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ARTHROPLASTY

No time to waste; the impact of the COVID-19 pandemic on hip, knee, and shoulder arthroplasty surgeries in the Netherlands and Denmark

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Aims

This study aimed to investigate the estimated change in primary and revision arthroplasty rate in the Netherlands and Denmark for hips, knees, and shoulders during the COVID-19 pandemic in 2020 (COVID-period). Additional points of focus included the comparison of patient characteristics and hospital type (2019 vs COVID-period), and the estimated loss of quality-adjusted life years (QALYs) and impact on waiting lists.

Methods

All hip, knee, and shoulder arthroplasties (2014 to 2020) from the Dutch Arthroplasty Register, and hip and knee arthroplasties from the Danish Hip and Knee Arthroplasty Registries, were included. The expected number of arthroplasties per month in 2020 was estimated using Poisson regression, taking into account changes in age and sex distribution of the general Dutch/Danish population over time, calculating observed/expected (O/E) ratios. Country-specific proportions of patient characteristics and hospital type were calculated per indication category (osteoarthritis/other elective/acute). Waiting list outcomes including QALYs were estimated by modelling virtual waiting lists including 0%, 5% and 10% extra capacity.

Results

During COVID-period, fewer arthroplasties were performed than expected (Netherlands: 20%; Denmark: 5%), with the lowest O/E in April. In the Netherlands, more acute indications were prioritized, resulting in more American Society of Anesthesiologists grade III to IV patients receiving surgery. In both countries, no other patient prioritization was present. Relatively more arthroplasties were performed in private hospitals. There were no clinically relevant differences in revision arthroplasties between pre-COVID and COVID-period. Estimated total health loss depending on extra capacity ranged from: 19,800 to 29,400 QALYs (Netherlands): 1,700 to 2,400 QALYs (Denmark). With no extra capacity it will take > 30 years to deplete the waiting lists.

Conclusion

The COVID-19 pandemic had an enormous negative effect on arthroplasty rates, but more in the Netherlands than Denmark. In the Netherlands, hip and shoulder patients with acute indications were prioritized. Private hospitals filled in part of the capacity gap. QALY loss due to postponed arthroplasty surgeries is considerable.

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Keywords: COVID-19 pandemic, Hip, Knee, Shoulder, Arthroplasty, Quality-adjusted life years, Waiting list

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Introduction

Although the number of hip, knee, and shoulder arthroplasty surgeries has been steadily growing in the past couple of

years,[1] the COVID-19 pandemic and the admittance of COVID-19 patients in hospitals resulted in the postponement of many arthroplasty surgeries worldwide.[2,3] With an already growing need for arthroplasty surgery in the Western world, the COVID-19 pandemic may have an additional impact on extending waiting lists for these patients.

Several countries drafted guidelines to prioritize patients with urgent indications. Especially in arthroplasty care, patients with high-priority indications, such as infection, progressive bone loss, loosening, fractures, dislocation, and tumours were prioritized.[4] However, it is currently unclear whether prioritizing based on certain patient characteristics or patient groups occurred. Patients with increased morbidity or the frail elderly might have been impacted more negatively, as some guidelines suggested operating on healthy patients first.[5,6] Although the situation of arthroplasty patients is not life-threatening, awaiting arthroplasty surgery imposes a large burden on healthcare systems, patients and their families, and thus entire societies.[7] The overall burden in terms of disability is substantial. Several studies showed that deferring joint arthroplasties is detrimental with regard to pain, joint and physical function after the surgery, mental health, and results in substantial loss of quality-adjusted life years (QALYs).[8-14] Clement et al[15] showed that over one-third of hip and one-quarter of knee patients awaiting total hip or knee arthroplasty surgery during the COVID-19 pandemic are (according to the EuroQoL five-dimension questionnaire (EQ-5D)) in a disease state "worse than death", which is nearly twice the number compared to pre-COVID-19.

In both the Netherlands and Denmark, performance of arthroplasty surgeries has been affected due to the COVID-19 pandemic. However, decreases in surgical arthroplasty rates, while taking into account the expected growth in the number of arthroplasties, are unavailable and the impact from a societal perspective is unknown. Additionally, literature on whether prioritization actually occurred, and information on the extent of loss of QALYs due to postponement of surgeries, is scarce.

This study has several aims: Firstly, we estimated the change in primary and revision arthroplasty surgery rate in the Netherlands and Denmark during the COVID-19 pandemic in 2020 (COVID-period). Secondly, we investigated whether prioritization occurred by comparing distributions of patient characteristics and hospital type between 2019 and the COVID-period. Lastly, we investigated the impact of the COVID-19 pandemic on disease burden by estimating the loss of QALYs within the primary arthroplasty population due to the postponement of arthroplasty surgeries, and the impact on the waiting lists and time needed to combat the backlog.

Methods

This study was declared exempt by the Medical Research Ethics Committee Leiden Den Haag Delft, as they were of opinion that the Medical Research Involving Human Subjects act (Dutch abbreviation: WMO) did not apply to this study (G21.124). According to Danish law, an ethics committee approval is not required for registry-based studies. This study was reported to the Danish Data Protection Agency through registration at Aarhus University (record number: AU-2016-051-000001, sequential number 880). Additionally, both the Dutch Arthroplasty Register and the Danish Hip and Knee Arthroplasty Registries approved the use of their data.

Data sources. This population-based cohort study used different data sources. Primary and revision arthroplasties and their characteristics were collected from the Dutch Arthroplasty Register (Landelijke Registratie Orthopedische Implantaten (LROI)); hip/knee/shoulder arthroplasties) and the Danish Hip and Knee Arthroplasty registries (DHR/DKR; no information regarding shoulder arthroplasties available). These registries have a high completeness (LROI primary arthroplasties: 99%, revision arthroplasties: 98%; DHR completeness 2020; primary arthroplasties: 95%, revision arthroplasties: 87%; DKR completeness 2020; primary and revision arthroplasties: 95%).[16,17] Data on the entire general Dutch and Danish populations were collected from Netherlands Statistics and Statistics Denmark. Data regarding age and sex composition changes in the general population between 2014 to 2020, as well as mortality numbers during this time, were extracted from these registries.

Study population. All hip, knee, and shoulder arthroplasties between 2014 and 2020 were extracted from the LROI/DHR/DKR, including both unilateral and bilateral procedures. Arthroplasties from January 2014 until March 2020 were categorized as 'pre-COVID', while arthroplasties between March 2020 and December 2020 were categorized as 'COVID-period'. The lockdown periods in the Netherlands were 23 March 2020 to 11 May 2020 (first lockdown) and 13 October to December 2020 (second lockdown). In Denmark, the following lockdown periods were defined: 11 March 2020 to 15 April 2020 (first lockdown) and 16 December to December 2020 (second lockdown).

Demographic details. We gathered the following demographic information: age at the time of procedure (< 40 up to ≥ 105 years old, in five-year age categories), sex, BMI (underweight < 18.5 kg/m^2, normal weight 18.5 to 25 kg/m^2, overweight 25 to 30 kg/m^2, obese 30 to 40 kg/m^2, morbidly obese > 40 kg/m^2), American Society of Anesthesiologists physical function (ASA) grade (I – normal health to IV – severe systemic disease that is a constant threat to life)[18] (not available in DKR), Charnley

classification (A/B/C),[19] Walch score (A/B/C; only for Dutch shoulder arthroplasties),[20] and indication (osteoarthritis (OA)/other elective indications (rheumatoid or inflammatory arthritis, osteonecrosis, post-Perthes' (hip), dysplasia (hip), cuff arthropathy (shoulder), irreparable cuff rupture (shoulder), other elective indications)/acute indications (fractures, tumours, post-traumatic)).

Arthroplasty. The following arthroplasty-related information was collected: date of procedure, type of procedure (primary/revision), type of hospital (general hospital/private or orthopaedic focus clinic), and fixation method (cemented/uncemented/hybrid).

Waiting list outcomes. Increased waiting time and QALY loss due to COVID-19 were estimated by modelling a virtual waiting list of patients who would otherwise already have had their primary arthroplasty.[21] Patients arrive at this virtual waiting list according to the expected numbers, as estimated from the pre-COVID-19 period with extrapolated time trend. Patients arriving with an acute indication are operated on immediately; other elective patients are operated on in order of arrival, depending on the available operating capacity. In 2020, the available operating capacity per country, joint, indication, and month is assumed equal to the actually observed number of operations in 2020. For 2021, only the total number of operations per country and joint was available, and we assumed the distribution over indications and months equal to 2020. For the first three months of 2022, available operating capacity was assumed equal to the first quarter of 2021. Starting from April 2022, we modelled three different scenarios to see how much additional capacity is needed to clear the backlog of patients that have arisen. The base-case scenario assumed 10% additional capacity for arthroplasty surgeries, as compared to the pre-COVID-19 trend. We also evaluated less optimistic scenarios with 5% and 0% additional capacity. While on the virtual waiting list, patients are assumed to die according to general Dutch and Danish mortality.

QALY loss was estimated by assuming that patients forgo the health benefit from arthroplasty for the duration they are on the virtual waiting list. This health benefit was estimated numerically by the difference in EQ-5D utility prior to arthroplasty compared to one year after arthroplasty, which was available for Dutch patients operated on from 2015 to 2019.[22] Due to lack of Danish EQ-5D data, we estimated the Danish arthroplasty benefit by applying the Danish EQ-5D tariff to the Dutch patient questionnaires.[23] QALY loss per patient was then calculated as the country-specific benefit in EQ-5D utility from arthroplasty multiplied by the average time on the virtual waiting list.

Statistical analysis. All analyses were stratified by country and joint (hip/knee/shoulder). Means with standard deviations (SDs) or frequencies with proportions were used to describe the different populations at baseline. First, we estimated the change in surgery rate by comparing the number of observed arthroplasties in 2020 per month with the expected number of arthroplasties. We used Poisson regression to estimate individual rates of primary hip, knee, and shoulder arthroplasty and revision within three months. The expected number of arthroplasties per month was based on the number of arthroplasties between 2014 and 2019, and change in composition of the general populations (age (< 40 and up to ≥ 105 years old, in five-year age categories) and sex). The calculated observed/expected (O/E) rates were then used to predict the total expected incidence of hip, knee, and shoulder arthroplasties in 2020. As revision surgery within the first three months is dependent on primary arthroplasty surgery, these extrapolations were based on the incidence rates of revision from the year 2014 to 2019.

We used descriptive statistics to investigate if patient characteristics and hospital type for arthroplasty surgery were different between the pre-COVID-19 period and COVID-period. Here, we compared the distribution of proportion per characteristic within 2019 (these proportions were assumed to be a closer representation of the 2020 proportions than those of the prior years) with the proportions per characteristic per month in 2020, stratified based on indication (OA/other elective/acute). All analyses were performed using R (R Foundation for Statistical Computing, Austria).

Results

Observed and expected primary arthroplasties during 2020 in the Netherlands and Denmark. During 2020, at least 40,791 hip arthroplasties were expected in the Netherlands, but 33,664 arthroplasties were actually performed. As such, 7,127 (18%) surgeries were not observed. In Denmark, 618 (6%) of the 11,196 expected hip arthroplasties in 2020 were not performed. In both populations the largest decrease in O/E ratio was observed in April (Netherlands: 0.25; Denmark: 0.30) (Figure 1a). For knee arthroplasties in the Netherlands, a total of 31,772 were expected in 2020, but 24,445 knee arthroplasties were performed, resulting in 7,327 (23%) unperformed knee arthroplasties. In Denmark, 372 (4%) of the expected 9,963 knee arthroplasties were not performed. Similar to the hip arthroplasty population, the largest decrease in O/E ratio was seen in April (Netherlands: 0.03; Denmark: 0.24) (Figure 1b). In the Netherlands, 3,603 shoulder arthroplasties were expected in 2020 of which 809 (22%) shoulder arthroplasties were not performed. Again, the largest decrease in O/E ratio was found in April (0.23) (Figure 1c).

Observed and expected revision arthroplasties during 2020 in the Netherlands and Denmark. In the Netherlands, overall the expected and observed proportions of hip, knee, and shoulder revisions within three months in 2020 were relatively similar, namely 1.3%

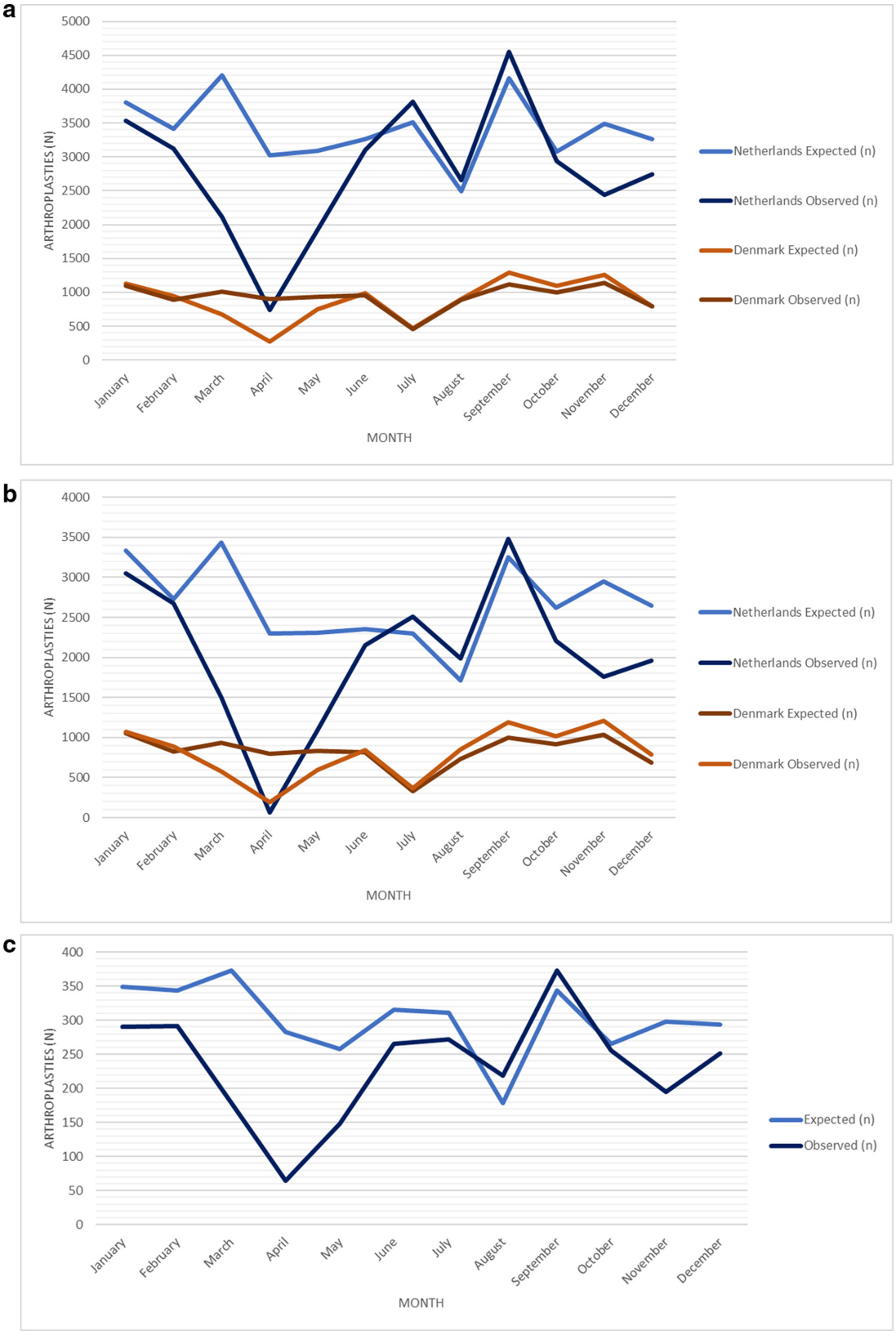

Fig. 1

a) Observed versus expected number of primary hip arthroplasties in 2020 in the Netherlands and Denmark. b) Observed versus expected number of primary knee arthroplasties in 2020 in the Netherlands and Denmark. c) Observed versus expected number of primary shoulder arthroplasties in 2020 in the Netherlands.

expected versus 1.3% observed, 0.6 versus 0.5% and 1.0% versus 1.2%, respectively (Supplementary Figure a to c). In Denmark, the observed proportion of hip revisions within three months in 2020 was slightly lower compared to the expected proportion (observed: 1.5% vs expected: 1.8%), with almost similar proportions for knee revisions (observed: 0.9% versus expected: 0.8%) (Supplementary Figure a to c).

Differences in patient and primary arthroplasty characteristics. We found several differences in patient characteristics between the pre-COVID-19 and COVID-period population. In the Netherlands, the proportion of patients undergoing hip and shoulder surgery due to osteoarthritis decreased during the COVID-period (hip: 74% E/68% O; shoulder: 44% E/42% O) (Table I). Overall, more patients were operated with ASA III to IV, and more uncemented and hybrid knee and shoulder arthroplasties were inserted in the COVID-period. In Denmark, results were rather similar to the Dutch population (Table I). Slightly more ASA III to IV patients received hip surgery in the COVID-period compared to the pre-COVID-19 period. More uncemented knee arthroplasties were performed in the COVID-period. In both countries, more patients received surgery in private hospitals (i.e. focus clinics without intensive care unit) in COVID-period.

In both the Netherlands and Denmark, no differences were found regarding patient characteristics within the different indication categories (OA/other elective/acute) (Supplementary Tables i to iii). The only difference observed was a shift in hospital type during the COVID-period towards more OA procedures performed in private hospitals.

Differences in patient and revision arthroplasty characteristics. In the Netherlands, more ASA III to IV hip (40% E/49% O) and knee (27% E/42% O) patients and more ASA II shoulder patients (52% E/60% O) received revision surgery within three months. Additionally, more hip patients with an acute indication for primary arthroplasty received revision surgery during the COVID-period (hip: 25% E/7% O) (Table II). Infection was more often the reason for revision during COVID-period (hip: 40% E/46% O; knee: 60% E/62% O; shoulder: 24% E/32% O). Similar to primary arthroplasties, a shift was seen to private hospitals to perform revision arthroplasties during COVID-period (hip: 4% E/7% O; knee: 9% E/14% O; shoulder: 4% E/8% O). No differences were found in the revision population of Denmark when comparing the pre-COVID-19 and COVID-period, apart from the proportion of women receiving knee revision surgery (pre-COVID-19: 52% E/44% O).

Waiting list outcomes. Figures 2a and 2b show the evolution of the virtual waiting lists due to COVID-19 assuming 10%, 5%, and 0% extra capacity (regardless of whether these patients are actually registered or not; additional insight into these models is provided in Supplementary Figure b). The waiting list outcome numbers are depicted in Table III. Assuming 10% extra capacity from April 2022 onwards, additional waiting times due to COVID-19 will last until 2025 or 2026 in the Netherlands and until 2023 or 2024 in Denmark (Table III). Average additional waiting times over this entire period are then estimated at 2.4 months in the Netherlands and 1.1 months in Denmark (and about double that time by the end of 2021). The mean forgone utility gain of arthroplasty was 0.24 and 0.26, respectively, resulting in a mean QALY loss of 0.049 (SD 0.031) and 0.024 (SD 0.014) per patient, respectively. When assuming 10% extra capacity, total QALY loss was estimated at 19,800 in the Netherlands and 1,500 in Denmark. Assuming a less optimistic scenarios with 5% additional post-COVID-19 capacity, the backlog will last until 2027 to 2029 in the Netherlands and until 2024 to 2026 in Denmark. If no additional post-COVID-19 capacity is available, the backlog will last for more than 30 years to come (> 2050).

Discussion

This study evaluated the impact of the COVID-19 pandemic on arthroplasty care in the Netherlands and Denmark. We showed that the impact of the pandemic in 2020 on primary arthroplasty surgeries was larger in the Netherlands compared to Denmark. In the Netherlands, 20% fewer primary arthroplasties than expected were performed, while in Denmark a 5% decrease was seen. The largest decrease was seen in the primary knee arthroplasty population in the Netherlands (23%).

During the pandemic, proportionally more acute primary hip and shoulder arthroplasties were performed, whereas the OA arthroplasty numbers dropped. No prioritizing took place based on age or patient comorbidity (ASA and Charnley) scores within each of the surgical indication categories (OA, other elective and acute surgery). However, within the total population in the Netherlands, an increase in ASA III to IV patients was observed. This was due to the prioritization of more acute non-OA indications, such as fractures and bone tumours (primary and metastases). We found an increase in uncemented primary knee arthroplasties during the COVID-period, which are generally (pre-COVID-19) performed in approximately 10% of the cases. No differences were found in fixation method in the primary hip and shoulder arthroplasty population.

Within the hip and knee revision populations, we found a shift towards a more comorbid population (i.e. more ASA III to IV patients) during the COVID-period. Conversely, patients in need of shoulder revision arthroplasty during the COVID-period were more often less comorbid (ASA II). Revision surgery for periprosthetic joint infection was relatively more common during the COVID-period, possibly due to the urgency of this indication.With regard to the delivery of care, a shift occurred

Table I. Patient and prosthesis characteristics primary arthroplasty patients.

Characteristic	The Netherlands						Denmark			
	Hip		Knee		Shoulder		Hip		Knee	
	Pre-COVID-19* (n = 223,198)	COVID-19 (n = 25,148)	Pre-COVID-19* (n = 179,726)	COVID-19 (n = 17,161)	Pre-COVID-19* (n = 17,216)	COVID-19 (n = 2,050)	Pre-COVID-19* (n = 62,648)	COVID-19 (n = 14,993)	Pre-COVID-19* (n = 52,780)	COVID-19 (n = 13,484)
Age, yrs; n (%)										
< 40	2,103 (0.9)	253 (1.0)	368 (0.2)	32 (0.2)	102 (0.6)	5 (0.2)	865 (1.4)	216 (1.4)	Masked†	37 (0.3)
40 to 45	1,800 (0.8)	182 (0.7)	867 (0.5)	44 (0.3)	96 (0.6)	6 (0.3)	902 (1.4)	177 (1.2)	414 (0.8)	92 (0.7)
45 to 50	4,732 (2.1)	442 (1.8)	3,324 (1.8)	259 (1.5)	251 (1.5)	26 (1.3)	1,899 (3.0)	476 (3.2)	1,386 (2.6)	300 (2.2)
50 to 55	8,909 (4.0)	995 (4.0)	9,851 (5.5)	926 (5.4	496 (2.9)	44 (2.1)	3,446 (5.5)	894 (6.0)	3,464 (6.6)	874 (6.5)
55 to 60	14,902 (6.7)	1,688 (6.7)	18,848 (10.5)	1,921 (11.2)	953 (5.5)	119 (5.8)	4,874 (7.8)	1,347 (9.0)	5,432 (10.3)	1,599 (11.9)
60 to 65	24,853 (11.1)	2,684 (10.7)	28,569 (15.9)	2,763 (16.1)	1,718 (10.0)	215 (10.5)	7,184 (11.5)	1,615 (10.8)	7,439 (14.1)	2,071 (15.4)
65 to 70	36,593 (16.4)	3,668 (14.6)	36,204 (20.1)	3,335 (19.4)	2,842 (16.5)	348 (17.0)	10,550 (16.8)	2,235 (14.9)	9,737 (18.4)	2,197 (16.3)
70 to 75	41,432 (18.6)	4,853 (19.3)	35,990 (20.0)	3,722 (21.7)	3,810 (22.1)	513 (25.0)	12,670 (20.2)	2,841 (18.9)	11,263 (21.3)	2,689 (19.9)
75 to 80	36,617 (16.4)	4,174 (16.6)	26,915 (15.0)	2,535 (14.8)	3,720 (21.6)	405 (19.8)	10,229 (16.3)	2,649 (17.7)	8,166 (15.5)	2,188 (16.2)
80 to 85	27,842 (12.5)	3,237 (12.9)	14,234 (7.9)	1,244 (7.2)	2,344 (13.6)	269 (13.1)	6,405 (10.2)	1,590 (10.6)	3,993 (7.6)	1,104 (8.2)
85 to 90	15,860 (7.1)	2,018 (8.0)	4,081 (2.3)	341 (2.0)	779 (4.5)	89 (4.3)	2,691 (4.3)	694 (4.6)	1,133 (2.1)	299 (2.2)
90 to 95	6,224 (2.8)	761 (3.0)	441 (0.2)	37 (0.2)	100 (0.6)	11 (0.5)	796 (1.3)	210 (1.4)	143 (0.3)	33 (0.2)
95 to 100	1,224 (0.5)	176 (0.7)	29 (0.0)	1 (0.0)	5 (0.0)	N/A	121 (0.2)	45 (0.3)	< 5 (Masked)	< 5 (Masked)
100 to 105	105 (0.0)	17 (0.1)	4 (0.0)	1 (0.0)	N/A	N/A	16 (0.0)	< 5 (Masked)	N/A	Masked
≥ 105	2 (0.0)	N/A	1 (0.0)	N/A	N/A	N/A	N/A	Masked	N/A	Masked
Female, n (%)	146,067 (65.4)	16,126 (64.1)	113,096 (62.9)	10,323 (60.2)	12,831 (74.5)	1,532 (74.4)	35,759 (57.1)	8,488 (56.6)	30,377 (57.6)	7,608 (56.4)
BMI, n (%)‡										
Underweight	3,508 (1.6)	411 (1.6)	274 (0.2)	23 (0.1)	158 (0.9)	14 (0.7)	562 (0.9)	251 (1.7)	161 (0.3)	34 (0.3)
Normal weight	78,346 (35.1)	9,415 (37.4)	30,068 (16.7)	3,156 (18.4)	4,623 (26.9)	571 (27.9)	12,568 (20.1)	4,963 (33.1)	10,114 (19.2)	2,458 (18.2)
Overweight	86,741 (38.9)	9,318 (37.1)	72,946 (40.6)	7,037 (41.0)	6,576 (38.2)	761 (37.1)	14,276 (22.8)	5,699 (38.0)	20,388 (38.6)	5,216 (38.7)
Obese	44,599 (20.0)	4,528 (18.0)	66,834 (37.2)	6,161 (35.9)	4,963 (28.8)	566 (27.6)	8,495 (13.6)	3,518 (23.5)	18,896 (35.8)	5,034 (37.3)
Morbidly obese	2,295 (1.0)	239 (1.0)	6,110 (3.4)	477 (2.8)	513 (3.0)	62 (3.0)	752 (1.2)	295 (2.0)	2,895 (5.5)	726 (5.4)
Missing	7,709 (3.5)	1,237 (4.9)	3,450 (1.9)	304 (1.8)	383 (2.2)	76 (3.7)	25,995 (41.5)	267 (1.8)	326 (0.6)	16 (0.1)
ASA grade, n (%)§										
I	33,210 (14.9)	3,290 (13.1)	25,246 (14.0)	2,317 (13.5)	1,383 (8.0)	140 (6.8)	7,227 (20.3)	2,620 (17.9)		
II	131,471 (58.9)	13,600 (54.1)	120,632 (67.1)	11,038 (64.3)	10,314 (59.9)	1,207 (58.9)	21,581 (60.6)	8,891 (60.7)		
III to IV	57,685 (25.8)	8,206 (32.6)	33,312 (18.5)	3,779 (22.0)	5,248 (30.5)	697 (34.0)	6,794 (19.1)	3,146 (21.5)		
Charnley classification, n (%)¶										
A	90,275 (40.4)	8,404 (33.4)	75,620 (42.1)	6,768 (39.4)			38,581 (61.6)	9,528 (63.5)	21,948 (41.6)	6,096 (45.2)
B	95,011 (42.6)	10,299 (40.9)	94,800 (52.7)	9,665 (56.3)			22,818 (36.4)	5,316 (35.5)	11,972 (22.7)	2,962 (22.0)
C	5,731 (2.6)	634 (2.5)	5,312 (3.0)	538 (3.1)			1,041 (1.7)	120 (0.8)	18,691 (35.4)	4,411 (32.7)
Walch score, n (%)										
A1					7,869 (45.7	784 (38.2)				

Continued

Table I. Continued

Characteristic	The Netherlands						Denmark			
	Hip		Knee		Shoulder		Hip		Knee	
	Pre-COVID-19* (n = 223,198)	COVID-19 (n = 25,148)	Pre-COVID-19* (n = 179,726)	COVID-19 (n = 17,161)	Pre-COVID-19* (n = 17,216)	COVID-19 (n = 2,050)	Pre-COVID-19* (n = 62,648)	COVID-19 (n = 14,993)	Pre-COVID-19* (n = 52,780)	COVID-19 (n = 13,484)
A2					3,732 (21.7)	465 (22.7)				
B1					1,730 (10.0)	157 (7.7)				
B2					876 (5.1)	131 (6.4)				
B3					260 (1.5)	49 (2.4)				
C					160 (0.9)	30 (1.5)				
Indication, n (%)										
OA	164,493 (73.7)	17,015 (67.7)	172,806 (96.1)	16,510 (96.2)	7,501 (43.6)	866 (42.2)	51,364 (82.0)	12.281 (81.9)	44,760 (84.8)	11,302 (83.8)
Other elective	11,740 (5.3)	1,265 (5.0)	3,485 (1.9)	343 (2.0)	5,552 (32.2)	579 (28.2)	4,802 (7.7)	1,215 (8.1)	7,465 (14.1)	2,057 (15.3)
Acute	44,766 (20.1)	6,566 (26.1)	2,627 (1.5)	245 (1.4)	4,055 (23.6)	597 (29.1)	6,347 (10.1)	1,487 (9.9)	555 (1.1)	125 (0.9)
Missing							135 (0.2)	10 (0.1)	N/A	N/A
Type of hospital, n (%)										
Public	208,864 (93.6)	21,809 (86.7)	156,210 (86.9)	13,414 (78.1)	16,336 (94.9)	1,884 (91.9)	58,707 (93.7)	11,861 (79.1)	48,854 (92.6)	10,105 (74.9)
Private	14,334 (6.4)	3,339 (13.3)	23,516 (13.1)	3,747 (21.8)	880 (5.1)	166 (8.1)	3,941 (6.3)	3,132 (20.9)	3,926 (7.4)	3,379 (25.1)
Fixation, n (%)										
Cemented	72,184 (32.3)	8,268 (32.9)	156,631 (87.1)	14,065 (82.0)	1,681 (9.8)	99 (4.8)	5,297 (8.5)	1,227 (8.2)	30,313 (57.4)	6,465 (47.9)
Uncemented	129,817 (58.2)	14,568 (57.9)	16,643 (9.3)	2,520 (14.7)	10,127 (58.8)	1,242 (60.6)	43,485 (69.4)	10,182 (67.9)	9,824 (18.6)	4,347 (32.2)
Hybrid	21,197 (9.5)	2,312 (9.2)	6,452 (3.6)	576 (3.3)	1,012 (31.4)	709 (65.4)	13,042 (20.8)	3,389 (22.6)	11,858 (22.5)	2,459 (18.2)
Other/unknown	N/A	N/A	N/A	N/A	N/A	N/A	15 (0.0)	0 (0.0)	785 (1.5)	213 (1.6)
Missing	N/A	N/A	N/A	N/A	N/A	N/A	809 (1.3)	195 (1.3)	N/A	N/A
Mean EQ-5D (SD)	0.533 (0.192)	0.522 (0.214)	0.566 (0.184)	0.561 (0.200)	0.527 (0.213)	0.520 (0.239)				

*2014 to March 2020.
†The DHR/DKR are not allowed to specify numbers < 5, for reasons of patient privacy.
‡BMI available in DHR/DKR from 2016 onwards.
§No ASA grade available for knee arthroplasty patients in Denmark.
¶No Charnley classification available for knee patients in Denmark.
ASA, American Society of Anesthesiologists; EQ-5D, EuroQol-five-dimension questionnaire; N/A, not applicable; OA, osteoarthritis.

Table II. Patient and prosthesis characteristics revision arthroplasty patients.

Characteristic	The Netherlands						Denmark			
	Hip		Knee		Shoulder		Hip		Knee	
	Pre-COVID-19* (n = 2,979)	COVID-19 (n = 339)	Pre-COVID-19* (n = 958)	COVID-19 (n = 91)	Pre-COVID-19* (n = 193)	COVID-19 (n = 25)	Pre-COVID-19* (n = 1,225)	COVID-19 (n = 134)	Pre-COVID-19* (n = 410)	COVID-19 (n = 66)
Age, yrs; n (%)										
< 40	26 (0.9)	3 (0.9)	4 (0.4)	N/A	1 (0.5)	N/A	Masked	< 5 (.)	N/A	N/A
40 to 45	23 (0.8)	2 (0.6)	6 (0.6)	N/A	1 (0.5)	N/A	12 (1.0)	< 5 (.)	< 5 (.)	0 (0.0)
45 to 50	59 (2.0)	3 (0.9)	14 (1.5)	1 (1.1)	2 (1.0)	1 (4.0)	30 (2.4)	< 5 (.)	8 (2.0)	< 5 (.)
50 to 55	98 (3.3)	10 (2.9)	49 (5.1)	4 (4.4)	2 (1.0)	1 (4.0)	50 (4.1)	< 5 (.)	19 (4.6)	< 5 (.)
55 to 60	162 (5.4)	27 (8.0)	83 (8.7)	11 (12.1)	10 (5.2)	3 (12.0)	90 (7.3)	6 (4.5)	31 (7.6)	7 (10.6)
60 to 65	300 (10.1)	36 (10.6)	124 (12.90	14 (15.4)	29 (15.0)	3 (12.0)	125 (10.2)	13 (9.7)	45 (11.0)	< 5 (.)
65 to 70	473 (159)	49 (14.5)	177 (18.5)	21 (23.1)	34 (17.6)	2 (8.0)	208 (17.0)	15 (11.2)	66 (16.1)	8 (12.1)
70 to 75	566 (19.0)	73 (21.5)	167 (17.4)	18 (19.8)	51 (26.4)	8 (32.0)	235 (19.2)	34 (25.4)	97 (23.7)	18 (27.3)
75 to 80	521 (17.5)	63 (18.6)	178 (18.6)	7 (7.7)	33 (17.1)	6 (24.0)	232 (18.9)	25 (18.7)	80 (19.5)	15 (22.7)
80 to 85	400 (13.4)	40 (11.8)	113 (11.8)	12 (13.2)	24 (12.4)	N/A	148 (12.1)	21 (15.7)	43 (10.5)	8 (12.1)
85 to 90	246 (8.3)	27 (8.0)	38 (4.0)	3 (3.3)	6 (3.1)	1 (4.0)	60 (4.9)	7 (5.2)	Masked	< 5 (.)
90 to 95	88 (3.0)	6 (1.8)	5 (0.5)	N/A	N/A	N/A	21 (1.7)	< 5 (.)	N/A	N/A
95 to 100	16 (0.5)	N/A	N/A	N/A	N/A	N/A	< 5 (.)	< 5 (.)	N/A	N/A
100 to 105	1 (0.0)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
≥ 105	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Female, n (%)	1,783 (59.9)	196 (57.8)	501 (52.3)	46 (50.5)	104 (53.9)	13 (52.0)	701 (57.2)	81 (60.4)	215 (52.4)	29 (43.9)
BMI, n (%)†										
Underweight	48 (1.6)	4 (1.2)	4 (0.4)	N/A	6 (3.1)	N/A	8 (0.7)	5 (3.7)	< 5 (.)	Masked
Normal weight	908 (30.5)	108 (31.9)	177 (18.5)	17 (18.7)	32 (16.6)	6 (24.0)	208 (17.0)	45 (33.6)	78 (19.0)	12 (18.2)
Overweight	1,103 (37.0)	109 (32.2)	354 (37.0)	32 (35.2)	71 (36.8)	13 (52.0)	251 (20.5)	49 (36.6)	143 (34.9)	17 (25.8)
Obese	755 (25.3)	90 (26.5)	340 (35.5)	36 (39.6)	70 (36.3)	4 (16.0)	216 (17.6)	29 (21.6)	135 (32.9)	35 (53.0)
Morbidly obese	81 (2.7)	10 (2.9)	57 (5.9)	4 (4.4)	7 (3.6)	2 (8.0)	33 (2.7)	< 5 (.)	Masked	< 5 (.)
Missing	84 (2.8)	18 (5.3)	26 (2.7)	2 (2.2)	7 (3.6)	N/A	509 (41.6)	< 5 (.)	13 (3.2)	0 (0.0)
ASA grade, n (%)‡										
I	232 (7.8)	17 (5.0)	110 (11.5)	8 (8.8)	8 (4.1)	2 (8.0)	56 (7.7)	7 (5.3)		
II	1,527 (51.3)	145 (42.8)	580 (60.5)	45 (49.5)	100 (51.8)	15 (60.0)	416 (57.5)	74 (56.5)		
III-IV	1,187 (39.8)	167 (49.3)	258 (26.9)	38 (41.8)	79 (40.9)	8 (32.0)	252 (34.8)	50 (38.2)		
Indication primary arthroplasty, n (%)										
OA	2,019 (67.8)	190 (56.0)	898 (93.7)	85 (93.4)	46 (23.8)	6 (24.0)	1,047 (77.0)	102 (76.1)	366 (89.3)	61 (92.4)
Other elective indication	211 (7.1)	24 (7.1)	18 (1.9)	2 (2.2)	60 (34.8)	9 (36.0)	Masked	Masked	38 (9.3)	5 (7.6)
Acute indication	749 (25.1)	125 (36.9)	57 (4.4)	4 (4.4)	76 (39.3)	10 (40.0)	202 (14.9)	18 (13.4)	6 (1.5)	N/A

Continued

Table II. Continued

Characteristic	The Netherlands						Denmark			
	Hip		Knee		Shoulder		Hip		Knee	
	Pre-COVID-19* (n = 2,979)	COVID-19 (n = 339)	Pre-COVID-19* (n = 958)	COVID-19 (n = 91)	Pre-COVID-19* (n = 193)	COVID-19 (n = 25)	Pre-COVID-19* (n = 1,225)	COVID-19 (n = 134)	Pre-COVID-19* (n = 410)	COVID-19 (n = 66)
Reason revision, n (%)§										
Aseptic loosening	369 (12.4)	37 (10.9)	67 (7.0)	5 (5.5)	27 (14.0)	1 (4.0)	Masked	< 5 (.)	19 (4.6)	6 (9.1)
Infection	1,176 (39.5)	155 (45.7)	574 (59.9)	56 (61.5)	47 (24.3)	8 (32.0)	484 (39.5)	50 (37.3)	245 (59.8)	36 (54.5)
Fracture	609 (20.4)	61 (18.0)	89 (9.3)	7 (7.7)	12 (6.2)	N/A	282 (23.0)	36 (26.9)	N/A	N/A
Dislocation	824 (27.7)	79 (23.0)	23 (2.4)	1 (1.1)	N/A	N/A	308 (25.1)	29 (21.6)	N/A	N/A
Pain only	N/A	N/A	7 (0.7)	N/A	N/A	N/A	6 (0.5)	0 (0.0)	6 (1.5)	N/A
Other reason	388 (13.0)	75 (22.1)	307 (32.0)	27 (29.7)	130 (67.4)	16 (64.0)	91 (7.4)	14 (10.4)	11 (2.7)	N/A
Missing	N/A	N/A	N/A	N/A	N/A	N/A	< 5 (.)	< 5 (.)	129 (31.5)	24 (36.4)
Type of hospital, n (%)										
Public	2,871 (96.4)	315 (92.9)	958 (91.3)	78 (85.7)	186 (96.4)	23 (92.0)	1,219 (99.5)	132 (98.5)	408 (99.5)	66 (100.0)
Private	108 (3.6)	24 (7.1)	91 (8.7)	13 (14.3)	7 (3.6)	2 (8.0)	6 (0.5)	Masked	2 (0.5)	N/A

*2014 to March 2020.
†BMI available in DHR/DKR from 2016 onwards.
‡No ASA grade available for knee arthroplasty patients in Denmark.
§In the LROI it is possible to mark multiple reasons for revision, therefore the sum of proportions exceeds 100%.
ASA, American Society of Anesthesiologists; N/A, not applicable; OA, osteoarthritis.

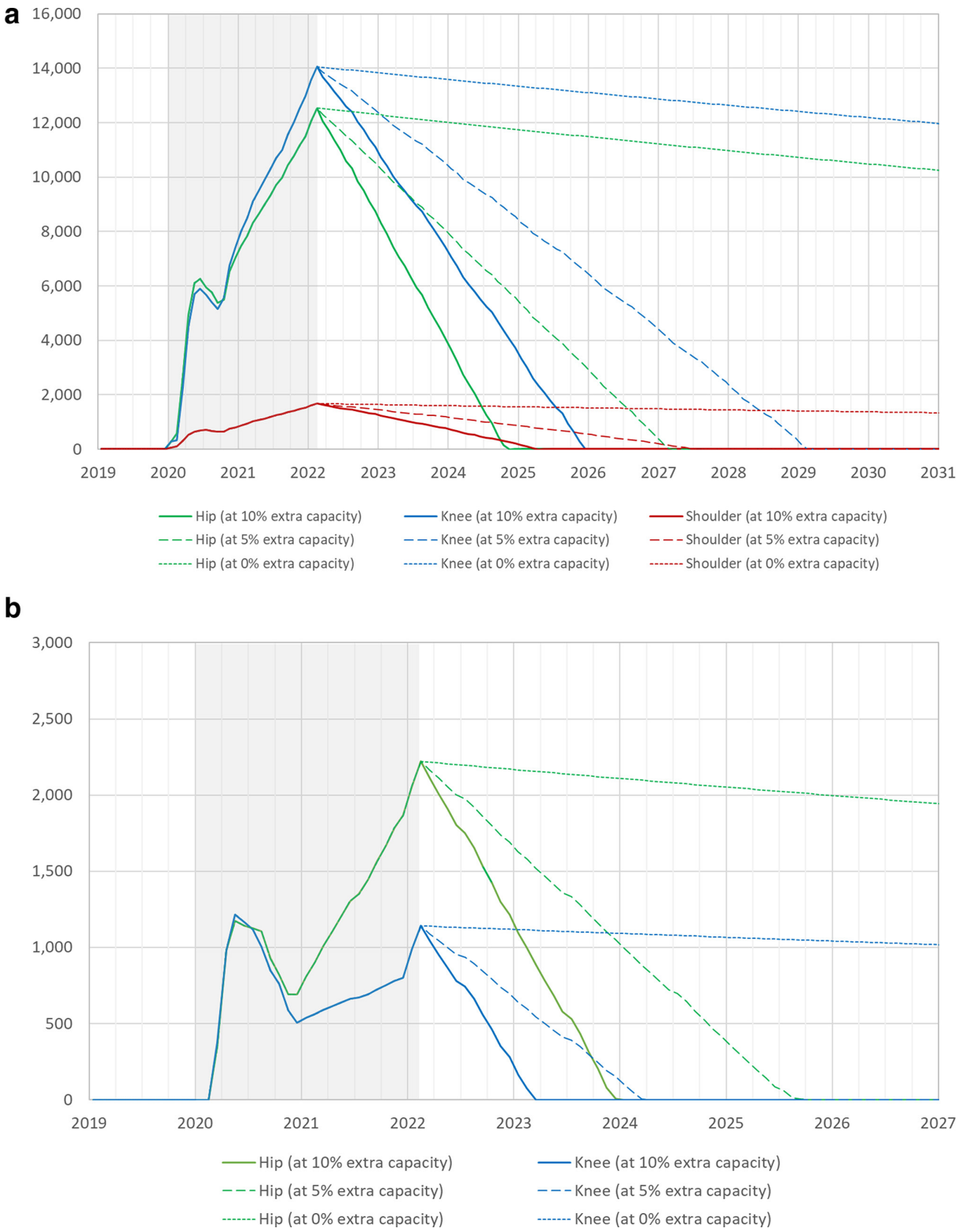

Fig. 2

a) Dutch virtual waiting lists due to COVID-19 by joint, depending on the post-COVID-19 extra capacity (0%, 5%, or 10%). b) Danish virtual waiting lists due to COVID-19 by joint, depending on the post-COVID-19 extra capacity (0%, 5%, or 10%).

Table III. Waiting list outcomes among elective patients assuming 10% additional capacity, 5% additional capacity, and 0% additional capacity.

Variable	End of virtual waiting list	Patients involved, n	Mean additional waiting time per patient, mths (SD)	Average QALY loss per patient	Total QALY loss
10% additional capacity					
The Netherlands					
Hips	2025	173,000	2.3 (1.4)	0.052 (0.032)	9,000
Knees	2026	209,000	2.5 (1.6)	0.047 (0.031)	9,900
Shoulders	2025	19,000	3.0 (2.0)	0.047 (0.031)	900
Total	2026	401,000	2.4 (1.5)	0.049 (0.031)	19,800
Denmark					
Hips	2024	42,000	1.3 (0.8)	0.025 (0.015)	1,000
Knees	2023	32,000	0.8 (0.5)	0.014 (0.011)	500
Total	2024	74,000	1.1 (0.7)	0.020 (0.014)	1,500
5% additional capacity					
The Netherlands					
Hips	2027	269,000	2.1 (1.4)	0.049 (0.032)	13,100
Knees	2029	335,000	2.4 (1.6)	0.045 (0.030)	15,000
Shoulders	2027	30,000	2.6 (1.9)	0.043 (0.031)	1,300
Total	2029	634,000	2.3 (1.5)	0.046 (0.031)	29,400
Denmark					
Hips	2026	62,000	1.2 (0.8)	0.024 (0.015)	1,500
Knees	2024	43,000	0.8 (0.5)	0.014 (0.010)	600
Total	2026	105,000	1.0 (0.7)	0.020 (0.015)	2,100
0% additional capacity*					
The Netherlands					
Hips	> 2050	1,739,000	1.9 (1.0)	0.045 (0.022)	77,700
Knees	> 2050	1,604,000	2.5 (1.1)	0.047 (0.022)	74,900
Shoulders	> 2050	573,000	0.8 (1.1)	0.012 (0.017)	7,000
Total	> 2050	3,916,000	2.0 (1.2)	0.041 (0.025)	159,000
Denmark					
Hips	> 2050	451,000	1.2 (1.6)	0.025 (0.011)	11,100
Knees	> 2050	445,000	0.7 (0.3)	0.013 (0.007)	5,600
Total	> 2050	896,000	1.0 (0.5)	0.019 (0.011)	16,700

*Outcome only up to 2050; waiting lists go beyond 2050.
QALY, quality-adjusted life years.

towards private hospitals for both primary and revision surgery during the COVID-period.

Finally, if we assume that after COVID-19 the available operating capacity can be increased by 10% compared to the pre-COVID-19 trend, then it will take three to four years to clear the backlog of patients in the Netherlands and one to two years in Denmark. In that case, the estimated total health loss in the Netherlands and Denmark will be 19,800 and 1,700 QALYS, respectively. With an additional capacity of only 5%, it will take about double the time before the backlogs are cleared (i.e. five to seven years in the Netherlands and two to four years in Denmark).

Although the numbers differ by country, worldwide orthopaedic care and arthroplasty surgical volume have been negatively affected by the COVID-19 pandemic.[24] Other countries mentioned major effects of the pandemic on hip and knee arthroplasty procedures, with drops ranging from 20% to 61%.[25–28] Similar to our results, these studies also observed the most significant decrease during April and May of 2020. Furthermore, a survey administered within the European Hip Society (EHS) and Knee Associates (EKA) showed that primary total joint replacements (TJRs), alongside with aseptic revisions, were impacted most, while septic revisions and periprosthetic fractures were still performed.[3]

Previous studies suggested prioritizing patients during the COVID-19 pandemic,[5,24] which could possibly worsen existing healthcare disparities. Our results indicate that no prioritizing based on patients' health seemed to have occurred within surgical indication categories in the Netherlands and Denmark. However, during the first lockdown more acute indications were prioritized over elective OA patients, thereby explaining the shift towards higher ASA grades in the total population in the Netherlands.[29] The shift towards higher ASA grades was not

apparent in the Danish population, which could be due to the fact that fewer arthroplasties were postponed and the DHR does not include hemi hip arthroplasties.

Although no prioritization occurred, a shift in healthcare delivery (i.e. arthroplasty surgery) towards private hospitals occurred during the COVID-period in both countries. Due to the absence of an intensive care unit (ICU), private hospitals generally perform surgery on patients with lower ASA grades. During the COVID-19 pandemic, several guidelines were suggested to postpone these patients first when healthcare capacities were impacted. However, private hospitals were able to fill in part of the capacity gap, thereby minimizing the impact on patients with lower ASA grades in the Netherlands and Denmark. Similar to the Netherlands and Denmark, the independent sector in the UK also helped reduce the burden on the elective care during the pandemic.[28] The independent sector lowered the elective workload, using a 'lift and shift' service, thereby decreasing the overall impact of the COVID-19 pandemic.

Due to the decline in surgical volume, as a consequence of anaesthesia personnel working at ICUs and recovery rooms in hospitals that were transformed into ICUs, the waiting lists increased. The backlog, caused by postponing arthroplasty surgery, occurred in many countries.[26] Oussedik et al[30] showed that elective orthopaedic waiting lists in England were approximately three times the pre-COVID-19 average in November 2020. Similarly to other studies, we estimate that the effect of the pandemic is long lasting, and will be cumulative if no extra surgical capacity can be created.[21,25,31,32] Several strategies have been proposed to combat the backlog, such as increased operating theatre schedules, risk stratification, and the use of outpatient and ambulatory surgical centres,[24] while others suggest that reducing the waiting lists should not solely rely on the length of time the patient has been waiting, but should also include the level of need of the patient.[9]

Due to the extended wait on the waiting list, the patient's health status could be negatively affected, thereby making them more susceptible to other health problems and also affecting rehabilitation after surgery.[10] Green et al[33] showed that time to surgery and length of stay in the hospital increased due to the pandemic, thereby possibly contributing to radiological and clinical deterioration of arthritis and general musculoskeletal conditioning. This in turn could affect patient rehabilitation, as well as increase the length of stay. Based on the scenarios described in this study, even with a 10% increase in capacity (including operating theatre personnel, hospital beds, nursing staff, and surgeons), compared to the pre-pandemic capacity in hospitals, it will take anywhere between one and four more years to reduce the extended waiting lists to their pre-COVID-19 length. Wilson et al[21] showed similar results regarding the long-term impact of the pandemic on the backlog in arthroplasty surgeries. Due to the elective case ban, the surplus of surgical volume is significant. Both the results from the current study and the study of Wilson et al[21] emphasize the value of anticipatory planning to lessen the impact of the pandemic.

Increase in waiting lists also significantly impacts patients' health status and quality of life.[9,14,34] However, previous studies did not mention the actual impact of the pandemic regarding QALY loss. Nevertheless, due to restricted possibilities in providing additional capacity for orthopaedic care, drastic changes within this field are needed, possibly resulting in a change of focus from surgical interventions towards prevention or non-surgical interventions for OA that can relieve pressure on orthopaedic healthcare. As a result, research aimed at improving patients' health status during the period between diagnosis and surgery, to facilitate their quality of life and health status to remain stable, seems a necessity.

This study has several strengths. First, we obtained data from national registries from two countries, which both have a completeness of 97% to 98%. Second, we took into account the expected number of arthroplasties for 2020, based on the growth in arthroplasty numbers and changes in the general population over the years. A possible limitation is the fact that some patients received bilateral arthroplasties during one procedure, which could result in an overestimation of the number of expected surgeries. However, only a small percentage of patients received this type of surgery. Furthermore, the DHR only contains information regarding total hip arthroplasties. No information regarding partial hip arthroplasties was available in the DHR, which could affect estimates regarding the switch towards acute surgeries in Denmark. In addition, within the DHR and DKR registers no EQ-5D scores are available, so the Danish health gain and QALY calculations were extrapolated from the Dutch arthroplasty population. Unfortunately, we had no information on the number of TJRs performed per month for 2021, and no information on the number of actual procedures performed after 2021. Additionally, we were not able to account for factors affecting the backlog during the ongoing COVID-19 pandemic, such as relative shortage of operating theatre capacity, other specialties also attempting to combat the backlog, and the unpredictable future course. As a result, it is difficult to determine whether healthcare systems are able to accommodate an increase in arthroplasty surgery volumes. Moreover, we did not include whether a patient's willingness to undergo elective surgery changed during the pandemic, thereby impacting the calculation of the procedure backlog. Although some studies showed that a proportion of patients were reluctant to undergo surgery during the pandemic, the majority wished to proceed with

the planned surgery.[35–37] Furthermore, studies showed that elective surgery can safely be resumed during the pandemic.[38–40] Although it is possible that willingness decreased during this time, it is also likely that reluctance decreases and an influx of new patient referrals will increase again when the pandemic eases.

The COVID-19 pandemic had a huge impact on patients in need of hip, knee, or shoulder arthroplasty. Within the first wave in the Netherlands, patients with more acute indications were prioritized. However, within the indication categories, no prioritization based on patient characteristics occurred. Relatively more surgeries were performed in private hospitals compared to pre-COVID-19. The QALY loss in the Netherlands and Denmark has been considerable, and will last for years to come. Although both the Netherlands and Denmark were affected by the pandemic, the impact on hip and knee arthroplasty volumes was greater in the Netherlands than Denmark. This could be explained by the relatively low rate of COVID-19 infections and related deaths in Denmark.[41] Furthermore, Denmark was one of the first European countries to partially reopen society,[41,42] most likely due to rapid interference by the Danish government, and a high level of trust and confidence in the government by the public.[41] In the future, there will be additional strain on the healthcare system, especially in orthopaedic departments, based on the reduced surgical rate throughout the pandemic. It is necessary to investigate which possible measures can be taken to eliminate the extended waiting lists. Evaluating interventions that provide patients with a way to cope with their symptoms or avoid aggravation of symptoms could benefit those awaiting surgery.

Take home message

- The COVID-19 pandemic had an enormous negative effect on patients in need of hip, knee, or shoulder arthroplasty.
- For years to come, there will be an addtional strain on healthcare systems, especially in orthopaedic departments, based on the reduced surgical rate throughout the pandemic.

Supplementary material

Figures including observed/expected ratios and virtual waiting list numbers, and tables including patient and prosthesis characteristics per subcategory of indication and country divided by month.

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