resulted in the increase of non-radiological methods. Fayh et al, and Evans et al have proposed methods using biochemical markers.[40,41] Other markers such as blood albumin levels and molecular markers have been speculated to reflect the existence of diminished muscle mass. Although these biomarkers have the potential in aiding diagnosis of decreased muscle mass, difficulties remain; the costs coverage, difficulty of access, and patient cooperation.

Understanding the correlation between BMI and FW

While literature examining the relationship between BMI and FW is relatively rich, these studies mainly focus on either younger patient populations or have been focused on osteoporosis. Still, the estimation of body composition without the use of radiological and biochemical methods seems to be challenging.

Our study showed significant correlations between FW and upper arm subcutaneous fat thickness and/or circumference. More importantly, BMI had a significant correlation with FW. These findings seem to be well received in international literature, especially when measured by impedance adipometry or DXA.[42] MW // BW - BMI would then theoretically represent muscle mass.

Upon understanding this dynamic relationship between the values of MW, BW, and BMI, we re-examined the correlations between these parameters, and found that LMW is significantly correlated with BW - BMI. From this correlation we devised an equation; 289.2 x (BW - BMI) + 3631, which could be applied as a relative index to identify underlying muscle mass. In Fig. 3 we see a large portion of patients' LMW indicating low muscle mass. Even when BMI offered no information on sarcopenia in these patients, the results of the SMW showed that most patients were sarcopenic. On the other hand, patients with low BMI did not necessarily show low LMW, as can be seen in Fig. 4. High BMI did not necessarily mean that the patients did not have diminished muscle mass; some patients with relatively high BMI even presented with low LMW.

Role of Osteoporosis in consideration of reoperation / Revision

Revision surgery is costly as well as time consuming. Here we demonstrate a 39 year old female patient with a 30 year history of immunosuppression (4mg of methylprednisolone) due to Juvenile Rheumatoid Arthritis (JRA) from the age of 8. She had been prescribed and had been continuously using Methylprednisolone, Methotrexate (22.5mg once a day), and Leflunomide. The patient gave birth in her mid 30s. She had been taking other osteoporotic medication from a young age as well, alongside her prosthetic surgeries; calcium, vitamin D (6000 International Units), Alendroate.

While immunosuppressive therapy provides benefits in the treatment of autoimmune diseases, the well-known side effects can lead to serious consequences, especially osteoporosis.[43] Not only do the young patients have to struggle with complications from taking immunosuppressants in itself, pregnancy while under immunosuppression also exacerbates the patient's condition; the alteration of the patients osteobiology, osteoporosis.[44]

In our case report, the patient had had a history of 30 years of immunosuppression at the age of 38, and received multiple surgeries over the course of more than ten years. Because of her advanced RA, she received three large total joint arthroplasties in her 20s. Also the fact that she gave birth accelerated her change in osteobiology, leaving her with brittle bone structure similar to an elderly patient. This led to a cascade of periprosthetic fractures, leading to multiple challenging surgical interventions. The challenges here that must be dealt with are numerous strategies.

Because of the advanced osteoporosis, she was put on an early treatment regime. *Sunyecz* reviewed that in compliant patients the use of calcium and vitamin D therapy decreases the risk of osteoporotic fractures.[45] The patient also took alendronate, which the American College of Rheumatology recommends against glucocorticoid induced osteoporosis. Because of the patients' multiple re-surgeries, Teriparatide was also introduced in November 2019. Although the effectiveness of teriparatide is moderate with a 7% increase in premenopausal women with glucocorticoid use when compared to alendronate, its adverse effect cannot be ignored. [46] While literature reviews that teriparatide increases the risk of osteosarcoma in rodents, it has not been shown to increase the risk in humans.[47] In humans, hypercalcemia after subcutaneous administration and urinary calcium excretion seems to be the most common complications, in our case the patient presented with palpitations and tachycardia, which could have been caused by ionic disturbances caused by multiple drug interactions. After discontinuation, the side effects resided, and to our surprise the patient later did not suffer from further periprosthetic fracture complications. According to *Lane et al*, even in glucocorticoid-induced osteoporosis, the effects of teriparatide continue up to 6 to 12 months, which may have been the cause of successful postoperative course in our patient as well.[48]

In the initial periprosthetic fracture treatment in October 201, the application of the FHP resulted in a periprosthetic fracture and the destruction of the titanium plate. In our initial treatment, an autograft collected from the patient's own pelvis was applied, which unfortunately resulted in the previously mentioned complication. Perhaps in an advanced osteoporotic patient with glucocorticoid use, the autograft was also osteoporotic in nature, which did not accelerate the ossification process, as expected.[49] Literatures mostly focus only on the decrease in bone mass in the hip and spine, and not on the pelvis, it difficult to project the effectiveness of autograft application in patients with glucocorticoid, let alone premenopausal women. Allograft implantations can be indicated in case of Type B3 Vancouver periprosthetic fractures, especially in young and active patients. [50] While *Hui et al* suggests that in Vancouver type B1 or C fractures, the union rates are similar with or without strut allografting, our case report indicates otherwise.[51] As unfortunate as it is, this specific case provides a rare perspective on the effectiveness of multiple osteoporotic medications and surgical techniques.

During the follow ups, we restricted the weight bearing of the patient’s operated limb (15kg during the first week, plus 5 kg per week), and introduced partial weight bearing as part of the patients rehabilitation program.As a general rule, most literature provides positive insight on immediate weight bearing during postoperative rehabilitation, they mostly analyzed cases in elderly patients without long term glucocorticoid use. [52, 53] One other important factor that should be taken into consideration is also the weight of the patient. According to *Keenan et al,* immediate weight bearing had no noticeable effect on reoperation risks in patients with lateral locked plate fixation of periprosthetic distal femoral fractures, although these apply to those older patients and not patients with histories of long term glucocorticoid use. [54] No differences in functional outcomes were noted in a randomized control study by Paulsson et al. [55] In cases of those with obesity, postoperative complications of THP are noticeably increased, which should be a consideration factor when introducing weight bearing exercises in rehabilitation. [56] While we proceeded with caution, the first FHP did in fact break not right after the surgery, but gradually. We might be able to suspect that the outcome would have been similar even if we started immediate weight bearing. However, considering the fact that our patient had a rare history of long term glucocorticoid use, alendronate and teriparatide application, the osteobiological changes cannot be simply applied in the general rule of periprosthetic fracture treatment in the elderly. In our latest attempt, we reconsidered the biological changes of the patient by utilizing an allograft to stabilize the periprosthetic fracture both mechanically and osteogenetically, which lead to successful results.

Attention needs to be brought that not only is it painful and difficult for the patient and the surgical team, multiple revisions can be very time costly and financially burdening for the surgical suite as well. This highlights the importance of incorporating patient factors into surgical planning.

Managing the Operating Theater applying stratifying patient factors

Managing an operating theater may be a controversial task. While surgeons think that surgery must not be done with haste, data on its prolonged duration has proved otherwise. With increased risk of infection, financial burdens, and environmental problems surrounding the discussion of surgical suite management, our series of research aims to identify the most prominent factors that may affect the IOD, and therefore those consequences. BMI has been a major factor affecting surgical duration, but its overuse seems to be questionable. BMI, is a body index that contains no information on the individual; fat, muscle, and bone quality cannot be identified or quantified. This would mean that an obese person and a muscular person would be registered as a “similar body type”. In our research BMI was also a predominant factor affecting IOD alongside surgeon experience. The interpretation of these results with BMI should be done with care, as it does not reflect the fat content nor the lean muscle mass of the subjecti patient. BMI as an index should be used with caution, since it may be the undesirably high fat content and low lean muscle mass that may lead to perioperative/intraoperative complications. Even in studies by Woon et al. utilize BMI as a measure of obesity and have concluded that obese patients have shorter hospital stays and higher home discharge rates.[57] Without the knowledge of body constituents, it is as if the presence of free fat can have a positive outcome to the postoperative condition of the patient, which can be misleading. A study by Stevens-Lapsley et al also found that BMI had no correlation with the postoperative functional outcome, which may also be translated to the following; BMI as an index does not contain functional information of the patient.[58] Hwang et al have found in a retrospective study that low lean muscle mass, namely sarcopenia is a crucial factor for postoperative complications such as anemia, delirium and acute kidney injury. [59] Evidence surrounding the opaque use of BMI as a unit for individual body composition may not necessarily support the application of it even in peri-operative planning.

The incorporation of stratified patient factors may also lead to prevention of revision surgery. While others focus on the selection of implants and techniques in trauma related surgeries, we advise to also pay attention to patient factors, and its possible incorporation in the pre-operative preparation process.[60] Revision surgeries, with its complex nature in itself, may be costly and time consuming to handle, and a myriad of methods should be invested to avoid it. [61,62] Other large scale strategies such as the national registries seem to also have a positive effect on reducing the proportion of revision procedures.[63]

Implications in surgical planning

By better understanding the effects of patient characteristics and comorbidities, we can utilize the values given by our data acquisition to "simulate" the surgery with predictive values. By pre-operatively acquiring the patient biometrics, comorbidities etc, we can predict the subprocedure time with high precision according to our database. This allows the surgery team to plan the operating schedule not only relying on the surgeons' estimated values, but also according to the pre-operative assessment, thus maximizing the use of limited work hours in the clinics. A simulation-based study parallel to the actual planning may provide better insight in the future.

Implication in device registration and others

Using an independent and flexible cloud registry system, we have also registered surgical devices, and its respective carbon emissions. By understanding the differences in subprocedure duration between different devices in detailed subprocedures, we can assign surgical devices to the fitting of the patient and the surgeon. No longer will this be only a question of personal preference, but a decision based on objective quantitative data. For example, younger surgeons will obviously benefit from operating on patients with relatively lower BMI (<30) while experienced surgeons could be encouraged to operate on patients with high BMI to maximize the use of the operating theaters.

With device registry as an additional function, we can evaluate the devices' performances which "fit" patient characteristics and other factors. More importantly, we can now "follow" the devices through the network, creating a virtual database containing all relevant information that we are able to cross analyze the data across hospitals, and ethnicities.

Limitations and Future Prospects

The use of an independent cloud service made the preoperative assessment, intraoperative measurement and postoperative analysis fast and effective. The postoperative analysis undertaken by the two independent surgeons gave similar results. Since this study requires the assistance of external observers, although the surgical steps are almost always similar and observers have been taught via a uniform program, it is still prone to personal bias. While breaking down the TKAs into detailed subprocedure steps, we stratified the most essential subprocedures into groups (Skin incision, Prosthetic Implantation, and Wound closure) to minimize the measurement deviations during evaluations.

While pre-operative biometrics and degree of OA were precisely recorded, comorbidities were very difficult to parametrize, since patients took different medications having different problems caused by different stages of their respective comorbidities. While only 2 patients answered that they do not smoke, this was epidemiologically not likely, considering the prevalence of smokers in Hungary.[57] The effects of smoking was also difficult to mathematicize, and we intend to apply the Brinkman Index in future research, to assess the quantifiable impact of smoking.

Because surgery room planning is crucial in relieving the physical, psychological, and financial burden of TKA waiting lists, we intend to research our predictive values to "virtually simulate" the surgery in the preoperative stage, and compare it to the actual relapsing operative time. We expect these high volume surgeries to be highly predictable to the minute , and the evaluation of the precision of prediction should be the question next in line.

Conventional TKAs are the most common way to perform TKAs, but new techniques that aid in the shortening of surgical time and improving the surgical quality have been arising. Intraoperative navigators, robot assisted TKAs, and 3D pre-operative templates are available in our closest market, and the real-time evaluation of these surgeries seem to be an interesting theme to pursue, since it theoretically decreases IOD, currently with sparse information to support their claims.

Post-operative monitoring should also be highlighted. A shorter IOD is indeed financially beneficial for the hospital, as well as the patient when considering postoperative infections. However the quality of work should also be evaluated; axis deviations seen on radiographs, soft tissue damage, blood loss leading to transfusions, and long term follow ups should be studied for a better comprehension of high volume TKAs.

Although this study suggested that MW could be roughly calculated, it still does not take different factors into consideration. While SMW appears to be accountable for a homogenous population, we have yet to understand modifying factors and its value in different ethnicities. Our subject population was mostly elderly patients, but it would be interesting to observe if the same principles apply in younger, healthier patients as well. Males and female differences should also be considered, modifying factors must be addressed and identified.

In the course of time we aim to increase the sample numbers for more detailed revision. Clinical pictures are of the utmost importance, and assessment for risk of falls, debilitation, and ambulatory function should also be considered if SMW were to be applicable in a realistic clinical situation, where indication of therapy would be required.

Conclusion

Patient factors such as high BMI and osteoporosis can drastically alter the design of surgical suite management. Patient biometrics and years of surgeon experience are significant factors when predicting IOD. Surgical durations are moderately affected by the BMI of patients, but those with less experience are markedly affected by the BMI of the patients, prolonging their IOD mostly at the level of prosthetic implantation phase. Patient stratification according to BMI and years of surgeon experience were the greatest predictors of intraoperative duration. Non-parametric factors like history of smoking, presence of HT or DM, use of anticoagulants showed minimal or no correlation with IOD prolongation. Degrees of OA do not seem to significantly alter the IOD in TKAs. A detailed breakdown and evaluation of components such as patient characteristics, device management, and surgical teams aid in the better understanding of surgical subprocedure times spent in the operating theater, thus leading to significantly more accurate forecasting.

Although BMI was one of the leading patient factors affecting IOD, it is also crucial to point out that BMI in itself does not include any information considering patient body constituents, and may possibly lead to a misinterpretation of the data acquired. BMI can also serve as an indicator of patient status to calculate muscle mass at a screening level with the use of DXA as well. Taking the above mentioned patient factors into consideration may lead to a more precise patient centered schedule planning, as well as a way to avoid reoperation. A multidisciplinary perioperative planning is necessary to ensure a successful postoperative course in order to minimize revision surgery.

DISCLOSURES

The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper. There has been no significant financial support for this work that could have influenced its outcome.

ETHICAL STATEMENT.

Participants have been fully informed and a written form of consent was acquired in accordance with the declaration of Helsinki. This study has been accepted by the Human biological ethical committee of the University of Szeged by the number 1/2022-SZTE RKEB.

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