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RESEARCH ARTICLE

# Epexegesis to the Norwegian Orthopaedic Register

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**Abstract:** National orthopaedic registries compile databases regarding the procedures and outcomes. Registers while used in policy development, projecting future trends and resource allocation also provide a means to monitor patient care, implant performance, support evidence-based practices and a scale in which to assess quality improvement in orthopaedic surgery. These databases can also facilitate shared decision-making between patients and surgeons. Since international databases exist on joint prostheses that can be used to generate a comparative analysis between different countries. By standardizing data collection among countries, one can compare various geographical and demographic factors that may play a role in data variation. In this paper, data from the "Norwegian National Network for Arthroplasty and Hip Fracture" registry was collected, and statistical analysis performed to identify differences and trends in the Norwegian data. The focus of this paper is on knee arthroplasties and, more specifically, the reasons for primary arthroplasty, revision surgery, and reoperation surgery. We compared the Norwegian data with Sweden, Switzerland, England, and Australian registries, however, due to reporting inconsistencies, no comparison was generated. Thus, this paper adds an epexegesis to the Norwegian National Registry on reasons for revisions data and constitutes a part of course work in Experimental Orthopaedic Engineering (BME 7220).

**Keywords:** orthopaedic registries, knee arthroplasty, comparative analysis, revision surgery, data standardization

## 1 Introduction

Norway, It is home to approximately 5.5 million people, with a projected population growth of 6.9 million by the year 2100 [1, 2]. A majority of the population is between 30 and 55 years old, with approximately 102 males per 100 females and a density of 18.2 people per square kilometer [2]. Many people live in the southern region of the country around the capital, Oslo, and in cities such as Bergen and Trondheim [1]. Ethnically, roughly 83.2% of the population is Nordic, exhibiting the physical and cultural attributes of Norwegians [1]. People originating from other European countries compose about 8.3% of the population, and the remaining 8.5% originate from other countries around the world [1]. Due to Norway's terrain, however, many of the cities and, consequently, much of the population are located on the coastline [1].

Much of mainland Norway is heavily mountainous with extreme climates and rough terrain, with the highest mountains measuring over 8,000 ft [1]. These mountains block coastal weather, resulting in cold winters, warmer summers, and little precipitation [1, 3]. On the contrary, the coastlines, where a majority of the population lives, are jagged fjords that were formed by glaciers thousands of years ago, as well as over 50,000 islands [1].

Healthcare in Norway is government-regulated, providing Norwegian citizens with access to free hospital care and medicine [1]. Most hospitals, where a majority of the country's doctors work, are owned by local and national government organizations [1]. Due to these government efforts, the people of Norway have one of the highest standards of living in the world [1].

### 1.1 Norwegian National Arthroplasty Registry

In the early 1980s, it was discovered that inferior hip implants were being used in Norwegian hospitals [4]. This subsequently prompted the creation of a national registry for hip arthroplasties in 1987, which grew to encompass all arthroplasties in 1994 [4]. In 2009, it was added to a national medical quality register, which now includes the arthroplasty register, hip fracture register, knee ligament register, and paediatric hip registry [4]. The Ministry of Health and Care Services changed the arthroplasty register to a National Advisory Unit in 2002 and changed the name to The Norwegian National Network for Arthroplasty and Hip Fractures in 2023 [4]. The goal of the registries was to identify shortcomings of joint prostheses and observe related trends over time [4]. These registries are operated by The National Network and funded by Helse Vest RHF and Helse Bergen HF [4]. The most recent completeness reporting was for the years 2019 through 2020. For primary knee prostheses, the reporting rate is 96.6%, and the reporting rate for knee revisions was 92.9% [5].

# 2 Methodology

Data from the Norwegian Arthroplasty Registry was collected for the ten most recently reported years [5–8]. These reports were published in 2024, 2023, 2022, and 2021 but contain data from the year prior [5–8]. Data was classified into the following categories: demographics, operation overview, and reasons for operation. Demographic data has been obtained for the past four years from graphs provided in the past four years' reports. As such, discrepancies in the recorded values may be derived from human error. Data for the operation overview and reasons for operation were provided for the past ten years in various tables in the most recent annual report. All data was compiled and analyzed in Microsoft Excel.

Data regarding reasons for revision of total knee prostheses with the patellar component, total knee prostheses without the patellar component, and unicondylar prostheses were analyzed using statistical methods to determine significant differences between reasons for each group, respectively. A square root variance stabilization was performed for each, followed by a one-way analysis of variance (ANOVA) and a Tukey-Kramer pair-wise comparison. The Tukey-Kramer test is a modified version of the post-hoc Tukey test that allows for uneven data sets [9, 10]. Rather than using the normal mean, it uses the harmonic mean to determine pair-wise differences under a studentized distribution [9,10]. This test is considered a stepwise procedure as it assumes one type I error, and each comparison is performed under one critical value, making each pair-wise comparison independent of one another [10]. Similar tests include Fisher's least significant difference test and the Bonferroni test [10].

Based on the results of this test, the three reasons for revision with the highest ten-year mean, or average, were further analyzed via regression models to determine if there is a predictable trend in the data. Regression models are used in statistics to determine a mathematical function that relates one or more independent variables to a single dependent variable [11, 12]. In this case, the independent variable is the year, and the dependent variable is the number of specific revisions performed. The efficiency of the regression model can be assessed with the coefficient of determination ($R^2$) [11, 12]. This coefficient explains the proportion of variation in the dependent variable that is considered by the model [11, 12]. Thus, an $R^2$ value closer to one means that there is less error in the variance and can be considered a better prediction model than that of a regression model with an $R^2$ closer to zero [11, 12]. In this article, the type of regression model was chosen based on which gave the highest $R^2$ value. In most cases, this model was polynomial, but in one case it was a linear model. The concern of overfitting the model was considered; hence, only a second-order polynomial model was fit, even though in some cases, a higher-order model produced a higher $R^2$ value. According to literature, an acceptable $R^2$ value is dependent on the field of study [13]. In engineering, it is stated that a $\geq 0.7$ $R^2$ value is acceptable, but the article concludes that in clinical medicine, a $\geq 0.15$ $R^2$ is acceptable [13].

Numerous other countries publish annual arthroplasty registry reports. An effort to find an annual report from another country that could be used in comparison to Norway was made; however, of the ones examined, none published their reasons for revision data in a manner that could be used in a one-to-one fashion. Countries such as Sweden, Switzerland, and England were reviewed as each, in some form, included reasons for revision in their annual report [14–16]. The country that had the closest method of publishing their reasons for revision data to that of Norway's, however, was Australia [17–26].

# 3 Results

## 3.1 Registry Report Data

The first section for which data was collected was demographics. Any information regarding the population was compiled in this section. It was noted, however, that there seemed to be missing information for 2021, as seen in Table 1. It was also noted that some information seemed to be copied directly from one annual report to the other, as seen in the proportion of men and women who received primary total and unicondylar arthroplasties in 2020 and 2021.

These noted peculiarities could have been a result of the COVID-19 pandemic that peaked in those years. Table 1 shows the number of arthroplasties per 100,000 in both men and women for the indicated years and the total incidence for men and women [5–8]. Table 2 and 3 show the proportion of primary total and unicondylar prostheses, respectively, for the age at which it was implanted [5–8]. Table 4 and 5 show the proportion of different age ranges that received total or unicondylar prostheses, respectively, for men and women each year [5–8].

**Table 1** Number of Operations per 100,000 (Incidence) [5–8]

| Number of Operations per 100,000 (Incidence) | | | | | | |
|---|---|---|---|---|---|---|
| | <39 yrs | 40-49 yrs | 50-59 yrs | 60-69 yrs | 70-79 yrs | >80 yrs |
| 2023 M | 0 | 20 | 160 | 410 | 600 | 350 |
| 2023 W | 0 | 30 | 210 | 430 | 730 | 350 |
| 2022 M | 0 | 30 | 150 | 430 | 590 | 310 |
| 2022 W | 0 | 30 | 190 | 440 | 720 | 320 |
| 2021 M | n/a | n/a | n/a | n/a | n/a | n/a |
| 2021 W | n/a | n/a | n/a | n/a | n/a | n/a |
| 2020 M | 0 | 30 | 140 | 350 | 500 | 290 |
| 2020 W | 0 | 30 | 180 | 360 | 600 | 300 |
| | 2023 | 2022 | 2021 | 2020 | | |
| Annual Total | 150 | 145 | 140 | 125 | | |

**Table 2** Proportion % of Primary Total Knee Prosthesis [5–8]

| Proportion % of Primary Total Knee Prosthesis | | | | | |
|---|---|---|---|---|---|
| | <45 yrs | 45-59 yrs | 60-69 yrs | 70-79 yrs | >79 yrs |
| 2023 | 0 | 18 | 33 | 37 | 12 |
| 2022 | 1 | 15 | 33 | 40 | 11 |
| 2021 | 1 | 17 | 34 | 37 | 11 |
| 2020 | 1 | 16 | 35 | 36 | 12 |

**Table 3** Proportion % of Primary Unicondylar Knee Prosthesis [5–8]

| Proportion % of Primary Unicondylar Knee Prosthesis | | | | | |
|---|---|---|---|---|---|
| | <45 yrs | 45-59 yrs | 60-69 yrs | 70-79 yrs | >79 yrs |
| 2023 | 3 | 22 | 37 | 30 | 8 |
| 2022 | 2 | 22 | 39 | 31 | 6 |
| 2021 | 1 | 23 | 39 | 31 | 6 |
| 2020 | 2 | 25 | 38 | 31 | 4 |

**Table 4** Proportion % of Primary Total Knee Prosthesis [5–8]

| Proportion % of Primary Total Knee Prosthesis | | | | | |
|---|---|---|---|---|---|
| | <45 yrs | 45-59 yrs | 60-69 yrs | 70-79 yrs | >79 yrs |
| 2023 M | 2 | 17 | 34 | 38 | 9 |
| 2023 W | 2 | 15 | 31 | 39 | 13 |
| 2022 M | 3 | 16 | 36 | 36 | 9 |
| 2022 W | 2 | 15 | 31 | 40 | 12 |
| 2021 M | 3 | 16 | 36 | 35 | 10 |
| 2021 W | 2 | 15 | 31 | 40 | 12 |
| 2020 M | 3 | 16 | 36 | 35 | 10 |
| 2020 W | 2 | 15 | 31 | 40 | 12 |

**Table 5** Proportion % of Primary Unicondylar Knee Prosthesis [5–8]

| Proportion % of Primary Unicondylar Knee Prosthesis | | | | | |
|---|---|---|---|---|---|
| | <45 yrs | 45-59 yrs | 60-69 yrs | 70-79 yrs | >79 yrs |
| 2023 M | 2 | 24 | 42 | 28 | 4 |
| 2023 W | 3 | 25 | 40 | 27 | 5 |
| 2022 M | 2 | 25 | 41 | 28 | 4 |
| 2022 W | 3 | 26 | 39 | 27 | 5 |
| 2021 M | 2 | 25 | 41 | 28 | 4 |
| 2021 W | 3 | 26 | 38 | 28 | 5 |
| 2020 M | 2 | 25 | 41 | 28 | 4 |
| 2020 W | 3 | 26 | 38 | 28 | 5 |

The second section was the operation overview, which contained general information and data about the number and types of arthroplasty operations. Table 6 contains an overview of the number and type of knee arthroplasties performed [5]. It was noted that data for the year 2014 was not available. Table 7 and 8report the classification of stability and modularity for primary and revision total prostheses, respectively [5]. Table 9 provides the legend for the abbreviations in Table 7 and 8 [5].

**Table 6** Number and Type of Arthroplasty [5]

| | Number of Operations | | | | Primary Operation Types | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Primary Operations | Reoperations | Revisions | Total Operations | Total w/ Patella | Total w/o Patella | Unicondylar | Patello-Femoral | Partial Resurfacing | Hinged Prosthesis | Total Stab. | Total Primary Operations |
| 2023 | 8653 | 62 | 647 | 9362 | 940 | 6241 | 1344 | 54 | 0 | 44 | 29 | 8653 |
| 2022 | 7868 | 58 | 580 | 8506 | 790 | 5798 | 1138 | 69 | 0 | 53 | 20 | 7868 |
| 2021 | 7637 | 53 | 595 | 8285 | 659 | 5834 | 1007 | 71 | 0 | 53 | 4 | 7628 |
| 2020 | 6707 | 36 | 550 | 7293 | 527 | 5248 | 842 | 44 | 1 | 45 | 0 | 6707 |
| 2019 | 7256 | 32 | 619 | 7907 | 586 | 5589 | 995 | 53 | 0 | 33 | 0 | 7256 |
| 2018 | 6933 | 29 | 637 | 7599 | 504 | 5338 | 1001 | 58 | 0 | 31 | 1 | 6933 |
| 2017 | 6581 | 26 | 605 | 7212 | 454 | 5152 | 868 | 75 | 0 | 32 | 0 | 6581 |
| 2016 | 6514 | 25 | 579 | 7118 | 221 | 5329 | 863 | 68 | 1 | 32 | 0 | 6514 |
| 2015 | 6120 | 14 | 542 | 6676 | 160 | 5134 | 753 | 39 | 0 | 33 | 0 | 6119 |
| 2014 | | | | | | | | | | | | |

**Table 7** Classification of Stability and Modularity: primary total prosthesis [5]

| Classification of Stability and Modularity: PRIMARY total prosthesis | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | MS | | | | | PS | | | | | | |
| | CR | | UC | | | | | | | | | |
| | All poly | MT | All poly | MT | MP | All poly | MT | CCK | Rotat. Plat. | Hin. Pros. | Seg. Pros. | Total |
| 2023 | 1 | 4931 | 217 | 583 | 187 | 0 | 820 | 55 | 420 | 42 | 3 | 7277 |
| 2022 | 0 | 4102 | 182 | 460 | 139 | 0 | 895 | 38 | 778 | 47 | 5 | 6657 |
| 2021 | 0 | 4158 | 207 | 240 | 121 | 1 | 775 | 33 | 945 | 50 | 4 | 6547 |
| 2020 | 21 | 3699 | 224 | 234 | 129 | 1 | 608 | 33 | 821 | 43 | 3 | 5820 |
| 2019 | 92 | 4024 | 11 | 175 | 233 | 1 | 607 | 33 | 989 | 28 | 4 | 6206 |
| 2018 | 1 | 3579 | 0 | 137 | 269 | 1 | 568 | 26 | 1244 | 28 | 3 | 5870 |
| 2017 | 0 | 3201 | 0 | 130 | 331 | 0 | 544 | 42 | 1348 | 31 | 1 | 5637 |
| 2016 | 4 | 3165 | 0 | 95 | 408 | 0 | 472 | 19 | 1370 | 27 | 5 | 5578 |
| 2015 | 2 | 3140 | 0 | 37 | 332 | 0 | 348 | 23 | 1403 | 30 | 3 | 5326 |
| 2014 | 2 | 3077 | 0 | 34 | 251 | 0 | 150 | 23 | 1416 | 18 | 2 | 4988 |

**Table 8** Classification of Stability and Modularity: revision total prosthesis [5]

| Classification of Stability and Modularity: REVISION total prosthesis | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | MS | | | | | PS | | | | | | |
| | CR | | UC | | | | | | | | | |
| | All poly | MT | All poly | MT | MP | All poly | MT | CCK | Rotat. Plat. | Hin. Pros. | Seg. Pros. | Total |
| 2023 | 0 | 97 | 0 | 38 | 11 | 0 | 115 | 66 | 62 | 93 | 10 | 492 |
| 2022 | 0 | 93 | 0 | 30 | 9 | 0 | 105 | 64 | 53 | 86 | 6 | 446 |
| 2021 | 0 | 101 | 0 | 19 | 11 | 0 | 106 | 63 | 71 | 80 | 7 | 459 |
| 2020 | 0 | 85 | 0 | 11 | 10 | 0 | 108 | 94 | 62 | 58 | 4 | 432 |
| 2019 | 1 | 88 | 0 | 30 | 18 | 0 | 120 | 80 | 82 | 72 | 9 | 500 |
| 2018 | 1 | 109 | 0 | 25 | 15 | 0 | 113 | 109 | 93 | 42 | 2 | 509 |
| 2017 | 0 | 87 | 0 | 17 | 20 | 0 | 134 | 66 | 89 | 63 | 2 | 478 |
| 2016 | 0 | 72 | 0 | 23 | 15 | 0 | 96 | 67 | 80 | 72 | 7 | 432 |
| 2015 | 0 | 82 | 0 | 29 | 16 | 0 | 102 | 50 | 75 | 59 | 7 | 420 |
| 2014 | 0 | 79 | 0 | 19 | 16 | 0 | 59 | 69 | 90 | 56 | 6 | 395 |

**Table 9** Classification of Stability and Modularity Legend [5]

| |
|---|
| CR=Posterior cruciate retaining |
| MS=Minimally stabilized=Posterior cruciate retaining prosthesis and deep dish |
| UC=Ultra congruent (dished) |
| MP=Medial Pivot knee has no all poly |
| PS=Posterior cruciate stabilizing prosthesis |
| CCK=Constrained Condylar Knee=High level stabilization |
| MT=Metal backed tibia |
| All poly=All polyethylene tibial component |

The last section for which data was collected was the reasons for operation. This section, as the name implies, provides the number of operations performed for a specific reason related to primary, revision, or reoperation. Table 10 and 11 show the reasons for primary total and unicondylar knee prostheses, respectively [5]. Table 12, 13, and 14 show the reasons for revision of total knee prostheses with the patella component, total knee prostheses without the patella component, and unicondylar knee prostheses, respectively [5]. Similarly, Table 15, 16, and 17 show the reasons for reoperation of total knee prostheses with the patella component, total knee prostheses without the patella component, and unicondylar knee prostheses, respectively [5]. It was noted that data was missing from the report for various years, as seen in Table 15 and 17.

**Table 10** Reasons for primary total knee prostheses [5]

| Reasons for **PRIMARY TOTAL** Knee Prostheses | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Idiopathic Osteoarthritis | Rheumatoid Arthritis | Sequelae after fracture | Mb. Bechterew | Sequelae, ligament tear | Sequelae, meniscal tear | Acute fracture | Sequelae infection | Psoriasis arthritis | Osteonecrosis | Other | Missing |
| 2023 | 6557 | 139 | 146 | 16 | 302 | 455 | 21 | 20 | 62 | 34 | 155 | 9 |
| 2022 | 6061 | 147 | 118 | 17 | 274 | 427 | 9 | 26 | 41 | 29 | 145 | 3 |
| 2021 | 5971 | 134 | 140 | 15 | 254 | 410 | 10 | 14 | 30 | 23 | 100 | 5 |
| 2020 | 5320 | 130 | 131 | 22 | 216 | 332 | 5 | 11 | 28 | 20 | 86 | 0 |
| 2019 | 5694 | 134 | 145 | 14 | 239 | 350 | 7 | 13 | 29 | 16 | 101 | 0 |
| 2018 | 5376 | 146 | 139 | 13 | 235 | 365 | 5 | 13 | 28 | 13 | 96 | 0 |
| 2017 | 5134 | 159 | 153 | 19 | 191 | 339 | 3 | 18 | 39 | 14 | 78 | 0 |
| 2016 | 5076 | 139 | 126 | 18 | 232 | 368 | 2 | 11 | 40 | 15 | 86 | 0 |
| 2015 | 4811 | 166 | 122 | 16 | 205 | 321 | 1 | 18 | 36 | 10 | 107 | 2 |
| 2014 | 4504 | 142 | 126 | 22 | 144 | 308 | 3 | 7 | 30 | 16 | 94 | 2 |

**Table 11** Reasons for primary unicondylar knee prostheses [5]

| Reasons for **PRIMARY UNICONDYLAR** Knee Prostheses | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Idiopathic Osteoarthritis | Rheumatoid Arthritis | Sequelae after fracture | Mb. Bechterew | Sequelae, ligament tear | Sequelae, meniscal tear | Sequelae infection | Osteonecrosis | Other | Missing |
| 2023 | 1251 | 0 | 4 | 1 | 2 | 113 | 0 | 21 | 58 | 0 |
| 2022 | 1066 | 0 | 2 | 0 | 2 | 104 | 1 | 22 | 49 | 0 |
| 2021 | 967 | 0 | 2 | 1 | 0 | 61 | 0 | 11 | 13 | 2 |
| 2020 | 804 | 0 | 3 | 0 | 2 | 54 | 0 | 14 | 17 | 0 |
| 2019 | 948 | 1 | 2 | 0 | 2 | 64 | 0 | 18 | 20 | 0 |
| 2018 | 954 | 2 | 8 | 0 | 2 | 80 | 0 | 14 | 18 | 0 |
| 2017 | 833 | 1 | 4 | 0 | 3 | 71 | 0 | 13 | 22 | 0 |
| 2016 | 830 | 1 | 2 | 1 | 1 | 54 | 1 | 16 | 13 | 0 |
| 2015 | 706 | 0 | 4 | 2 | 5 | 70 | 0 | 11 | 13 | 0 |
| 2014 | 575 | 2 | 2 | 0 | 0 | 50 | 0 | 13 | 20 | 0 |

**Table 12** Reasons for revision: total knee prostheses with patella [5]

| Reasons for **REVISION TOTAL** Knee Prostheses **W/ PATELLA** | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Loose proximal comp. | Loose distal comp. | Loose patella comp. | Dislocation of patella | Dislocation (not patella) | Instability | Malalignment | Deep infection | Prolonged wound drainage | Fracture near implant | Pain | Defect polyethylene | Arthrofibrosis /fibrosis | Other | Missing |
| 2023 | 4 | 6 | 1 | 1 | 2 | 10 | 2 | 8 | 2 | 3 | 9 | 2 | 2 | 4 | 0 |
| 2022 | 3 | 4 | 0 | 0 | 0 | 2 | 1 | 11 | 3 | 1 | 0 | 2 | 0 | 2 | 1 |
| 2021 | 1 | 5 | 1 | 0 | 0 | 8 | 2 | 6 | 0 | 3 | 3 | 1 | 0 | 1 | 0 |
| 2020 | 1 | 7 | 2 | 1 | 0 | 7 | 3 | 9 | 1 | 0 | 10 | 1 | 1 | 2 | 0 |
| 2019 | 2 | 7 | 1 | 1 | 2 | 5 | 2 | 10 | 0 | 3 | 4 | 2 | 1 | 4 | 0 |
| 2018 | 0 | 2 | 0 | 0 | 0 | 5 | 1 | 9 | 0 | 2 | 4 | 1 | 0 | 2 | 0 |
| 2017 | 0 | 0 | 0 | 0 | 1 | 3 | 1 | 6 | 0 | 0 | 2 | 2 | 0 | 0 | 0 |
| 2016 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 6 | 0 | 1 | 3 | 1 | 0 | 1 | 0 |
| 2015 | 3 | 1 | 2 | 0 | 1 | 5 | 1 | 2 | 0 | 0 | 4 | 1 | 0 | 1 | 0 |
| 2014 | 2 | 1 | 1 | 0 | 0 | 3 | 2 | 1 | 1 | 0 | 5 | 2 | 0 | 1 | 0 |

**Table 13** Reasons for revision: total knee prostheses without patella [5]

| Reasons for **REVISION TOTAL** Knee Prostheses **W/O PATELLA** | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Loose proximal comp. | Loose distal comp. | Dislocation of patella | Dislocation (not patella) | Instability | Malalignment | Deep infection | Prolonged wound drainage | Fracture near implant | Pain | Defect polyethylene | Progression of Osteoarthritis | Arthrofibrosis /fibrosis | Other | Missing |
| 2023 | 21 | 36 | 5 | 6 | 89 | 15 | 64 | 5 | 7 | 67 | 11 | 31 | 14 | 25 | 1 |
| 2022 | 16 | 42 | 5 | 1 | 87 | 16 | 60 | 6 | 9 | 81 | 14 | 19 | 11 | 22 | 0 |
| 2021 | 12 | 43 | 12 | 3 | 89 | 25 | 75 | 2 | 15 | 103 | 13 | 22 | 3 | 28 | 0 |
| 2020 | 21 | 46 | 6 | 0 | 63 | 27 | 72 | 1 | 13 | 58 | 12 | 10 | 0 | 31 | 0 |
| 2019 | 21 | 42 | 7 | 2 | 68 | 31 | 76 | 0 | 16 | 71 | 7 | 12 | 8 | 34 | 0 |
| 2018 | 33 | 68 | 6 | 0 | 84 | 26 | 83 | 0 | 15 | 74 | 8 | 6 | 4 | 30 | 0 |
| 2017 | 19 | 49 | 4 | 3 | 79 | 30 | 70 | 3 | 20 | 90 | 13 | 8 | 3 | 25 | 0 |
| 2016 | 19 | 39 | 3 | 3 | 81 | 33 | 73 | 1 | 9 | 92 | 13 | 8 | 0 | 30 | 0 |
| 2015 | 15 | 47 | 3 | 3 | 73 | 30 | 58 | 1 | 7 | 95 | 9 | 10 | 3 | 26 | 0 |
| 2014 | 16 | 60 | 2 | 4 | 75 | 31 | 57 | 2 | 14 | 67 | 4 | 2 | 2 | 24 | 0 |

**Table 14** Reasons for revision: unicondylar knee prostheses [5]

Reasons for **REVISION UNICONDYLAR** Knee Prostheses

| | Loose proximal comp. | Loose distal comp. | Dislocation | Instability | Malalignment | Deep infection | Prolonged wound drainage | Fracture near implant | Pain | Defect polyethylene | Progression of Osteoarthritis | Subluxation | Other | Missing |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2023 | 13 | 14 | 3 | 33 | 6 | 15 | 1 | 5 | 31 | 10 | 60 | 7 | 9 | 1 |
| 2022 | 8 | 16 | 3 | 24 | 6 | 9 | 0 | 4 | 37 | 5 | 53 | 4 | 10 | 2 |
| 2021 | 6 | 12 | 6 | 20 | 8 | 7 | 1 | 2 | 23 | 4 | 52 | 3 | 7 | 0 |
| 2020 | 8 | 17 | 6 | 19 | 10 | 5 | 0 | 1 | 21 | 10 | 46 | 1 | 10 | 0 |
| 2019 | 9 | 13 | 9 | 20 | 18 | 13 | 0 | 6 | 26 | 12 | 40 | 3 | 14 | 0 |
| 2018 | 12 | 15 | 11 | 16 | 12 | 9 | 0 | 3 | 37 | 8 | 53 | 2 | 9 | 0 |
| 2017 | 12 | 15 | 7 | 10 | 5 | 7 | 0 | 4 | 37 | 8 | 48 | 0 | 4 | 0 |
| 2016 | 9 | 8 | 9 | 7 | 5 | 13 | 1 | 4 | 25 | 6 | 36 | 3 | 4 | 0 |
| 2015 | 5 | 8 | 4 | 10 | 9 | 4 | 0 | 4 | 37 | 6 | 43 | 1 | 5 | 0 |
| 2014 | 14 | 15 | 3 | 15 | 8 | 4 | 0 | 0 | 37 | 6 | 33 | 1 | 6 | 0 |

**Table 15** Reasons for reoperation: total knee prostheses with patella [5]

Reasons for **REOPERATION TOTAL** Knee Prostheses **W/ PATELLA**

| | Loose proximal comp. | Loose distal comp. | Loose patella comp. | Dislocation of patella | Dislocation (not patella) | Instability | Malalignment | Deep infection | Prolonged wound drainage | Fracture near implant | Pain | Defect polyethylene | Arthrofibrosis /fibrosis | Other | Missing |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2023 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 2 | 1 | 0 | 2 | 1 | 0 |
| 2022 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 2 | 0 | 0 | 1 | 0 | 1 |
| 2021 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 2 | 0 | 0 | 0 | 1 | 1 |
| 2020 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| 2019 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| 2018 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 3 | 0 |
| 2017 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 1 | 0 |
| 2016 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2015 | | | | | | | | | | | | | | | |
| 2014 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

**Table 16** Reasons for reoperation: total knee prostheses without patella [5]

Reasons for **REOPERATION TOTAL** Knee Prostheses **W/O PATELLA**

| | Loose proximal comp. | Loose distal comp. | Dislocation of patella | Dislocation (not patella) | Instability | Malalignment | Deep infection | Prolonged wound drainage | Fracture near implant | Pain | Defect polyethylene | Progression of Osteoarthritis | Arthrofibrosis /fibrosis | Other | Missing |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2023 | 0 | 0 | 1 | 1 | 1 | 0 | 8 | 0 | 30 | 1 | 0 | 0 | 16 | 8 | 0 |
| 2022 | 0 | 0 | 0 | 0 | 1 | 0 | 6 | 0 | 25 | 1 | 0 | 0 | 6 | 10 | 0 |
| 2021 | 0 | 0 | 1 | 0 | 0 | 0 | 4 | 0 | 23 | 1 | 0 | 0 | 2 | 6 | 0 |
| 2020 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 0 | 11 | 0 | 0 | 0 | 0 | 10 | 0 |
| 2019 | 0 | 0 | 2 | 1 | 1 | 1 | 2 | 1 | 11 | 0 | 0 | 0 | 3 | 3 | 0 |
| 2018 | 0 | 0 | 1 | 1 | 0 | 0 | 6 | 2 | 5 | 1 | 0 | 0 | 1 | 3 | 0 |
| 2017 | 1 | 0 | 2 | 0 | 0 | 0 | 7 | 0 | 3 | 2 | 0 | 0 | 0 | 5 | 0 |
| 2016 | 0 | 0 | 0 | 0 | 0 | 0 | 5 | 0 | 5 | 0 | 0 | 0 | 1 | 5 | 0 |
| 2015 | 0 | 0 | 0 | 0 | 0 | 0 | 5 | 1 | 0 | 2 | 0 | 0 | 1 | 1 | 0 |
| 2014 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

**Table 17** Reasons for reoperation: unicondylar knee prostheses [5]

Reasons for **REOPERATION UNICONDYLAR** Knee Prostheses

| | Loose proximal comp. | Loose distal comp. | Dislocation | Instability | Malalignment | Deep infection | Prolonged wound drainage | Fracture near implant | Pain | Defect polyethylene | Progression of Osteoarthritis | Subluxation | Other | Missing |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2023 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2022 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 |
| 2021 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 |
| 2020 | | | | | | | | | | | | | | |
| 2019 | | | | | | | | | | | | | | |
| 2018 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2017 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2016 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| 2015 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2014 | | | | | | | | | | | | | | |

## 3.2 Reasons for Revision Pair-Wise Statistical Analysis

The reasons for revision of total knee prostheses with the patellar component, total knee prostheses without the patellar component, and unicondylar prostheses were further investigated due to their impact on prosthesis design. Insight into the reasons for revision allows for a focused approach when engineering improvements for these devices. The first group analyzed was the reasons for revision of total knee prostheses with the patellar component (TK w/ P). Table 18 shows the square root stabilized transformation of the raw data. Table 19 shows the one-way ANOVA performed on this transformed data. Similarly, Figure 1 and 2 show a scatter plot and a box and whisker plot of the transformed data. Table 20 shows the results of the Tukey-Kramer pair-wise comparison.

**Table 18** TK w/P Square Root Stabilized Transformation

| Sqrt Variance Stabilizing Transformation | Loose proximal comp. | Loose distal comp. | Loose patella comp. | Dislocation of patella | Dislocation (not patella) | Instability | Malalignment | Deep infection | Prolonged wound drainage | Fracture near implant | Pain | Defect polyethylene | Arthrofibrosis /fibrosis | Other | Missing |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2023 | 2.00 | 2.45 | 1.00 | 1.00 | 1.41 | 3.16 | 1.41 | 2.83 | 1.41 | 1.73 | 3.00 | 1.41 | 1.41 | 2.00 | 0.00 |
| 2022 | 1.73 | 2.00 | 0.00 | 0.00 | 0.00 | 1.41 | 1.00 | 3.32 | 1.73 | 1.00 | 0.00 | 1.41 | 0.00 | 1.41 | 1.00 |
| 2021 | 1.00 | 2.24 | 1.00 | 0.00 | 0.00 | 2.83 | 1.41 | 2.45 | 0.00 | 1.73 | 1.73 | 1.00 | 0.00 | 1.00 | 0.00 |
| 2020 | 1.00 | 2.65 | 1.41 | 1.00 | 0.00 | 2.65 | 1.73 | 3.00 | 1.00 | 0.00 | 3.16 | 1.00 | 1.00 | 1.41 | 0.00 |
| 2019 | 1.41 | 2.65 | 1.00 | 1.00 | 1.41 | 2.24 | 1.41 | 3.16 | 0.00 | 1.73 | 2.00 | 1.41 | 1.00 | 2.00 | 0.00 |
| 2018 | 0.00 | 1.41 | 0.00 | 0.00 | 0.00 | 2.24 | 1.00 | 3.00 | 0.00 | 1.41 | 2.00 | 1.00 | 0.00 | 1.41 | 0.00 |
| 2017 | 0.00 | 0.00 | 0.00 | 0.00 | 1.00 | 1.73 | 1.00 | 2.45 | 0.00 | 0.00 | 1.41 | 1.41 | 0.00 | 0.00 | 0.00 |
| 2016 | 1.00 | 1.00 | 1.00 | 1.00 | 0.00 | 1.00 | 1.00 | 2.45 | 0.00 | 1.00 | 1.73 | 1.00 | 0.00 | 1.00 | 0.00 |
| 2015 | 1.73 | 1.00 | 1.41 | 0.00 | 1.00 | 2.24 | 1.00 | 1.41 | 0.00 | 0.00 | 2.00 | 1.00 | 0.00 | 1.00 | 0.00 |
| 2014 | 1.41 | 1.00 | 1.00 | 0.00 | 0.00 | 1.73 | 1.41 | 1.00 | 1.00 | 0.00 | 2.24 | 1.41 | 0.00 | 1.00 | 0.00 |

**Table 19** TK w/P One-way ANOVA

| Sqrt Variance Stabilized Data | | | | | | |
|---|---|---|---|---|---|---|
| Anova: Single Factor | | | | | | |
| | | | | | | |
| SUMMARY | | | | | | |
| *Groups* | *Count* | *Sum* | *Average* | *Variance* | | |
| Loose proximal comp. | 10 | 11.29253 | 1.129253 | 0.471987 | | |
| Loose distal comp. | 10 | 16.39127 | 1.639127 | 0.792513 | | |
| Loose patella comp. | 10 | 7.828427 | 0.782843 | 0.319064 | | |
| Dislocation of patella | 10 | 4 | 0.4 | 0.266667 | | |
| Dislocation (not patella) | 10 | 4.828427 | 0.482843 | 0.407625 | | |
| Instability | 10 | 21.22298 | 2.122298 | 0.439837 | | |
| Malalignment | 10 | 12.38891 | 1.238891 | 0.072389 | | |
| Deep infection | 10 | 25.07001 | 2.507001 | 0.572161 | | |
| Prolonged wound drainage | 10 | 5.146264 | 0.514626 | 0.483511 | | |
| Fracture near implant | 10 | 8.610366 | 0.861037 | 0.620684 | | |
| Pain | 10 | 19.27666 | 1.927666 | 0.760115 | | |
| Defect polyethylene | 10 | 12.07107 | 1.207107 | 0.047659 | | |
| Arthrofibrosis/fibrosis | 10 | 3.414214 | 0.341421 | 0.314924 | | |
| Other | 10 | 12.24264 | 1.224264 | 0.334642 | | |
| Missing | 10 | 1 | 0.1 | 0.1 | | |
| | | | | | | |
| | | | | | | |
| ANOVA | | | | | | |
| *Source of Variation* | *SS* | *df* | *MS* | *F* | *P-value* | *F crit* |
| Between Groups | 69.94142 | 14 | 4.995816 | 12.48168 | 2.77E-18 | 1.765688 |
| Within Groups | 54.03399 | 135 | 0.400252 | | | |
| | | | | | | |
| Total | 123.9754 | 149 | | | | |

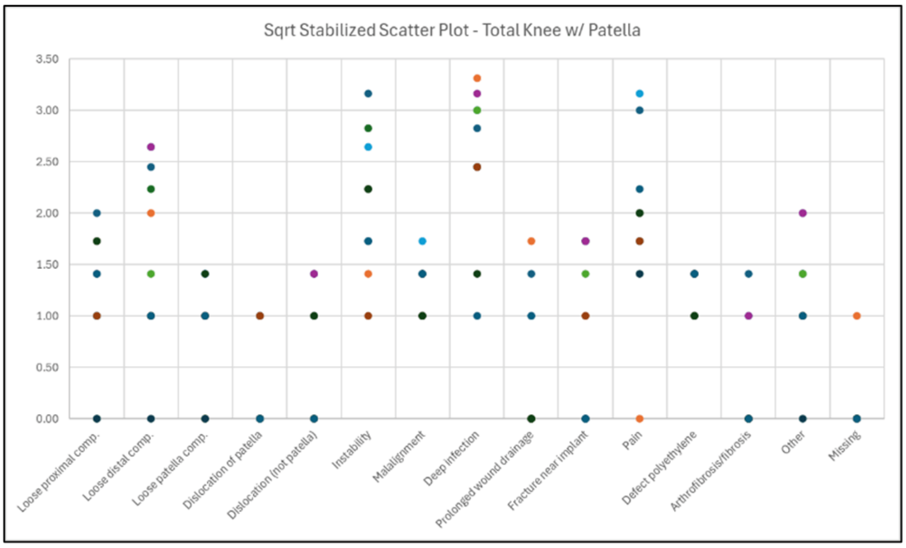


**Figure 1** TK w/ P Scatter Plot

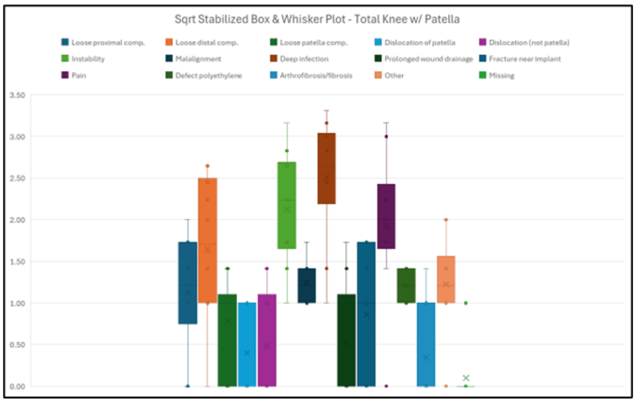


**Figure 2** TK w/P Box and Whisker Plot

**Table 20** TK w/P Tukey-Kramer Comparison

| Group | Tukey-Kramer Pair-wise Comparison - Total Knee w/ Patella | | | | | | | | | | | | | | | Average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Deep infect | Instability | Pain | Loose dista | Malalignme | Other | Defect poly | Loose prox | Fracture ne | Loose pate | Prolonged | Dislocatior | Dislocatior | Arthrofibro | Missing | |
| Deep infection | ↓ | | | | | | | | | | | | | | | 2.507001 |
| Instability | | ↓ | | | | | | | | | | | | | | 2.122298 |
| Pain | | | ↓ | | | | | | | | | | | | | 1.927666 |
| Loose distal comp. | | | | ↓ | | | | | | | | | | | | 1.639127 |
| Malalignment | | | | | ↓ | | | | | | | | | | | 1.238891 |
| Other | | | | | | ↓ | | | | | | | | | | 1.224264 |
| Defect polyethylene | | | | | | | ↓ | | | | | | | | | 1.207107 |
| Loose proximal comp. | | | | | | | | ↓ | | | | | | | | 1.129253 |
| Fracture near implant | | | | | | | | | ↓ | | | | | | | 0.861037 |
| Loose patella comp. | | | | | | | | | | ↓ | | | | | | 0.782843 |
| Prolonged wound drainage | | | | | | | | | | | ↓ | | | | | 0.514626 |
| Dislocation (not patella) | | | | | | | | | | | | ↓ | | | | 0.482843 |
| Dislocation of patella | | | | | | | | | | | | | ↓ | | | 0.400000 |
| Arthrofibrosis/fibrosis | | | | | | | | | | | | | | ↓ | | 0.341421 |
| Missing | | | | | | | | | | | | | | | ↓ | 0.100000 |

The second group analyzed was the reasons for revision of total knee prostheses without the patellar component (TK w/o P). Table 21 shows the square root stabilized transformation of the raw data. Table 22 shows the one-way ANOVA performed on this transformed data. Similarly, Figure 3 and 4 show a scatter plot and a box and whisker plot of the transformed data. Table 23 shows the results of the Tukey-Kramer pair-wise comparison.

**Table 21** TK w/o P Square Root Stabilized Transformation

| Sqrt Variance Stabilizing Transformation | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Loose proximal comp. | Loose distal comp. | Dislocation of patella | Dislocation (not patella) | Instability | Malalignment | Deep infection | Prolonged wound drainage | Fracture near implant | Pain | Defect polyethylene | Progression of Osteoarthritis | Arthrofibrosis /fibrosis | Other | Missing |
| 2023 | 4.58 | 6.00 | 2.24 | 2.45 | 9.43 | 3.87 | 8.00 | 2.24 | 2.65 | 8.19 | 3.32 | 5.57 | 3.74 | 5.00 | 1.00 |
| 2022 | 4.00 | 6.48 | 2.24 | 1.00 | 9.33 | 4.00 | 7.75 | 2.45 | 3.00 | 9.00 | 3.74 | 4.36 | 3.32 | 4.69 | 0.00 |
| 2021 | 3.46 | 6.56 | 3.46 | 1.73 | 9.43 | 5.00 | 8.66 | 1.41 | 3.87 | 10.15 | 3.61 | 4.69 | 1.73 | 5.29 | 0.00 |
| 2020 | 4.58 | 6.78 | 2.45 | 0.00 | 7.94 | 5.20 | 8.49 | 1.00 | 3.61 | 7.62 | 3.46 | 3.16 | 0.00 | 5.57 | 0.00 |
| 2019 | 4.58 | 6.48 | 2.65 | 1.41 | 8.25 | 5.57 | 8.72 | 0.00 | 4.00 | 8.43 | 2.65 | 3.46 | 2.83 | 5.83 | 0.00 |
| 2018 | 5.74 | 8.25 | 2.45 | 0.00 | 9.17 | 5.10 | 9.11 | 0.00 | 3.87 | 8.60 | 2.83 | 2.45 | 2.00 | 5.48 | 0.00 |
| 2017 | 4.36 | 7.00 | 2.00 | 1.73 | 8.89 | 5.48 | 8.37 | 1.73 | 4.47 | 9.49 | 3.61 | 2.83 | 1.73 | 5.00 | 0.00 |
| 2016 | 4.36 | 6.24 | 1.73 | 1.73 | 9.00 | 5.74 | 8.54 | 1.00 | 3.00 | 9.59 | 3.61 | 2.83 | 0.00 | 5.48 | 0.00 |
| 2015 | 3.87 | 6.86 | 1.73 | 1.73 | 8.54 | 5.48 | 7.62 | 1.00 | 2.65 | 9.75 | 3.00 | 3.16 | 1.73 | 5.10 | 0.00 |
| 2014 | 4.00 | 7.75 | 1.41 | 2.00 | 8.66 | 5.57 | 7.55 | 1.41 | 3.74 | 8.19 | 2.00 | 1.41 | 1.41 | 4.90 | 0.00 |

**Table 22** TK w/o P One-way ANOVA

| Sqrt Variance Stabilized Data | | | | | | |
|---|---|---|---|---|---|---|
| Anova: Single Factor | | | | | | |
| | | | | | | |
| SUMMARY | | | | | | |
| *Groups* | *Count* | *Sum* | *Average* | *Variance* | | |
| Loose proximal comp. | 10 | 43.547173 | 4.354717 | 0.37382 | | |
| Loose distal comp. | 10 | 68.39408 | 6.839408 | 0.469442 | | |
| Dislocation of patella | 10 | 22.359284 | 2.235928 | 0.334027 | | |
| Dislocation (not patella) | 10 | 13.791907 | 1.379191 | 0.664259 | | |
| Instability | 10 | 88.63641 | 8.863641 | 0.262076 | | |
| Malalignment | 10 | 51.002698 | 5.10027 | 0.430276 | | |
| Deep infection | 10 | 82.795945 | 8.279595 | 0.275905 | | |
| Prolonged wound drainage | 10 | 12.246036 | 1.224604 | 0.667051 | | |
| Fracture near implant | 10 | 34.856814 | 3.485681 | 0.388917 | | |
| Pain | 10 | 88.989136 | 8.898914 | 0.677042 | | |
| Defect polyethylene | 10 | 31.813216 | 3.181322 | 0.310214 | | |
| Progression of Osteoarthritis | 10 | 33.926294 | 3.392629 | 1.433407 | | |
| Arthrofibrosis/fibrosis | 10 | 18.497075 | 1.849708 | 1.531758 | | |
| Other | 10 | 52.333085 | 5.233308 | 0.12498 | | |
| Missing | 10 | 1 | 0.1 | 0.1 | | |
| | | | | | | |
| | | | | | | |
| ANOVA | | | | | | |
| *Source of Variation* | *SS* | *df* | *MS* | *F* | *P-value* | *F crit* |
| Between Groups | 1144.08 | 14 | 81.72003 | 152.4026 | 2.37361E-75 | 1.765688 |
| Within Groups | 72.38856 | 135 | 0.536212 | | | |
| | | | | | | |
| Total | 1216.469 | 149 | | | | |

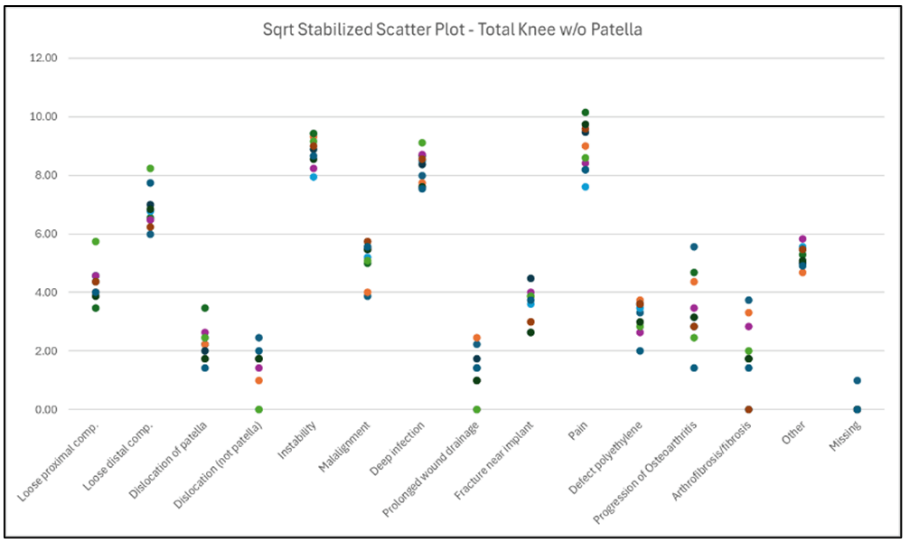


**Figure 3** TK w/o P Scatter Plot

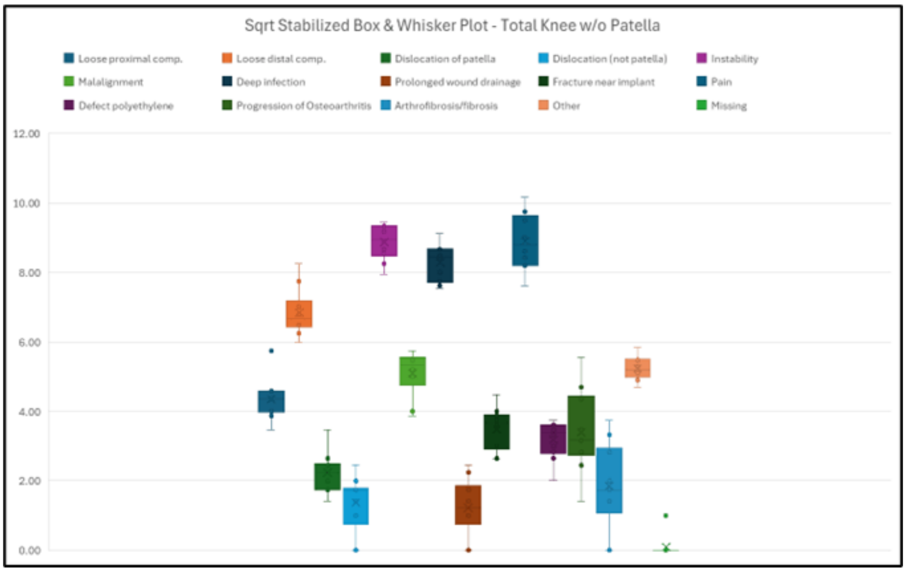


**Figure 4** TK w/o P Box and Whisker Plot

**Table 23** TK w/o P Tukey-Kramer Comparison

| Group | Tukey-Kramer Pair-wise Comparison - Total Knee w/o Patella | | | | | | | | | | | | | | | Average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Pain | Instability | Deep infect | Loose dista | Other | Malalignme | Loose prox | Fracture ne | Progressio | Defect poly | Dislocatior | Arthrofibro | Dislocatior | Prolonged | Missing | |
| Pain | ↓ | | | | | | | | | | | | | | | 8.898914 |
| Instability | | ↓ | | | | | | | | | | | | | | 8.863641 |
| Deep infection | | | ↓ | | | | | | | | | | | | | 8.279595 |
| Loose distal comp. | | | | ↓ | | | | | | | | | | | | 6.839408 |
| Other | | | | | ↓ | | | | | | | | | | | 5.233308 |
| Malalignment | | | | | | ↓ | | | | | | | | | | 5.100270 |
| Loose proximal comp. | | | | | | | ↓ | | | | | | | | | 4.354717 |
| Fracture near implant | | | | | | | | ↓ | | | | | | | | 3.485681 |
| Progression of Osteoarthritis | | | | | | | | | ↓ | | | | | | | 3.392629 |
| Defect polyethylene | | | | | | | | | | ↓ | | | | | | 3.181322 |
| Dislocation of patella | | | | | | | | | | | ↓ | | | | | 2.235928 |
| Arthrofibrosis/fibrosis | | | | | | | | | | | | ↓ | | | | 1.849708 |
| Dislocation (not patella) | | | | | | | | | | | | | ↓ | | | 1.379191 |
| Prolonged wound drainage | | | | | | | | | | | | | | ↓ | | 1.224604 |
| Missing | | | | | | | | | | | | | | | ↓ | 0.100000 |

The final group analyzed was the reasons for revision of unicondylar prostheses. Table 24 shows the square root stabilized transformation of the raw data. Table 25 shows the one-way ANOVA performed on this transformed data. Similarly, Figure 5 and 6 show a scatter plot and a box and whisker plot of the transformed data. Table 26 shows the results of the Tukey-Kramer pair-wise comparison.

**Table 24** Unicondylar Square Root Stabilized Transformation

| Sqrt Variance Stabilizing Transformation | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Loose proximal comp. | Loose distal comp. | Dislocation | Instability | Malalignment | Deep infection | Prolonged wound drainage | Fracture near implant | Pain | Defect polyethylene | Progression of Osteoarthritis | Subluxation | Other | Missing |
| 2023 | 3.61 | 3.74 | 1.73 | 5.74 | 2.45 | 3.87 | 1.00 | 2.24 | 5.57 | 3.16 | 7.75 | 2.65 | 3.00 | 1.00 |
| 2022 | 2.83 | 4.00 | 1.73 | 4.90 | 2.45 | 3.00 | 0.00 | 2.00 | 6.08 | 2.24 | 7.28 | 2.00 | 3.16 | 1.41 |
| 2021 | 2.45 | 3.46 | 2.45 | 4.47 | 2.83 | 2.65 | 1.00 | 1.41 | 4.80 | 2.00 | 7.21 | 1.73 | 2.65 | 0.00 |
| 2020 | 2.83 | 4.12 | 2.45 | 4.36 | 3.16 | 2.24 | 0.00 | 1.00 | 4.58 | 3.16 | 6.78 | 1.00 | 3.16 | 0.00 |
| 2019 | 3.00 | 3.61 | 3.00 | 4.47 | 4.24 | 3.61 | 0.00 | 2.45 | 5.10 | 3.46 | 6.32 | 1.73 | 3.74 | 0.00 |
| 2018 | 3.46 | 3.87 | 3.32 | 4.00 | 3.46 | 3.00 | 0.00 | 1.73 | 6.08 | 2.83 | 7.28 | 1.41 | 3.00 | 0.00 |
| 2017 | 3.46 | 3.87 | 2.65 | 3.16 | 2.24 | 2.65 | 0.00 | 2.00 | 6.08 | 2.83 | 6.93 | 0.00 | 2.00 | 0.00 |
| 2016 | 3.00 | 2.83 | 3.00 | 2.65 | 2.24 | 3.61 | 1.00 | 2.00 | 5.00 | 2.45 | 6.00 | 1.73 | 2.00 | 0.00 |
| 2015 | 2.24 | 2.83 | 2.00 | 3.16 | 3.00 | 2.00 | 0.00 | 2.00 | 6.08 | 2.45 | 6.56 | 1.00 | 2.24 | 0.00 |
| 2014 | 3.74 | 3.87 | 1.73 | 3.87 | 2.83 | 2.00 | 0.00 | 0.00 | 6.08 | 2.45 | 5.74 | 1.00 | 2.45 | 0.00 |

**Table 25** Unicondylar One-way ANOVA

| Sqrt Variance Stabilized Data | | | | | | |
|---|---|---|---|---|---|---|
| Anova: Single Factor | | | | | | |
| | | | | | | |
| SUMMARY | | | | | | |
| *Groups* | *Count* | *Sum* | *Average* | *Variance* | | |
| Loose proximal comp. | 10 | 30.61782 | 3.061782 | 0.250543 | | |
| Loose distal comp. | 10 | 36.21022 | 3.621022 | 0.209111 | | |
| Dislocation | 10 | 24.05751 | 2.405751 | 0.34707 | | |
| Instability | 10 | 40.79 | 4.079 | 0.846396 | | |
| Malalignment | 10 | 28.89699 | 2.889699 | 0.388489 | | |
| Deep infection | 10 | 28.61166 | 2.861166 | 0.459701 | | |
| Prolonged wound drainage | 10 | 3 | 0.3 | 0.233333 | | |
| Fracture near implant | 10 | 16.83182 | 1.683182 | 0.518775 | | |
| Pain | 10 | 55.459 | 5.5459 | 0.381099 | | |
| Defect polyethylene | 10 | 27.03005 | 2.703005 | 0.215294 | | |
| Progression of Osteoarthritis | 10 | 67.85438 | 6.785438 | 0.397592 | | |
| Subluxation | 10 | 14.25612 | 1.425612 | 0.51959 | | |
| Other | 10 | 27.39752 | 2.739752 | 0.326398 | | |
| Missing | 10 | 2.414214 | 0.241421 | 0.268573 | | |
| | | | | | | |
| | | | | | | |
| ANOVA | | | | | | |
| *Source of Variation* | *SS* | *df* | *MS* | *F* | *P-value* | *F crit* |
| Between Groups | 418.2167 | 13 | 32.17051 | 83.99667 | 1.69298E-55 | 1.798584 |
| Within Groups | 48.25768 | 126 | 0.382997 | | | |
| | | | | | | |
| Total | 466.4743 | 139 | | | | |

**Table 26** Unicondylar Tukey-Kramer Comparison

| Group | Tukey-Kramer Pair-wise Comparison - Unicondylar | | | | | | | | | | | | | | Average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Progressio | Pain | Instability | Loose dista | Loose prox | Malalignme | Deep infect | Other | Defect poly | Dislocatior | Fracture ne | Subluxatio | Prolonged | Missing | |
| Progression of Osteoarthritis | ↓ | | | | | | | | | | | | | | 6.785438 |
| Pain | | ↓ | | | | | | | | | | | | | 5.545900 |
| Instability | | | ↓ | | | | | | | | | | | | 4.079000 |
| Loose distal comp. | | | | ↓ | | | | | | | | | | | 3.621022 |
| Loose proximal comp. | | | | | ↓ | | | | | | | | | | 3.061782 |
| Malalignment | | | | | | ↓ | | | | | | | | | 2.889699 |
| Deep infection | | | | | | | ↓ | | | | | | | | 2.861166 |
| Other | | | | | | | | ↓ | | | | | | | 2.739752 |
| Defect polyethylene | | | | | | | | | ↓ | | | | | | 2.703005 |
| Dislocation | | | | | | | | | | ↓ | | | | | 2.405751 |
| Fracture near implant | | | | | | | | | | | ↓ | | | | 1.683182 |
| Subluxation | | | | | | | | | | | | ↓ | | | 1.425612 |
| Prolonged wound drainage | | | | | | | | | | | | | ↓ | | 0.300000 |
| Missing | | | | | | | | | | | | | | ↓ | 0.241421 |

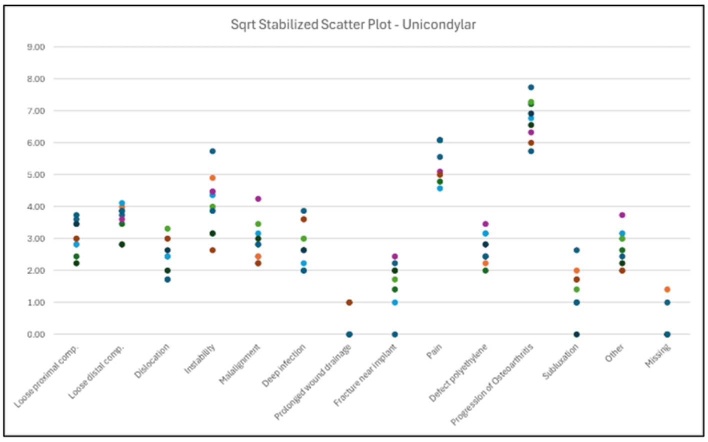


**Figure 5** Unicondylar Scatter Plot

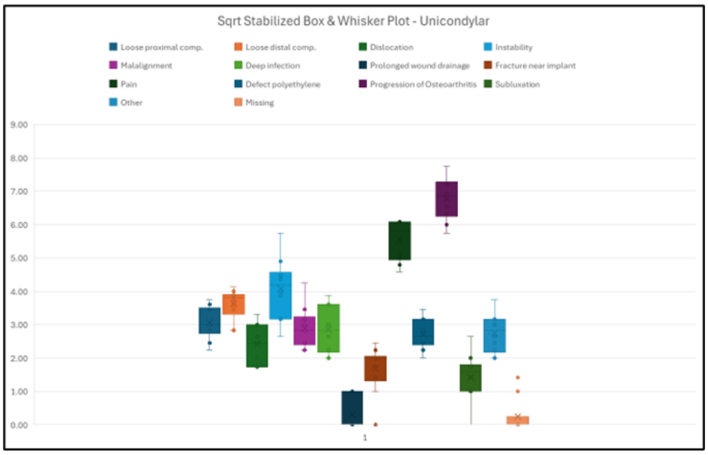


**Figure 6** Unicondylar Box and Whisker Plot

## 3.3 Reasons for Revision Regression Statistical Analysis

In order to identify an equation that can be used to predict the future outcome of the top three reasons for revision of each group of knee arthroplasties, a regression model was used. Figure 7, 8, and 9 show a plot of deep infection, instability, and pain, respectively, over time for total knee prostheses with the patella. Each plot also displays the regression model trendline, equation, and $R^2$ value.

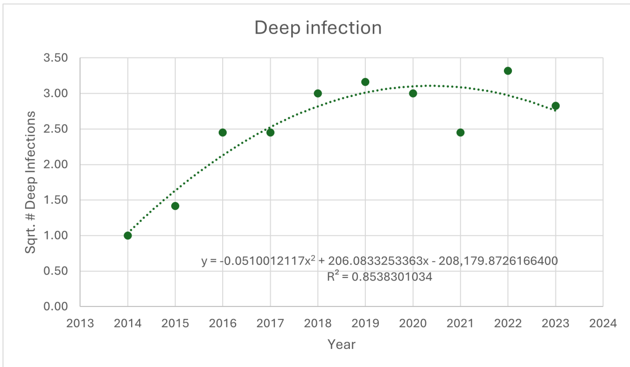


**Figure 7** TK w/P Deep Infection Regression

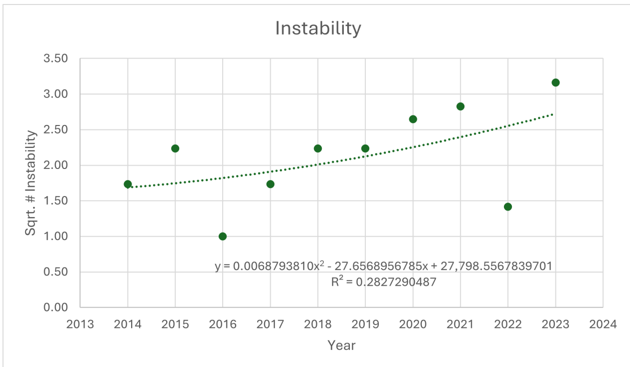


**Figure 8** TK w/P Instability Regression

Figure 10, 11, and 12 show a plot of pain, instability, and deep infection, respectively, over time for total knee prostheses without the patella. Each plot also displays the regression model trendline, equation, and $R^2$ value.

Figure 13, 14, and 15 show a plot of the progression of osteoarthritis, pain, and instability, respectively, over time for unicondylar knee prostheses. Each plot also displays the regression model trendline, equation, and $R^2$ value.

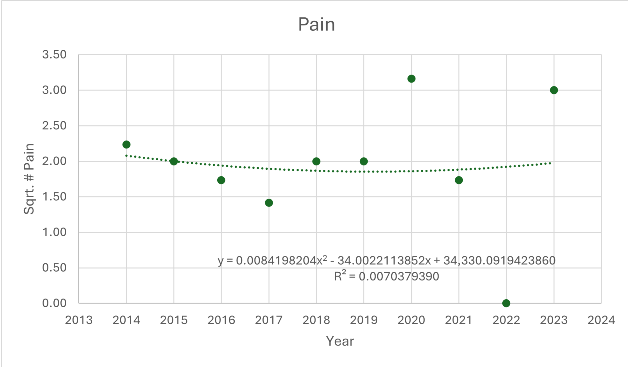


**Figure 9** TK w/P Pain Regression

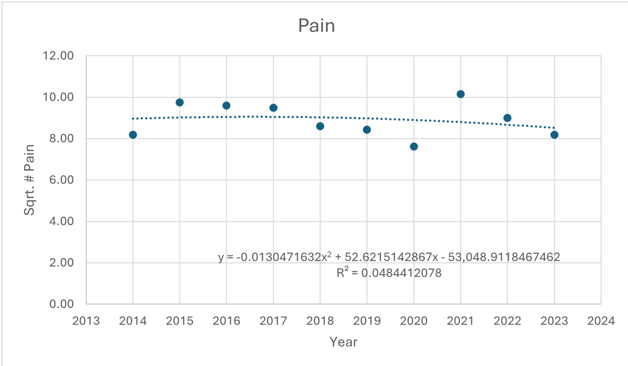


**Figure 10** TK w/o P Pain Regression

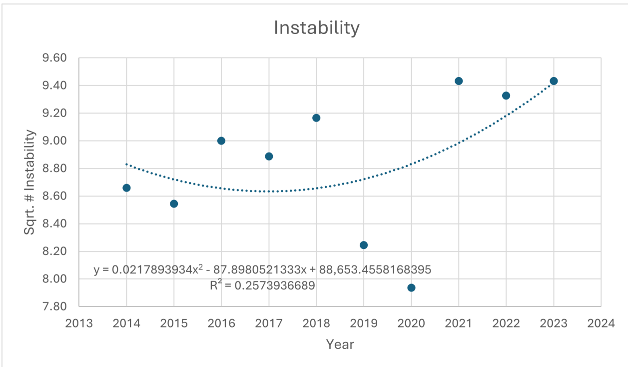


**Figure 11** TK w/o P Instability Regression

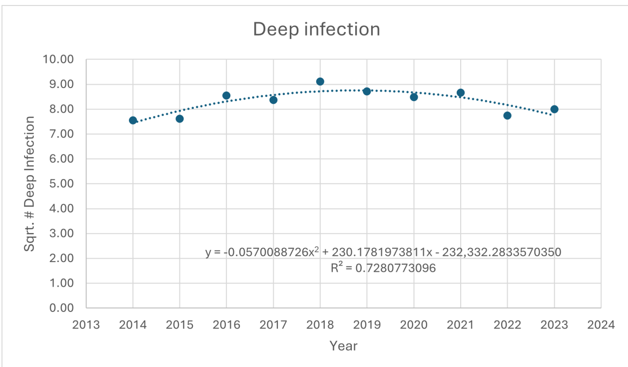


**Figure 12** TK w/o P Deep Infection Regression

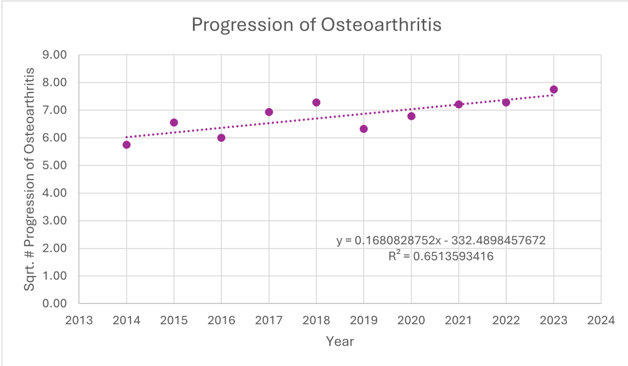


**Figure 13** Unicondylar Progression of Osteoarthritis Regression

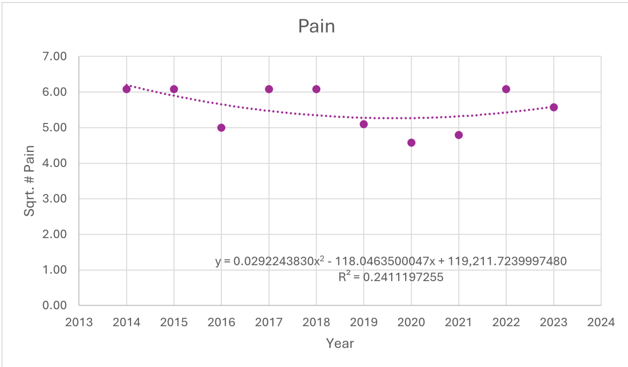


**Figure 14** Unicondylar Pain Regression

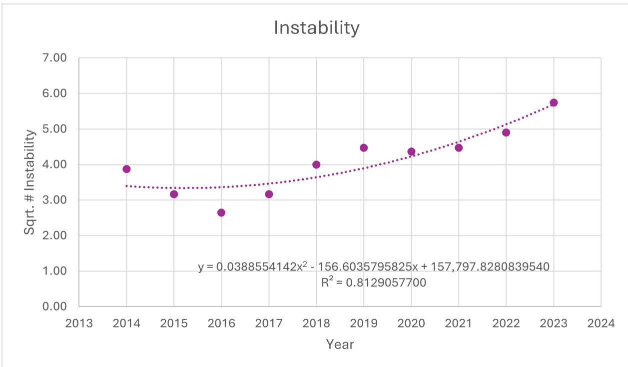


**Figure 15** Unicondylar Instability Regression

Table 27 below summarizes each of the regression models above. It includes the category, the reason for revision, the regression model equation, the $R^2$ value, and a prediction for the year 2030. This prediction, since the regression models are based on the square root stabilized data, is a square root prediction. Since the number of revisions cannot go below zero, any negative predictions can be considered as zero as well.

**Table 27** Regression Model Summary

| Regression Summary | | | | |
|---|---|---|---|---|
| Category | Reason for Revision | Equation | R2 | 2030 Sqrt. Prediction |
| TK w/ P | Deep Infection | $y = -0.0510012117x^2 + 206.0833253363x - 208,179.8726166400$ | 0.8538 | -2 |
| | Instability | $y = 0.0068793810x^2 - 27.6568956785x + 27,798.5567839701$ | 0.2827 | 4 |
| | Pain | $y = 0.0084198204x^2 - 34.0022113852x + 34,330.0919423860$ | 0.0070 | 3 |
| TK w/o P | Pain | $y = -0.0130471632x^2 + 52.6215142867x - 53,048.9118467462$ | 0.0484 | 7 |
| | Instability | $y = 0.0217893934x^2 - 87.8980521333x + 88,653.4558168395$ | 0.2574 | 12 |
| | Deep Infection | $y = -0.0570088726x^2 + 230.1781973811x - 232,332.2833570350$ | 0.7281 | 2 |
| Unicondylar | Progression of Osteoarthritis | $y = 0.1680828752x - 332.4898457672$ | 0.6514 | 9 |
| | Pain | $y = 0.0292243830x^2 - 118.0463500047x + 119,211.7239997480$ | 0.2411 | 8 |
| | Instability | $y = 0.0388554142x^2 - 156.6035795825x + 157,797.8280839540$ | 0.8129 | 12 |

## 3.4 Australian Reasons for Revision Data

The Australian arthroplasty registry had the reasons for revision data reported in the most similar manner to Norway among other countries examined. Table 28 below shows the number of each reason for revision of total knee arthroplasties (TKA) for each year, cumulatively [17–26]. Similarly, Table 29 below shows the number of each reason for revision of unicondylar knee arthroplasties (UKA) for each year, cumulatively [17–26].

**Table 28** Australian TKA Reasons for Revision [17–26]

| Total Reasons for Revision | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Infection | Loosening | Instability | Pain | Patellofemoral Pain | Patella Erosion | Arthrofibrosis | Fracture | Malalignment | Wear Tibial Insert | Lysis | Incorrect Sizing | Metal Related pathology | Other |
| 2023 | 6740 | 5134 | 2501 | 1798 | 1585 | 1751 | 1013 | 938 | 505 | 334 | 275 | 223 | 96 | 1233 |
| 2022 | 7089 | 5844 | 2543 | 1995 | 1878 | 1745 | 1027 | 973 | 582 | 355 | 324 | 255 | 104 | 1290 |
| 2021 | 6724 | 5667 | 2427 | 2020 | 1994 | 1655 | 989 | 893 | 584 | 351 | 340 | 253 | 113 | 1241 |
| 2020 | 6055 | 5194 | 2170 | 1846 | 1931 | 1451 | 879 | 789 | 532 | 294 | 304 | 244 | 109 | 1101 |
| 2019 | 6539 | 6805 | 2345 | 2250 | 2519 | 1645 | 990 | 860 | 592 | 521 | 541 | 295 | 354 | 1324 |
| 2018 | 5766 | 6183 | 1994 | 2024 | 2425 | 1427 | 884 | 736 | 537 | 459 | 487 | 273 | 340 | 1187 |
| 2017 | 5085 | 5620 | 1734 | 1838 | 2304 | 1218 | 787 | 649 | 487 | 391 | 428 | 260 | 327 | 1077 |
| 2016 | 4412 | 5074 | 1429 | 1694 | 2143 | 992 | 689 | 541 | 428 | 331 | 389 | 239 | 304 | 962 |
| 2015 | 3985 | 4990 | 1194 | 1535 | 2059 | 772 | 611 | 486 | 403 | 290 | 4990 | 222 | 286 | 897 |
| 2014 | 3522 | 4503 | 982 | 1382 | 1894 | 591 | 559 | 416 | 357 | 245 | 4503 | 204 | 267 | 781 |

**Table 29** Australian UKA Reasons for Revision [17–26]

| Unicondylar Reasons for Revision | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Progression of Disease | Loosening | Pain | Infection | Bearing Dislocation | Fracture | Instability | Lysis | Wear Tibial Insert | Malalignment | Other | Implant Breakage Tibial | Wear Tibial | Patellofemoral Pain |
| 2023 | 1867 | 1545 | 357 | 269 | 187 | 151 | 98 | 91 | 79 | 63 | 221 | 50 | | |
| 2022 | 1776 | 1527 | 359 | 251 | 179 | 141 | 89 | 88 | 76 | 60 | 267 | | | |
| 2021 | 1602 | 1443 | 342 | 232 | 166 | 130 | 81 | 81 | 67 | 60 | 245 | | | |
| 2020 | 1691 | 1567 | 364 | 224 | 153 | 129 | 71 | 110 | 71 | 59 | 251 | | | |
| 2019 | 2704 | 2958 | 613 | 298 | 161 | 175 | 99 | 223 | 138 | 84 | 261 | 51 | 51 | 48 |
| 2018 | 2413 | 2765 | 583 | 271 | 147 | 157 | 84 | 197 | 119 | 76 | 237 | 46 | 51 | 47 |
| 2017 | 2116 | 2566 | 559 | 246 | 132 | 145 | 74 | 177 | 103 | 69 | 311 | | 50 | |
| 2016 | 1844 | 2352 | 524 | 232 | 117 | 136 | 62 | 147 | 83 | 66 | 283 | | 48 | |
| 2015 | 1566 | 2317 | 508 | 220 | 108 | 122 | 55 | 2317 | 65 | 56 | 260 | | 47 | |
| 2014 | 1384 | 2143 | 482 | 200 | 102 | 112 | 47 | 2143 | 54 | 54 | 252 | | 44 | |

# 4 Discussion

Analyzing the data collected allows one to identify reasons for revision that differ significantly from others and identify trends between these reasons. Table 20 analyses the reasons for revision of total knee prostheses with the patellar component in a pair-wise fashion. Deep infection appears to have the highest average over the past ten years, however, only 35 out of the 105 pair-wise comparisons (33.33%) were significantly different. This suggests that not many of the reasons differ significantly for the 305 revision procedures over the past ten years. Table 23 analyses the reasons for revision of total knee prostheses without the patellar component in a pair-wise manner. Pain appears to have the highest average over the past ten years, and 86 out of 105 pair-wise comparisons (81.90%) were significantly different. Unlike previously, this suggests that many of the reasons differ significantly for the 3,983 revision procedures over the past ten years. Table 26 analyses the reasons for revision of unicondylar knee prostheses in a pair-wise method. Progression of osteoarthritis appears to have the highest average over the past ten years, with 67 out of 91 pair-wise comparisons (73.63%) differing significantly. This suggests that a majority of the reasons differ significantly for the 1,629 revision procedures over the past ten years. The Scatter plots (Figure 2 through Figure 4) and the Box & Whisker plots (Figure 5 through Figure 7) visualize the distribution of the square root stabilized data. Thus, based on data from the past ten years in Norway, deep infection, pain, and progression of osteoarthritis have the highest average for total knee prostheses with the patellar component, total knee prostheses without the patellar component, and unicondylar knee prostheses, respectively. Additionally, 81.90%, 73.63%, and 33.33% of the pair-wise comparisons differed significantly for total knee prostheses without the patellar component, unicondylar knee prostheses, and total knee prostheses with the patellar component, respectively.

The regression models give insight into the trends of the top three reasons for revision for each of the three categories of knee prostheses. As mentioned above, for engineering studies, an acceptable $R^2$ value is considered 0.7 or above [13]. The only regression models that meet this criterion are total knee prostheses with the patella deep infection at 0.8538, total knee prostheses without the patella deep infection at 0.7281, and unicondylar knee prostheses instability at 0.8129. On the other hand, clinical medicine considers an $R^2$ value of 0.15 or greater to be acceptable. In this case, only the pain models for total knee prostheses with and without the patella at 0.007 and 0.0484, respectively, did not meet this criterion. Thus, by engineering standards, only three of the regression models had what could be considered acceptable models, whereas by clinical medicine standards, seven of the models could be considered acceptable. The prediction for the year 2030 for deep infection of total knee prostheses with the patella suggests that if the current trend continues, and the regression model is correct, then the number of this reason for revision should be minimal, if not eliminated.

The Australian registry data has many similarities to the Norwegian registry [17–26]. Many of the reasons for revision are similar or could be grouped into similar reasons, such as pain, loosening, infection, instability, fracture, patella issues, malalignment, arthrofibrosis, and others. The Australian registry also divides the data between total knee arthroplasties and unicondylar arthroplasties. While the Norwegian registry categorizes the total knee arthroplasties even further into those with and without the patella, having the split between total and unicondylar is sufficient, as some countries like England that did report reasons for revision only gave a total across all arthroplasties [16]. The problem with the way in which the Australian registry reports the reasons for revision data is that for each year from 2000 to 2019, the cumulative sum was reported. Then, after 2019, a 20-year sum was reported. This contrasts with the year-to-year discrete number reported in the Norwegian registry. Logically, one would reason that the year-to-year value could be calculated by subtracting the cumulative sum from the year prior. Yet, this means that to calculate the 2020 value, the value from the year 2000 is needed. However, in the early years of the registry, including the year 2000, the total number across all types of knee arthroplasties was reported for each reason, similar to the way England reports their values now [**?**, 16]. This makes it impossible, for an outsider, to calculate the year-to-year value for 2020 and onward based on the yearly reports. Again, of the countries' annual reports that were examined, Australia reported its reasons for revision data the most similar to the way Norway reports theirs. Thus, while it is beneficial for countries to have and report their registry data, it is crucial that a uniform method of reporting data be established so that research on multinational differences can be conducted.

# 5 Conclusion

In this article, knee arthroplasty data from national registries were analyzed with a focus on Norway's registry and reasons for revision. Data on knee arthroplasties regarding demographics, the type of operations, and the reasons for operation for the ten most recently reported years were collected from Norway's national registry. The focus of this report was to analyze the reasons for revision, as this data could give insight into future development in knee prosthesis design and studies into geographical and demographic factors that may influence the data. The reasons for revision data were analyzed using the Tukey-Kramer test to identify statistically significant differences between reasons in a pair-wise manner. From this analysis, it was found that 81.90%, 73.63%, and 33.33% of the pair-wise comparisons differed significantly for total knee prostheses without the patellar component, unicondylar knee prostheses, and total knee prostheses with the patellar component, respectively. The three reasons for revision that had the highest mean for each type of knee arthroplasty were further analyzed via regression modeling to identify possible trends. $R^2$ values, offer a prediction for the year 2030 based on the formulas. By engineering standards, only three of the nine models had acceptably high enough $R^2$ values, while by clinical medicine standards, seven of the nine models are acceptable . Finally, an attempt to compare Norway's data to other countries' data was made. Of the countries investigated, Australia had the closest format to that of Norway; however, due to how the country reported its data in years past, a comparison could not be made. This necessitates a standardization of the way in which countries report their arthroplasty data in their annual reports. Only then can comparative analysis be done between countries that may give insight into differences between trends, demographics, and geographic factors.

# Conflicts of Interest

The authors declare that they have no conflict of interest.

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