Osteoarthritis and Cartilage xxx (xxxx) xxx–xxx

Osteoarthritis and Cartilage

OARSI OSTEOARTHRITIS RESEARCH SOCIETY INTERNATIONAL

Utilization rates of knee arthroplasty in OECD countries revised

Jonas Backes [a, *, 1], Christof Pabinger [b, 2], Harald Lothaller [c, 3], Alexander Geissler [a, 4]

[a] Chair of Health Economics, Policy and Management, School of Medicine, University of St. Gallen, Switzerland
[b] OPZ Graz, Orthopedic and Physiotherapy Center Graz, Austria
[c] Study Center, University of Music and Performing Arts Graz, Austria

A R T I C L E I N F O

Article history:
Received 16 October 2025
Accepted 4 March 2026

Keywords:
Knee arthroplasty
Utilization
OECD
Obesity
COVID-19

A B S T R A C T

Background: In 2015, we reported rapid growth and variation in knee arthroplasty across OECD countries, especially in patients ≤64 years, projecting a four-fold increase by 2030. Since then, clinical practice and external conditions have evolved. This study re-examines trends through 2022 and expands previous analyses.
Methods: We analyzed data from 25 OECD countries (2005–2022) using OECD and national sources. Age-specific utilization rates (≤64 vs. ≥65 years) were derived from population-adjusted incidence. We calculated compound annual growth rates (CAGR), mean annual differences (MAD), and tested robustness via sensitivity analyses. We calculated within- and between-country associations of obesity/overweight with utilization.
Results: From 2011 to 2022, volume increased (CAGR: +2.33% [2.33; 2.34]; MAD: 37,700 [35,700; 39,600]), although slower than between 2005 and 2011 (CAGR: +4.75% [4.73; 4.78]; MAD: 58,100 [55,500; 60,700]). Patients aged 64 and younger now account for ~50% of procedures (CAGR: +4.46% [4.28; 5.81]; MAD: 32,300 [30,700; 33,900]), while growth slowed in older adults (CAGR: +0.61% [0.60; 0.61]; MAD: 5400 [5000; 5700]). A percentage point rise in obesity was linked to +1.1–1.9% higher utilization, stronger in older cohorts and lower-income settings. COVID-19 led to around −22% (~406,500 [386,600; 426,300] procedures) drop in 2020, followed by a faster recovery in younger adults. Growth remains below our original projection in 2015.
Conclusion: Growth to 2022 has fallen short of the earlier 2015 projection. Still, utilization remains on an upward trajectory, with a growing share of procedures among younger patients, now accounting for > 50% of volume. Cross-country variation has narrowed vs. our earlier analysis, with lower volume countries catching up. Obesity remains associated with higher utilization, with the strengths of this association varying by national income. Post-COVID-19 recovery patterns are consistent with sustained demand and higher relative contribution from younger, lower-risk populations.

Introduction

Knee osteoarthritis (OA) is a leading cause of mobility loss among adults, affecting millions worldwide. Between 1990 and 2021, the number of prevalent cases more than doubled, thus rising demand for knee arthroplasty and placing increasing pressure on health systems across Organization for Economic Co-operation and Development (OECD) countries [1,2]. Considering clinical and demographic changes, health authorities and policy makers must understand past trends to anticipate corresponding growth in surgical knee arthroplasty volume, and everything connected (e.g., workforce requirements, implant-related expenditures) [3].

In 2015, we conducted an OECD-wide analysis on knee arthroplasty utilization [4]. Our research was triggered by expectations of exponential growth in knee arthroplasty and our concern over the limitations of using aggregated OECD incidence rates for evaluating trends across age groups [5]. Utilization rates varied ten-fold across countries, and patients

* Corresponding author.
E-mail addresses: jonas.backes@unisg.ch (J. Backes), pabinger@opz.at (C. Pabinger), harald@lothaller.net (H. Lothaller), alexander.geissler@unisg.ch (A. Geissler).
[1] ORCID: 0009-0000-0987-866X.
[2] ORCID: 0000-0003-4622-9399.
[3] ORCID: 0000-0003-4598-7649.
[4] ORCID: 0000-0002-7445-2929.

https://doi.org/10.1016/j.joca.2026.03.002

≤64 years drove growth at twice the speed of older adults (≥65 years). Considering demographic factors such as rising obesity, we projected a four-fold increase by 2030, raising concerns for revision planning.

Since our analysis, changes in surgical technique, perioperative care, and demographic factors occurred. Robotic-assisted surgeries, patient-specific instruments (PSI), and new arthroplasty geometry (medial pivot design) improved implant-placement precision and are now common across OECD operating rooms [6,7]. Minimally invasive techniques and fast-track surgery have led to shorter hospital stays and recovery [8]. Innovations in implant materials, such as highly cross-linked ultra-high molecular weight polyethylene (UHMWPE) and cementless fixation have increased longevity of implants [7,9,10]. These developments, alongside demographic (e.g., age and obesity) and economic shifts (e.g., health expenditure and gross domestic product (GDP)), call for a re-examination of knee arthroplasty utilization trends [11,12].

Similar studies remain limited, mostly relying on aggregated incidences that obscure age-specific differences [13]. Yet, age-specific trends remain relevant for long-term implant planning and health system preparedness. Although some works focus on single nations/regions or procedure types (e.g., revisions or unicompartmental replacement), few cover the OECD spectrum for both total and partial knee arthroplasty [14–18]. We seek to contribute by offering an updated, age-stratified OECD perspective reflecting clinical, technological, and demographic developments.

This study addresses the following questions:

- How have knee arthroplasty utilization rates evolved across OECD countries since 2011, overall and within age groups (≤64 vs. ≥65 years)?
- What trends are associated with the development of knee arthroplasty procedures between 2011 and 2022?

Methods

Data sourcing, handling of missing values, conversion to utilization rates, age group stratification, and sensitivity analyses followed a similar approach to our revised hip arthroplasty study [19].

Data sourcing

For 25 countries we extracted (i) Inpatient cases per 100,000 inhabitants and (ii) procedures per 1,000 persons aged ≥65 years from OECD Health Statistics [11]. Both include surgical codes 81.54 (total knee replacement) and 81.55 (revision of knee replacement) from the *International Classification of Diseases, 9th Revision, Clinical Modification* (ICD-9-CM). We extracted an annual time series covering 2005–2022, spanning both the period of our previous paper (2005–2010) and the updated observation window (2011–2022).

We also collected demographic and macro-economic data for each country year. Total population and the proportion aged ≥65 years were downloaded from the World Bank Data portal [12]. Health expenditure per capita (indicator of priority and relevance of healthcare within a country) and GDP per capita (proxy for overall economic strength) were obtained from the same source. From OECD Health Statistics, we included national overweight and obesity rates (risk factors for knee arthroplasty), life expectancy (measure of population health status), and hospital beds per capita (proxy for healthcare supply) [11].

Handling of incomplete (or missing) data

Australia, Mexico, and the United States (U.S.) exhibited substantial gaps in the OECD series between 2005 and 2022. Where necessary, we substituted non-existent inpatient cases with total procedure counts for Australia and Mexico, which are also provided by OECD Health Statistics [11]. Differences between inpatient and total procedure counts were consistently ± 5% across comparator countries (i.e., France, Germany, Italy, and Spain).

For the U.S., OECD figures were missing after 2010. Thus, we used the National Inpatient Sample (NIS), a stratified 20% sample of U.S. hospitals to extract primary and revision procedures. Because the NIS switched from ICD-9 to ICD-10 in 2015, the 2015 value was linearly interpolated. Because it is uncertain whether the NIS captures all knee arthroplasty procedures post 2018 [20], we adjusted 2018–2019 volumes using Medicare growth rates reported by Shichman et al [3]. : +4.37% (2018) and +3.75% (2019). For 2020–2022, counts were projected from the average OECD year-on-year change.

In 2012, NIS underwent a redesign in its sampling strategy. While improving precision, the change introduced a break in the time-series. Thus, the Healthcare Cost and Utilization Project (HCUP) provides weights for 2005–2011 to harmonize data with the post-2012 design. Although our U.S. figures already incorporated these adjustments, recognizing the change is an important context for interpreting U.S. trends. Where possible, we validated NIS figures against external sources, with deviations not exceeding ± 5%.

Missing observations from all other countries were handled with three imputation strategies. Countries that lacked consecutive years at the start or end of the series (Estonia, Ireland, Korea, and Norway), we extrapolated data by applying the average year-on-year growth rate seen in OECD members with complete data. Single-year gaps within continuous time series (Belgium, the Netherlands, and Norway) were filled by linear interpolation. Lastly, when 2022 data were missing (Australia, the Netherlands, and New Zealand), we projected the 2021 value forward by the growth rate over the previous four years.

Translating incidence into utilization rates

We report utilization rates rather than the raw incidence figures. OECD defines incidence as new knee-arthroplasty cases per 100,000 inhabitants, a denominator that may hide age-specific variation. We obtain age-adjusted utilization rates as follows:

$$Utilzation\ rate_{a,t,c} = \left(\frac{Incidence_{a,t,c} \times Populaiton_{total,t,c}}{100,000} / Population_{a,t,c}\right) \times 100,000$$

where *Incidence* denotes the OECD-reported incidence rate [11], *a* the age group (either ≤64 or ≥65 years), *t* the year, and *c* the country. This adjustment reflects the true procedure burden within each age group, an approach previously shown to influence cross-country comparisons and interpretation [4].

Stratification by age categories

Knee procedures were analyzed in two age groups: ≤64 and ≥65 years. While OECD provided ≥65 years procedure counts, counts for the ≤64 group were obtained by subtraction. Utilization rates for both sub-groups were then calculated as described above, using the corresponding population denominators. Data checks showed ≥65 counts exceeded national totals in Israel and Mexico, so both countries were dropped from further analysis (Supplementary material 1). Age-specific utilization rates were unavailable in NIS data. Therefore, we applied the average OECD ≥65/≤64 split in our base case and conducted sensitivity analyses to test robustness.

Comparison of compound annual growth rates and mean annual differences

Compound annual growth rates (CAGR) and mean annual differences (MAD) were used to summarize changes in utilization. For any country, CAGR was calculated as $(U_t/U_0)^{1/n} - 1$ where U_0 is the utilization rate in the first year, U_t is the rate in the final year, and n is the number of years between them. This metric expresses the steady annual growth rate over an observed time, allowing us to compare trends between countries and periods. MAD was computed as $(U_t - U_0)/n$, representing the average annual utilization rate change. To contextualize trends relative to our 2015 projection we use the CAGR to compare expected with observed 2022 volume.

National overweight and obesity rates

Overweight (Body mass index (BMI) 25– < 30 kg/m²) and obesity (≥30 kg/m²) prevalences came from measured data (e.g., via direct physical measurement of weight and height in health examination centers) when available and patient self-reported data (e.g., via national health surveys) otherwise. Two gap-handling rules applied: (i) Linear interpolation for values bracketed by observations and (ii) CAGR-based extrapolation for open-ended gaps, extending the last observed point.

Sensitivity analyses

We conducted two sensitivity analyses. First, we applied a ± 10% variation with 2.5% increments to NIS volumes to assess the impact of data uncertainty on OECD-level results. Second, we tested the assumption that U.S. age-specific utilization follows the OECD average by applying five alternative scenarios: the top five countries with the lowest (Scenario 1) and highest (Scenario 5) ≥65-year shares and interquartile values across OECD countries (Scenario 2–4) (Supplementary material 2). The base scenario does not apply any variation.

Statistical analyses

We used *within-country* models to assess how obesity/overweight changes relate to knee utilization, and *between-country* models to examine if higher obesity/overweight countries have higher utilization. Analyses used the base dataset (Tables 1–3) for 2005–2019. We omitted 2020–2022 data due to heterogeneous COVID-19 responses that disrupted comparability.

Models controlled for obesity (% of adult population BMI ≥ 30 kg/m²), overweight (% of adult population (BMI 25 to < 30 kg/m²), GDP (USD per capita), health expenditure (USD per capita), life expectancy (years at birth), hospital beds (per 1000 inhabitants), and the share of the population ≥ 65 years. Obesity × GDP and overweight × GDP interaction terms assessed variations in effects driven by national income. We used contemporaneous BMI values as introducing multi-year lags would substantially reduce the panel length and statistical power.

Outliers (> ± 3 standard deviations (SD) from the mean) were removed. Variable distributions were then inspected in R (version 4.4.1) with scatterplots [21]. We assessed bivariate associations

	Population			Inpatient cases per 100,000 inhabitants														Change inpatient cases			
Country	CAGR '05 - '11 [%]	CAGR '11 - '22 [%]	Total in '22 [Mio]	2005	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	Total implants in 2022	CAGR '05 - '11 [%]	CAGR '11 - '22 [%]	MAD '05 - '11	MAD '05 - '22
Australia	1.7	1.4	26.0	132	178	180	191	197	208	212	212	211	203	252	215	215*	55,973	5.2	1.8	7.8	3.4
Austria	0.3	0.7	9.1	160	219	217	215	221	215	212	228	230	229	181	195	213	19,246	5.4	-0.3	9.9	-0.6
Belgium	0.8	0.5	11.6	143	185	187	191	203	210†	218	210	207	212	137	164	180	21,000	4.3	-0.2	6.9	-0.4
Canada	1.1	1.1	38.9	125	160	166	170	172	178	184	191	201	196	135	132	168	65,208	4.1	0.4	5.8	0.7
Denmark	0.5	0.5	5.9	114	166	168	166	170	162	155	156	172	191	182	156	206	12,158	6.4	2.0	8.6	3.6
Estonia	-0.3	0.1	1.3	77‡	92	94	97	99	94	89	82	108	110	104	94	109	1,466	3.0	1.5	2.5	1.5
Finland	0.4	0.3	5.6	172	193	206	201	191	187	219	221	233	237	221	255	197	10,923	2.0	0.2	3.5	0.4
France	0.6	0.4	67.9	98	133	140	145	156	160	166	173	179	182	141	162	179	121,685	5.1	2.8	5.7	4.2
Germany	-0.4	0.4	83.8	164	210	206	190	197	206	219	223	223	227	203	201	231	193,573	4.2	0.9	7.7	1.9
Hungary	-0.2	-0.3	9.6	45	55	51	57	71	87	88	85	89	94	57	28	69	6,692	3.2	2.2	1.6	1.3
Ireland	1.7	1.0	5.1	41	40	47	50	45	52	50	49	48	49	38‡	43‡	49‡	2,474	1.2	2.7	-0.2	0.7
Italy	0.5	-0.2	58.9	77	100	102	104	108	112	121	125	130	137	104	127	155	91,358	4.3	4.1	3.7	5.0
Korea	0.6	0.3	51.6	83‡	112‡	114	114	114	121	136	135	139	153	140	150	160	82,502	5.1	3.3	4.8	4.4
Luxembourg	1.8	2.1	0.7	157	154	178	178	181	195	214	226	219	187	143	167	159	1,037	-0.3	0.3	-0.5	0.5
Netherlands	0.4	0.5	17.7	84	127†	137	140	151	149	154	155	156	155	118	128	122*	21,672	7.1	-0.4	7.2	-0.4
New Zealand	1.0	1.4	5.1	86	93	98	97	111	106	111	121	115	109	102	100*	96*	4,896	1.3	0.2	1.2	0.2
Norway	1.2	0.9	5.5	62‡	88†	90	88	96	100	118	126	130	117	108	121	122	6,641	6.0	3.0	4.3	3.1
Poland	0.2	-0.2	37.8	6	22	24	26	31	39	47	63	66	74	54	69	86	32,380	25.2	13.1	2.7	5.8
Portugal	0.1	-0.1	10.4	40	60	68	68	62	66	73	62	61	67	49	75	80	8,376	7.2	2.7	3.4	1.8
Slovenia	0.4	0.2	2.1	40	110	112	108	106	107	124	128	133	137	105	112	146	3,068	18.6	2.6	11.8	3.2
Spain	1.1	0.2	47.6	85	105	104	111	120	118	121	135	137	139	97	121	135	64,090	3.6	2.3	3.4	2.7
Sweden	0.8	1.0	10.5	94	124	136	133	127	124	127	137	133	137	94	96	133	13,990	4.7	0.7	5.0	0.9
Switzerland	1.0	0.9	8.8	141	205	212	210	214	242	258	254	250	260	256	273	304	26,634	6.4	3.6	10.7	8.9
U.K.	0.8	0.6	67.3	111	140	139	141	148	148	154	145	148	141	45	108	114	76,990	3.9	-1.8	4.8	-2.3
U.S.[1]	0.9	0.6	333.3	181	221	223	232	236	245†	254	259	269Δ	278Δ	216‡	241‡	271‡	904.088	3.4	1.9	6.7	4.5
Total	**0.7**	0.5	**922.3**														**1,848,121**				
Incidence				**129**	**164**	**166**	**170**	**175**	**181**	**190**	**194**	**199**	**205**	**159**	**178**	**200**		**4.8**	**1.8**	**5.8**	**3.3**
Mean utilization rate				**129**	**164**	**166**	**170**	**175**	**181**	**190**	**194**	**199**	**205**	**159**	**178**	**200**		**4.8**	**1.8**	**5.8**	**3.3**

Bold figures show summary. Framed figures show an increase in the growth rate/MAD compared to the previous period. Figures are underlined if the population growth exceeds the inpatient growth in the same period and vice versa. Shaded values reflect the time intervals used for CAGR/MAD comparison. [1]Based on National Inpatient Sample data until 2018 *Data extrapolated based on last four-year CAGR; † estimated values by applying the CAGR between the adjacent available years; ‡ previous/next year utilization rate extrapolated based on year-on-year growth rate of knee arthroplasty procedures across other OECD countries. Δ 2018 and 2019 growth rate based on primary knee arthroplasty Medicare patients from Shichman et al. [50].

Table 1

Osteoarthritis and Cartilage

Knee arthroplasty inpatient cases per 100,000 population from 2005 to 2022.

Country	Population CAGR '05 – '11 [%]	Population CAGR '11 – '22 [%]	Population Total in 2022 [Mio]	Inpatient cases per 100,000 inhabitants 2005	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	Total implants in 2022	Change inpatient cases CAGR '05 – '11 [%]	Change inpatient cases CAGR '11 – '22 [%]	Change inpatient cases MAD '05 - '11	Change inpatient cases MAD '05 - '22
Australia	2.8	3.3	4.4	779	933	898	924	914	931	922	890	863	805	944	762	737*	32,693	3.0	-2.1	25.7	-17.8
Austria	1.8	1.6	1.8	604	701	674	649	652	628	616	656	656	639	491	522	559	9,868	2.5	-2.0	16.1	-12.9
Belgium	0.9	1.7	2.3	482	618	610	602	628	637†	647	607	584	582	369	431	468	10,710	4.2	-2.5	22.6	-13.7
Canada	2.7	3.6	7.3	735	769	754	734	703	693	683	679	682	638	416	383	473	34,648	0.8	-4.3	5.8	-27.0
Denmark	2.6	2.2	1.2	503	567	538	509	499	459	432	422	452	492	454	379	495	5,970	2.0	-1.2	10.6	-6.5
Estonia	0.5	1.5	0.3	273‡	296	291	291	285	265	240	216	280	276	253	226	266	728	1.3	-1.0	3.7	-2.8
Finland	2.3	2.7	1.3	678	606	602	551	493	460	513	497	500	485	436	485	367	4,723	-1.8	-4.5	-12.0	-21.7
France	1.2	2.4	14.3	367	460	467	461	473	462	456	457	454	446	336	375	403	57,751	3.8	-1.2	15.5	-5.3
Germany	1.0	1.0	18.5	459	494	478	437	449	466	487	493	484	485	425	412	470	87,150	1.2	-0.4	5.7	-2.2
Hungary	0.9	1.6	2.0	185	196	176	190	226	265	255	239	240	245	139	69	165	3,279	1.0	-1.6	2.0	-2.8
Ireland	2.5	3.4	0.8	333	301	326	324	284	307	278	265	245	247	183‡	198‡	219‡	1,682	-1.7	-2.9	-5.3	-7.5
Italy	1.3	1.2	14.1	198	233	234	230	231	232	242	249	250	260	192	228	271	38,311	2.7	1.4	5.7	3.5
Korea	4.2	4.6	9.0	864‡	893‡	862	795	744	733	781	712	679	693	566	549	521	46,982	0.6	-4.8	4.8	-33.8
Luxembourg	1.6	2.7	0.1	760	740	845	834	828	880	956	1001	954	803	605	695	648	627	-0.5	-1.2	-3.4	-8.3
Netherlands	2.4	2.7	3.6	417	499†	502	480	489	462	458	444	431	414	306	321	298*	10,617	3.0	-4.6	13.7	-18.3
New Zealand	2.6	3.4	0.8	600	529	526	483	536	502	511	546	513	465	424	400*	367*	3,087	-2.1	-3.3	-11.8	-14.7
Norway	1.8	2.6	1.0	295‡	378†	374	355	374	381	430	447	445	385	344	371	360	3,602	4.2	-0.4	13.9	-1.7
Poland	0.7	3.0	7.3	30	117	121	124	133	161	180	228	221	236	158	197	235	17,022	25.3	6.5	14.5	10.7
Portugal	1.7	2.0	2.5	133	168	181	177	153	155	161	135	127	133	91	137	143	3,551	4.0	-1.5	5.9	-2.3
Slovenia	1.6	2.5	0.4	168	397	389	359	339	325	353	350	346	345	249	253	319	1,434	15.4	-2.0	38.2	-7.1
Spain	1.8	1.6	9.6	308	354	337	346	360	344	340	372	368	364	249	306	332	31,902	2.4	-0.6	7.7	-2.0
Sweden	2.0	1.8	2.1	313	354	374	358	333	320	324	348	337	341	234	233	324	6,921	2.1	-0.8	6.9	-2.7
Switzerland	2.2	2.0	1.7	560	711	712	686	684	755	793	770	740	754	732	767	832	13,953	4.1	1.4	25.1	11.1
U.K.	1.4	1.8	12.7	440	508	482	466	476	465	478	441	442	410	129	305	317	40,379	2.4	-4.2	11.4	-17.4
U.S.[1]	2.0	3.1	57.8	922	996	954	948	924	921	917	900	895	885	672	719	775	447,804	1.3	-2.3	12.4	-20.1
Total	**1.7**	**2.3**	**177.0**														**915,590**				
Incidence				**82**	**98**	**98**	**98**	**99**	**101**	**104**	**105**	**106**	**107**	**82**	**90**	**99**		**3.1**	**0.1**	**2.7**	**0.1**
Mean utilization rate				**560**	**630**	**613**	**602**	**597**	**597**	**604**	**597**	**593**	**586**	**444**	**477**	**517**		**2.0**	**-1.8**	**11.7**	**-10.3**

Bold figures show summary. Framed figures show an increase in the growth rate/MAD compared to the previous period. Figures are underlined if the population growth exceeds the inpatient growth in the same period and vice versa. Shaded values reflect the time intervals used for CAGR/MAD comparison. *Data extrapolated based on last four-year CAGR; † estimated values by applying the CAGR between the adjacent available years; ‡ previous/next year utilization rate extrapolated based on year-on-year growth rate of knee arthroplasty procedures across other OECD countries; 1. OECD-wide age split (i.e., ≥65 years vs. ≤64 years) of total implants for respective year applied to U.S. data.

Table 2 Osteoarthritis and Cartilage

Total utilization rate of knee arthroplasty procedures per 100,000 inhabitants aged 65 and older from 2005 to 2022.

using simple linear regression and Pearson correlation coefficients before modelling.

Results

Knee arthroplasty development

Between 2005 and 2011, OECD-wide knee arthroplasty volume grew at a CAGR of +4.75% [sensitivity corridor: 4.73%; 4.78%] and MAD of 58,100 procedures [55,500; 60,700] (Fig. 1). Growth slowed between 2011 and 2022 (CAGR: +2.33% [2.33%; 2.34%]; MAD: 37,700 [35,700; 39,600]). Absolute annual procedures increased by ~414,300 [392,900; 435,800], from 1.43 million [1.36; 1.50] in 2011 to 1.85 [1.76; 1.94] million in 2022. Therewith, absolute numbers now exceed those for hip arthroplasty (~1.65 million) in OECD countries [19].

On a country level, France, Germany, and the U.S. together accounted for > 60% of all procedures in 2022; this share remained constant vs. 2011. Their utilization rates growth slowed down but still outpaced population growth. Korea, Slovenia, and Switzerland climbed most sharply, whereas Luxembourg, New Zealand, and the U.K. registered the steepest relative falls. Overall, countries with previously low utilization rates are catching up. Four out of five countries with rates below 50 in 2011 now show CAGRs above the OECD average (see Supplementary material 3).

Fig. 2 shows dispersion narrowing from a tenfold gap in 2011 (Poland vs. U.S.) to sixfold in 2022 (Ireland vs. Switzerland) [4], even as the absolute difference widened. From 2005 to 2011 procedure growth exceeded population growth in 23 (92%) countries. Meanwhile from 2011 to 2022 this was true for only 16 (60%).

Our 2015 study, with a slightly different country scope, projected a rise from ~1.49 million procedures in 2011 to ~5.7 million by 2030 (CAGR 7.33%). Under this trajectory, expected 2022 vol would have been ~3.12 million procedures. Instead, we observed ~1.85 million, i.e., ~41% fewer procedures than implied by the earlier projection. To still achieve the initially expected CAGR of 7.33% between 2011 and 2030, an annual growth of ~14.60% would be required based on the current figures.

Age-related difference

Age patterns have shifted. In 2005, patients aged ≥65 years received 63% [62%; 73%] of all knee arthroplasties; by 2022 younger patients already accounted for more than half of procedures (Fig. 1). From 2005–2011 younger patients experienced high growth with a CAGR of +6.34% [6.16%; 7.48%] vs. +3.77% [3.68%; 4.02%] in the ≥65 group. MAD was relatively equal in this period (MAD: 29,700 [28,300; 31,000] vs. 28,400 [27,200; 29,700] in the ≥65 group). Post-2011, younger patients' growth slowed (CAGR: 4.46% [4.28%; 5.81%], MAD: 32,300 [30,700; 33,900]) but remained the group with the largest absolute volume increase. In contrast, volume for ≥65 years

Country	Population CAGR '05 – '11 [%]	Population CAGR '11 – '22 [%]	Population Total in 2022 [Mio]	2005	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	Total implants in 2022	Change inpatient cases CAGR '05 – '11 [%]	Change inpatient cases CAGR '11 – '22 [%]	Change inpatient cases MAD '05 - '11	Change inpatient cases MAD '05 - '22
				Inpatient cases per 100,000 inhabitants																	
Australia	1.5	1.0	21.5	35	57	62	68	74	81	85	88	90	89	117	104	108*	23,280	8.4	6.0	3.6	4.7
Austria	0.0	0.5	7.3	74	116	117	119	124	122	120	130	132	133	107	117	129	9,379	7.8	1.0	7.0	1.2
Belgium	0.8	0.3	9.4	73	94	98	102	110	115†	122	119	120	125	82	99	110	10,290	4.4	1.4	3.5	1.4
Canada	0.8	0.7	31.6	34	57	63	69	74	80	86	92	101	102	73	75	97	30,560	9.2	4.9	3.9	3.6
Denmark	0.1	0.2	4.7	45	83	89	90	96	94	90	93	105	117	113	99	132	6,188	10.6	4.3	6.3	4.4
Estonia	-0.5	-0.2	1.1	37‡	49	51	53	57	54	53	50	66	69	66	60	69	738	4.5	3.2	1.9	1.8
Finland	0.1	-0.3	4.3	76	103	116	119	116	118	142	147	159	167	159	187	145	6,201	5.3	3.2	4.6	3.8
France	0.4	-0.1	53.6	46	66	72	77	85	90	98	104	111	115	91	107	119	63,934	6.2	5.6	3.3	4.9
Germany	-0.8	0.2	65.2	95	136	134	125	131	137	147	150	151	156	141	141	163	106,423	6.2	1.7	6.8	2.5
Hungary	-0.4	-0.7	7.7	19	26	25	29	38	47	50	49	53	57	37	18	45	3,414	5.0	5.0	1.1	1.7
Ireland	1.6	0.6	4.3	5	6	9	11	11	14	15	15	16	17	13‡	16‡	18‡	792	3.3	10.7	0.2	1.1
Italy	0.3	-0.6	44.8	48	65	67	70	74	79	87	89	95	101	77	95	118	53,046	5.2	5.6	2.8	4.9
Korea	0.2	-0.4	42.6	6‡	15‡	17	21	25	31	38	43	49	59	60	71	83	35,520	16.5	17.2	1.5	6.3
Luxembourg	1.9	2.0	0.6	58	59	69	71	75	82	91	97	96	83	65	76	74	410	0.3	2.1	0.2	1.4
Netherlands	0.0	0.1	14.1	29	57†	65	70	78	80	86	88	91	93	72	80	78*	11,054	11.6	2.9	4.6	1.9
New Zealand	0.7	1.1	4.3	16	27	30	33	39	38	42	46	45	44	43	43*	42*	1,809	9.0	4.2	1.8	1.4
Norway	1.0	0.5	4.5	22‡	35†	37	38	43	46	56	61	65	61	57	66	68	3,040	8.5	6.1	2.3	3.0
Poland	0.1	-0.8	30.6	2	7	8	9	12	17	22	30	34	39	31	40	50	15,358	23.5	19.7	0.8	3.9
Portugal	-0.2	-0.7	8.0	20	35	41	41	39	42	49	42	42	48	36	56	61	4,825	9.4	5.2	2.4	2.4
Slovenia	0.2	-0.3	1.7	16	53	56	55	55	59	71	76	81	85	68	74	98	1,634	22.1	5.8	6.2	4.1
Spain	1.0	-0.2	38.0	40	53	55	60	66	67	70	79	81	84	59	75	85	32,188	4.6	4.4	2.1	2.9
Sweden	0.5	0.8	8.4	48	71	80	79	77	76	79	85	82	86	59	61	85	7,068	6.7	1.6	3.8	1.2
Switzerland	0.8	0.7	7.1	62	102	108	109	113	130	140	139	139	147	146	158	179	12,681	8.6	5.3	6.6	7.0
U.K.	0.7	0.3	54.6	49	67	68	73	78	79	83	79	82	80	26	62	67	36,611	5.3	0.1	3.0	0.0
U.S.[1]	0.7	0.2	275.5	76	103	107	114	120	127	135	141	150	159	125	144	166	456,283	5.2	4.4	4.5	5.7
Total	**0.5**	**0.1**	**745.24**														**932,727**				
Incidence				**47**	**66**	**69**	**72**	**76**	**80**	**86**	**89**	**93**	**97**	**77**	**88**	**101**		**5.7**	**4.0**	**3.2**	**3.2**
Mean utilization rate				**56**	**78**	**81**	**86**	**91**	**96**	**104**	**108**	**114**	**119**	**95**	**109**	**125**		**5.9**	**4.4**	**3.7**	**4.3**

Bold figures show summary. Framed figures show an increase in the growth rate/MAD compared to the previous period. Figures are underlined if the population growth exceeds the inpatient growth in the same period and vice versa. Shaded values reflect the time intervals used for CAGR/MAD comparison. *Data extrapolated based on last four-year CAGR; † estimated values by applying the CAGR between the adjacent available years; ‡ previous/next year utilization rate extrapolated based on year-on-year growth rate of knee arthroplasty procedures across other OECD countries; 1. OECD-wide age split (i.e., ≥65 years vs. ≤64 years) of total implants for respective year applied to National Inpatient Sample data.

Table 3 Osteoarthritis and Cartilage

Total utilization rate of knee arthroplasty procedures per 100,000 inhabitants aged 64 and younger from 2005 to 2022.

slowed by 3.2pp, despite faster population growth (+2.4% vs. +1.7% previously). Table 2 confirms population outpacing utilization growth in nearly every country for ≥65 patients. Conversely, Table 3 shows utilization exceeded population growth in all countries for ≤64 patients.

Effect of utilization conversion

Our base case shows that ignoring age-specific cohort size in incidence calculations hides true utilization rates. Among patients ≥65 years, the OECD-based incidence rose from 82 [78; 86] to 99 [94; 104] between 2005 and 2022. However, when the same data are recalculated as an age-specific utilization, rates fall from 560 [532; 587] to 517 [492; 542], indicating an 8% decline in procedures in this age group. The discrepancy between both metrics is less severe in the patients ≤64 years as this group represents ~81% of the total population yet only 50% of procedures (Supplementary material 4).

Utilization rate dynamics during COVID-19

Between 2019 and 2020, knee-arthroplasty procedures fell by around 22%, from 1.87 [1.78; 1.96] to 1.46 [1.39; 1.53] million, with similar declines in both age groups. 17 of 25 countries recorded a drop of ≥10%, with the U.K. showing the steepest decline (-68%). Recovery between 2020 and 2022 was rapid: 20 countries grew ≥10% and 11 exceeded pre-COVID volumes. Overall, volume in 2022 remained ~19,000 procedures [18,100; 20,000] (-1.0%) below the pre-pandemic peak. Yet, recovery between 2020 and 2022 was age-dependent, with procedures for ≤64 years increasing by +31.88% [30.32%; 33.83%] (i.e., ~225,500 [214,400; 236,500] procedures), whereas the ≥65 age group increased by +21.49% [21.28%; 22.78%] (i.e., ~161,900 [154,000; 169,800] procedures). Supplementary material 5 visualizes the dip and recovery from COVID-19.

Sensitivity analyses

We tested alternative procedure distributions between U.S. patients aged ≥65 and ≤64 years. Scenarios 1–3 closely matched our base, with deviations within ~1% range. In contrast, Scenarios 4 and 5 showed the younger cohort had not yet surpassed the 50% share in 2022. Compared to baseline growth (2011–2022) of +7% (≥65) and +62% (< 65), Scenario 5 showed +3% and +86%, respectively (Supplementary material 6). In 2022, OECD-wide utilization rates differed by ~13–14% between sensitivity bounds for both age groups (Supplementary material 7 and 8). Overall direction of utilization rate trends remained consistent.

Combining age distribution scenarios with NIS volume variation (up to ± 10%), shifted overall utilization by ~10%, with greater variation in age-specific rates due to compounded volume and allocation assumptions (Supplementary material 9 and 10).

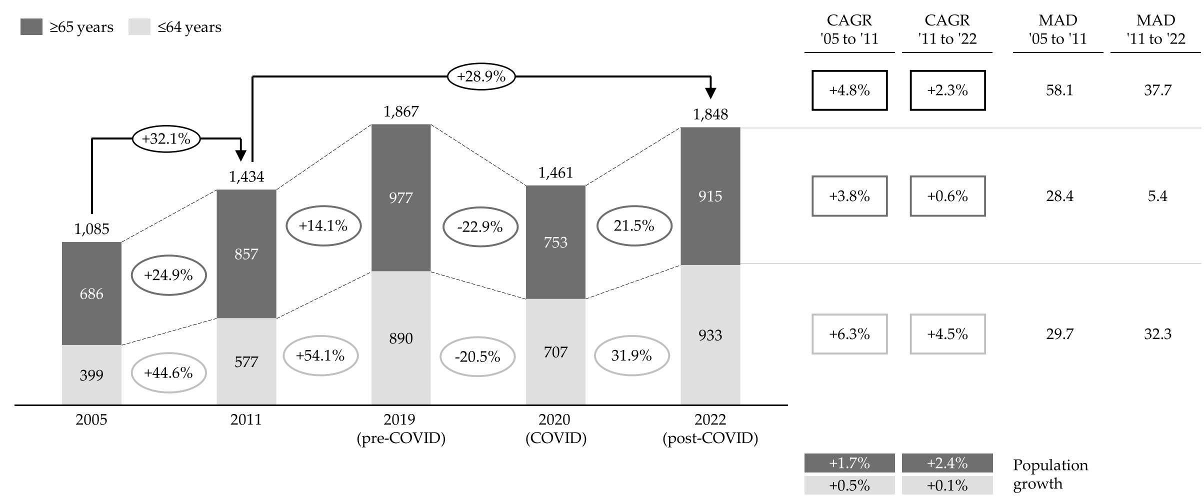

Fig. 1 Osteoarthritis and Cartilage

Total number of knee arthroplasties from 2005 to 2022 (in thousands). Note: Bars show 2005, 2011, and 2022 volumes, divided by age group. Numbers within bars indicate absolute procedure volumes (in thousands). Percentages between bars show an absolute increase in knee arthroplasty volume for the respective period. MAD also reported in thousands.

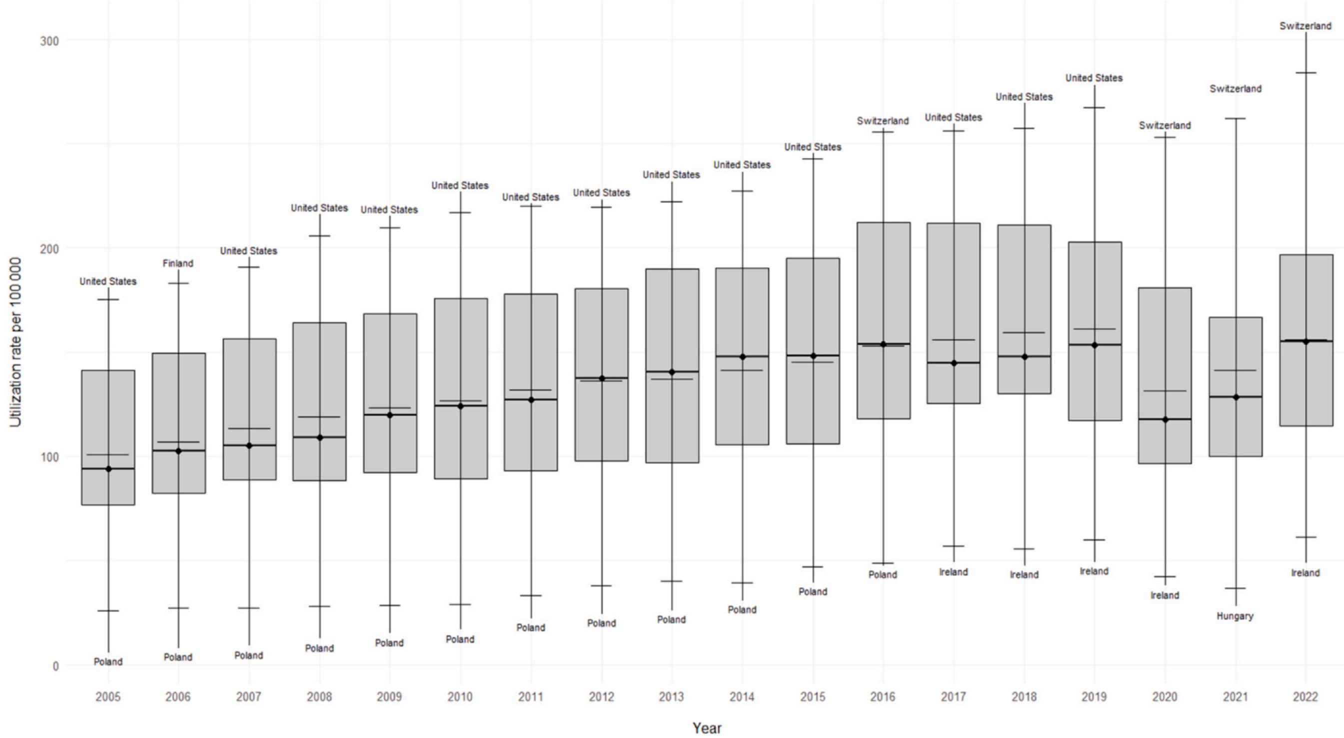

Fig. 2 Osteoarthritis and Cartilage

Knee arthroplasty utilization rate in OECD countries per 100,000 population (2005–2022). Note: For each year from 2005 to 2022, boxes display the range spanning 1.5 times the interquartile range (IQR) of knee arthroplasty utilization rates across OECD countries. Vertical whiskers above and below indicate the 95% confidence interval around the median. The thin horizontal black line within each box denotes the annual mean, while the bold black line with dots shows the median. Country names label the lowest and highest values observed each year. Figure displays NIS data as extracted with no sensitivity deviation.

Country	Obesity[a] [% of population]	Overweight[a] [% of population]	GDP [$/capita]	Health expenditure [$/capita]	Life expectancy [in years]	Hospital beds [per 1000 inhabitants]	Population aged ≥65 [% of population]
Australia	30.7	33.30	65,835	5616	83.2	3.9	17.1
Austria	17.8	34.50	70,676	5519	81.4	6.7	19.5
Belgium	24.2	36.10	68,080	5141	81.8	5.5	19.7
Canada	24.4	35.81	62,708	5432	81.6	2.5	18.8
Denmark	19.1	34.16	77,335	5070	81.3	2.5	20.4
Estonia	[S]21.0	[S]31.70	47,762	2525	78.1	4.2	20.3
Finland	30.2	39.70	61,293	4426	81.2	2.6	23.2
France	[S]15.5	[S]32.02	56,134	5133	82.3	5.5	21.1
Germany	[S]16.9	[S]36.00	67,533	6392	80.7	7.7	22.1
Hungary	34.8	34.77	43,665	2420	76.0	6.7	20.6
Ireland	[S]21.0	[S]37.00	137,231	5421	82.6	2.9	15.1
Italy	11.4	35.00	56,172	3383	82.8	3.1	23.9
Korea	7.1	29.40	50,792	4107	82.7	12.8	17.5
Luxembourg	17.1	31.90	144,751	5518	83.0	4.0	14.8
Netherlands	14.6	34.10	77,087	5348	81.7	2.5	20.1
New Zealand	34.9	33.70	53,071	4875	82.0	2.6	16.4
Norway	16.0	36.00	122,516	6331	82.6	3.4	18.3
Poland	19.1	38.63	46,039	2374	77.2	6.1	19.2
Portugal	[S]15.9	[S]37.30	44,520	3401	81.8	3.5	23.8
Slovenia	20.2	37.10	51,036	3491	81.3	4.1	21.3
Spain	14.9	35.30	50,454	3442	83.2	3.0	20.2
Sweden	16.1	36.00	66,320	5292	83.1	1.9	20.3
Switzerland	12.1	30.80	90,139	7214	83.7	4.4	19.1
U.K.	29.2	36.20	58,393	4524	80.9	2.5	18.9
U.S.[a]	45.7	30.30	78,035	10,635	76.4	2.8	17.3
Mean	28.3	33.1	66,699	6824	79.7	3.03	13.8

[a] 2012 measured rates where available. In cases no measured data was reported, self-reported obesity percentages ([S]) were used as the best alternative estimate.

Table 4 Osteoarthritis and Cartilage

Descriptive statistics of explanatory variables for 2022.

Within- and between-country modelling

We examined scatterplots and skewness of covariates (Supplementary material 11). GDP per capita showed right skewness and was log-transformed, while life expectancy was left-skewed and squared.

Descriptives of explanatory variables for 2022 are shown in Table 4. Mean obesity prevalence was 28.3% and overweight averaged 33.1%. GDP per capita showed wide variation (mean: USD 66,699; range: USD 12,516–144,751). Average health expenditure was USD 6824 per capita, life expectancy 79.7 years, hospital beds 3.0 per 1000 inhabitants, and share of population aged ≥65 years averaged 13.8%.

Table 5 summarizes the panel characteristics. Mean utilization across 300 country-years was 133.6, with greater between-country (SD: 54.3) than within-country variation (SD: 21.2). Age-specific means were 461.4 (≥65 years) and 68.2 (≤64 years). Obesity averaged 17.26% of the adult population, while being overweight was twice as common (35.20%). Overall, most variability for knee arthroplasty utilization and BMI measures was *between* countries.

Knee utilization correlated strongly with health expenditure (β = 25.18; 95% CI: 22.78–27.58; r = 0.70), GDP (β = 1.24; 95% CI: 0.98–1.50; r = 0.41), and life expectancy (β = 10.66; 95% CI: 8.33–13.03; r = 0.39), with stronger GDP effects after log transformation (β = 83.30; 95% CI: 70.77–95.84; r = 0.53) (Table 6, Supplementary Material 12). Obesity was positively associated with utilization (β = 1.37; 95% CI: 0.68–2.06), while overweight showed weak/negative associations (β = −4.39; 95% CI: −6.23 to −2.55).

Table 7 presents three fixed effects models linking obesity/overweight to knee arthroplasty utilization.

In Model 1, health expenditure, hospital beds, and population share of ≥65 years showed positive significant impact on overall utilization. Meanwhile, GDP had a negative influence.

In Model 2, obesity and overweight were significantly positively associated with total utilization (obesity: 14.31 (standard error (SE): 4.30); overweight: 19.23 (SE: 6.10)), and model fit improved compared to the baseline Model 1 (R^2 = 0.22 vs. 0.09). Age-stratified models revealed differences in the strength of associations. Among individuals ≤64 (Model 3), obesity/overweight coefficients were substantially smaller (6.34 (SE: 3.07) and 6.57 (SE: 4.47)), whereas in the ≥65 population (Model 4), these coefficients increased sharply (73.84 (SE: 15.31) and 57.13 (SE: 22.28)). We found no associations between overweight and utilization rates in the ≤64 cohort.

For interpretation: In Model 2, each additional USD 1000 in health expenditure per capita linked to ~9.5 extra procedures overall and ~35.9 in adults ≥65. For obesity, the effect varied by income level. At mean GDP (log = 3.71; ≈ USD 40,850), a 1pp obesity rise was linked to 2.5 more procedures per 100,000 older adults; effects rose to 4.7 in low-income countries (GDP ≈ USD 20,100) and fell to near zero in high-income ones (GDP ≈ USD 81,450). While absolute effects were higher in ≥65 patients, the increase as % of mean utilization rate were similar across cohorts (e.g., +1.9% in Model 2, +1.1% in Model 4).

Across all within-country models, *Overweight/Obesity × GDP* was negative, indicating diminishing weight-related effects with rising country income, especially in the ≥65 group.

Between-country models (Models 5–8) showed no consistent association between obesity/overweight and utilization rates. Only Model 6 and 8 showed significant positive associations for overweight.

Discussion

Utilization growth concentrated in patients below 65

Projections by Kurtz et al [22]. that half of all knee replacements would be performed in patients ≤64 “by 2030” have already

Variable	Dimension	Mean	SD	Min.	Max.	Observations
Knee utilization rate	overall	133.62	57.03	5.7	259.9	NT = 300
	within		21.16	-67.45	51.25	T = 15
	between		54.25	30.63	208.65	N = 20
Knee utilization rate ≤64 years	overall	68.16	36.91	1.96	166.79	NT = 300
	within		17.8	-45.01	52.91	T = 15
	between		33.12	9.04	131.83	N = 20
Knee utilization rate ≥65 years	overall	461.35	193.7	30.29	933.27	NT = 300
	within		44.35	-144.27	140.1	T = 15
	between		193.13	126.29	878.22	N = 20
Obesity (% of population)	overall	17.26	6.03	7.68	32.5	NT = 300
	within		1.66	-3.74	8.7	T = 15
	between		5.94	9.83	29.25	N = 20
Overweight (% of population)	overall	35.20	2.62	26.19	40.8	NT = 300
	within		1.03	-3.16	3.08	T = 15
	between		2.46	29.35	39.09	N = 20
GDP per capita (in thousands)	overall	42.42	11.82	13.94	92.81	NT = 300
	within		7.04	-17.62	35.53	T = 15
	between		9.73	23.65	61.48	N = 20
GDP per capita (log)	overall	3.71	0.28	2.63	4.53	NT = 300
	within		0.16	-0.49	0.53	T = 15
	between		0.24	3.13	4.11	N = 20
Health expenditure per capita (in thousands)	overall	4.03	1.08	1.12	6.76	NT = 300
	within		0.37	-1.04	0.92	T = 15
	between		1.04	1.64	5.93	N = 20
Life expectancy (in years)	overall	81.02	1.53	75	84	NT = 300
	within		0.86	-2.57	1.88	T = 15
	between		1.3	76.75	82.84	N = 20
Life expectancy (sqt)	overall	6567.17	245.66	5625	7056	NT = 300
	within		138.14	-405.96	306.67	T = 15
	between		208.07	5891.12	6863.01	N = 20
Hospital beds (per 1000 inhabitants)	overall	4.44	1.72	2.07	8.47	NT = 300
	within		0.46	-1.89	2.07	T = 15
	between		1.7	2.58	8.2	N = 20
Population aged ≥65 (% of population)	overall	17.05	2.56	10.76	23.06	NT = 300
	within		1.26	-2.74	3.38	T = 15
	between		2.29	12.16	21.19	N = 20

Note: N = Number of observations (i.e., countries); T = Number of time periods (i.e., years); NT = Number of total observations (i.e., N * T).

Table 5 Osteoarthritis and Cartilage

Panel summary statistics.

materialized in our base case (Fig. 1). Several factors drawn from prior literature may help explain factors behind the increase in utilization in the ≤64 cohort which goes beyond population growth.

First, body weight has been shown to increase more quickly in younger than in older adults, imposing supra-physiological loads on articular cartilage, accelerating degeneration and pain onset [23]. We show that obesity prevalence within countries correlates with utilization rates.

Second, Snoeker et al[24]. show that a more active population has brought a steady incidence of traumatic knee injuries such as anterior-cruciate-ligament rupture or intra-articular fractures. Such sport-related injuries raise OA risk in the 40–50 s [25] Notably, rising weight and active populations are not necessarily mutually exclusive, but rather reflect a polarization, with more individuals at both ends of the spectrum. Finnish epidemiological data attribute ~70% of knee OA hospitalizations to prior injury, physical workload, and/or excessive weight [26].

Third, access criteria now emphasize symptoms and function over age [25,27]. Younger patients with severe symptoms are now considered appropriate surgical candidates, especially because better baseline health predicts favorable long-term outcomes.

Lastly, technological and surgical advances have been shown to expand candidacy for knee replacement among younger, active adults [7–10]. Modern implants (e.g., enhanced polyethylene) now show > 80% survival beyond 25 years [28]. A 40-year follow-up from the Hospital for Special Surgery found most patients < 55 years did not require revision [29]. This progress may have fostered a growth cycle: surgeons operate earlier, and patients accept surgery sooner.

Recovery dynamics post COVID-19

Volumes recovered post COVID-19 once elective surgery resumed, but our data show that the rebound was steeper among patients ≤64 years. We hypothesize based on prior literature that three factors may have favored this cohort.

Triage protocols introduced in 2020–2021 prioritized low-risk, short-stay cases to protect bed capacity and minimize postoperative Intensive Care Unit (ICU) use. Hospitals in Canada and Finland reported case-mix shift toward healthier patients with shorter length of stay and more direct-to-home discharges [30–32].

Moreover, Thaler et al. [33] showed that staffing shortages limited operating-room throughput. When capacity was constrained, schedulers favored cases unlikely to require intensive peri-operative resources [30]. Exceptions underline the role of policy: when Finland explicitly targeted backlog reduction in adults ≥70 years, procedure volume rose by 29% within six months of reopening [32]. Overall, however, external data shows that most OECD countries prioritized younger backlogs, leaving a residual elderly deficit.

Predictor	Outcome	β (slope)	95% CI (β)	Pearson r	95% CI (r)
Obesity (% of population)	Total utilization	1.369	[0.681; 2.057]	0.182	[0.091; 0.270]
	Utilization rate ≥65	5.300	[2.651; 7.948]	0.183	[0.092; 0.270]
	Utilization rate ≤64	0.701	[0.255; 1.147]	0.144	[0.053; 0.234]
Overweight (% of population)	Total utilization	-4.389	[-6.232; −2.547]	0.216	[0.126; 0.302]
	Utilization rate ≥65	-29.658	[-36.386; −22.930]	0.379	[0.297; 0.455]
	Utilization rate ≤64	-0.897	[-2.111; 0.318]	0.068	[-0.024; 0.160]
GDP per capita (in thousands)	Total utilization	1.239	[0.981; 1.497]	0.407	[0.327; 0.481]
	Utilization rate ≥65	3.956	[2.931; 4.980]	0.338	[0.253; 0.417]
	Utilization rate ≤64	0.691	[0.52; 0.861]	0.352	[0.268; 0.430]
Health expenditure per capita (in thousands)	Total utilization	25.181	[22.782; 27.580]	0.698	[0.647; 0.742]
	Utilization rate ≥65	76.634	[65.867; 87.401]	0.551	[0.484; 0.612]
	Utilization rate ≤64	14.532	[12.844; 16.220]	0.624	[0.565; 0.678]
Life expectancy (in years)	Total utilization	10.680	[8.333; 13.027]	0.389	[0.308; 0.465]
	Utilization rate ≥65	27.839	[18.370; 37.307]	0.263	[0.175; 0.347]
	Utilization rate ≤64	6.250	[4.713; 7.788]	0.353	[0.270; 0.431]
Hospital beds (per 1000 inhabitants)	Total utilization	1.426	[-1.219; 4.070]	0.050	[-0.043; 0.142]
	Utilization rate ≥65	8.835	[-1.333; 19.003]	0.080	[-0.012; 0.171]
	Utilization rate ≤64	0.311	[-1.397; 2.018]	0.017	[-0.076; 0.109]
Population aged ≥65 (% of population)	Total utilization	442.764	[252.551; 632.977]	0.211	[0.121; 0.298]
	Utilization rate ≥65	-3548.190	[-4221.649; −2874.731]	0.439	[0.362; 0.511]
	Utilization rate ≤64	754.369	[650.193; 858.544]	0.558	[0.491; 0.618]

Note: β coefficients indicate the change in knee arthroplasty utilization (per 100,000 population). Pearson correlation coefficients (r) reflect the strength and direction of the relationship. Estimates are based on simple linear regressions using pooled country-year data from 2005 to 2022. Corresponding scatterplots are available in Supplementary material 6. Results for transformed predictors are shown in Supplementary material 7.

Table 6 Osteoarthritis and Cartilage

Linear regression results for knee arthroplasties and selected predictors across OECD countries.

Lastly, it has been shown that risk tolerance differed by age. Surveys from the U.S. showed that adults ≤64 years were more willing to accept peri-operative COVID-19 exposure and to proceed with surgery (44% vs. 31%) [34]. Gómez-Barrena et al. [31] reported older patients often postponed surgery until pain became intolerable.

	Dependent variable: Knee utilization rate							
	Within country variation				**Between** countries' variation			
Independent variables	**(1)** Base	**(2)** Total	**(3)** ≤64 yrs	**(4)** ≥65 yrs	**(5)** Base	**(6)** Total	**(7)** ≤64 yrs	**(8)** ≥65 yrs
Obesity *% with BMI ≥ 30*		14.313***	6.343*	73.837***		-44.171	-38.725	-189.931
		(4.203)	(3.070)	(15.308)		(27.775)	(29.635)	(95.026)
Overweight *% with BMI ≥ 25–30*		19.228**	6.570	57.125*		128.161*	63.218	494.850*
		(6.096)	(4.468)	(22.280)		(46.831)	(51.411)	(164.854)
GDP (log) *1000 USD per capita*	-30.083**	217.572***	60.649	896.138***	-175.413	1095.017*	231.036	3904.398*
	(10.838)	(60.140)	(44.021)	(219.511)	(113.329)	(432.204)	(465.249)	(1491.846)
Health expenditure *1000 USD per capita*	11.833***	9.471**	-0.782	35.895**	68.665*	27.741	53.234*	137.021
	(3.552)	(3.388)	(2.413)	(12.031)	(27.186)	(25.974)	(23.863)	(76.520)
Life expectancy (sqt) *in years*	-0.004	-0.009	-0.027*	0.183**	0.025	0.009	0.050	0.134
	(0.018)	(0.017)	(0.013)	(0.062)	(0.061)	(0.037)	(0.036)	(0.116)
Hospital beds *per 1000 inhabitants*	6.089**	5.536**	-3.117*	43.308***	2.999	8.885	5.758	13.074
	(1.861)	(1.751)	(1.238)	(6.173)	(7.030)	(4.306)	(4.724)	(15.148)
Population ≥65 *% of population*	4.632**	6.442***			3.717	12.073**		
	(1.611)	(1.537)			(4.454)	(3.549)		
Obesity x GDP (log)		-3.181**	-1.381	-18.559***		13.604	10.445	57.874*
		(0.984)	(0.720)	(3.592)		(7.430)	(7.988)	(25.614)
Overweight x GDP (log)		-5.222**	-1.746	-15.204*		-35.472*	-15.722	-136.460*
		(1.676)	(1.228)	(6.126)		(12.640)	(13.897)	(44.560)
Observations *(N)*	300	300	300	300	20	20	20	20
R^2	0.092	0.221	0.143	0.363	0.649	0.919	0.713	0.913
Adjusted R^2	-0.040	0.094	0.007	0.262	0.523	0.847	0.503	0.850

Note: * p < 0.05, ** p < 0.01, *** p < 0.001; number in brackets indicate standard errors of coefficients.

Table 7 Osteoarthritis and Cartilage

Results of within- and between-country models.

Obesity and overweight implications on utilization rate

Each 1pp rise in adult obesity was associated with an increase of knee arthroplasty utilization by 2.5 procedures (+1.9%) per 100,000 in middle-income countries (GDP(log) = 3.7; ≈USD 40,850), with effects varying slightly by age and GDP. Between-country models showed no strong link, suggesting obesity is more strongly associated with within-country year-to-year changes rather than between countries.

Widely known, excess body weight accelerates progression to end-stage OA via mechanical overload and metabolic injury, including cartilage degradation from higher joint loads, adipose-derived inflammatory cytokines, and hyperglycemia-induced cartilage stiffening [35,36]. Obesity and overweight increase knee replacement risk by ~100% and ~40%, respectively, and obesity shortens the time to surgery [35,37]. Our age-stratified models mostly showed a stronger impact of obesity vs. overweight echoing Hussain et al.'s [38] finding that obesity carries higher arthroplasty risk.

The negative *Obesity/Overweight* × *GDP* implies that the association between weight and knee arthroplasty utilization is weaker in higher GDP countries; possibly due to broader access to non-surgical management, like weight management programs (physical and educational) or physiotherapy [39,40]. Hence, progression from obesity to end-stage joint damage may eventually be slowed.

Lastly, we observed weaker associations in between-country models, which may reflect variance in system-level factors (e.g., national healthcare capacity, waitlist management, and resource availability). Differences in guidelines, reimbursement structures, and surgeon density may further moderate how obesity prevalence translates to volume [27].

To illustrate cost impacts, a simplified U.S.-based calculation shows a 1pp rise in obesity increases utilization from 271 to 276 per 100,000 (+1.9%), equating to 17,177 extra procedures annually. With average costs of USD 20,000 per total knee arthroplasty (TKA) [41,42] and a 12.6% revision rate [7], this implies incremental annual costs of ~USD 300.2 million per year. While simplified, this underscores the cost exposure and once more illustrates the value that policies preventing obesity trajectories may have.

Policy implications

Rising knee arthroplasty volume among younger adults requires consideration of tailored policy responses:

Given substantial variation in access, reimbursement, and guideline endorsement for pharmacological treatments (e.g., platelet-rich plasma and hyaluronic acid), policy efforts should foster broadly supported non-operative regimens [43]. OECD health systems could implement mandatory, structured non-operative care plans before stepwise escalation to pharmacological treatments, thus making conservative care systematic instead of ad hoc. Endorsed by major international guidelines (i.e., Osteoarthritis Research Society International (OARSI) [44], European Society for Clinical and Economic Aspects of Osteoporosis (ESCEO) [45]), such plans should include physiotherapy or supervised exercise, weight-management support, and patient education. Clear, patient-centered escalation criteria should guide referral to orthopedic care when first-line non-operative options are insufficient. International examples such as GLA:D [46] and AktivA [47] (from Denmark and Sweden) illustrate how evidence-based non-operative treatments are exhausted in primary care prior to knee arthroplasty. Recent efforts in high utilization rate countries, such as Switzerland, further demonstrate ongoing efforts to develop care models and treatment algorithms which prioritize non-operative options. Still, in case of surgical procedures, structured care pathways tailored to working-age adults (e.g., fast track surgery and faster return-to-work protocols) have proven effective in reducing system strain [48].

Second, evidence suggests that the pandemic revealed systematic postponement of older patients with weaker volume recovery [30,33]. Age-neutral triage protocols may help to avoid systematic deferral of older, higher-risk patients during future service disruptions. Particularly in lower-GDP countries, continued investment in weight-management programs and lifestyle education may help to exhaust non-operative options first.

Lastly, harmonizing European registries would ensure consistent definitions and reporting, enabling like-for-like cross-country comparisons. It would potentially reduce reliance on imputations, provide more precise age-stratified data, and make reporting on implant type, fixation, patient characteristics, and revision causes more feasible. With the new EU Health Technology Assessment (HTA) Regulation (EU 2021/2282) [49], which mandates joint HTAs, a harmonized pan-European arthroplasty registry could be a valuable next step.

Looking back on the previous projection

Our 2015 model projected a four-fold rise in knee-arthroplasty volume between 2011 and 2030. With data available up to 2022, cumulative growth reached +29%, well below the path to meet that forecast. Thus, suggesting that updated trend implies a lower near-term burden. The pandemic-related contraction and plateau likely contributed. Whether utilization will re-accelerate or stabilize at a lower trajectory, as argued by Le Stum et al. [13], remains to be validated.

Limitations and future direction

This study has some limitations. Data availability varied by country and year, requiring imputation and substitution. While sensitivity analyses showed a minimal impact on overall trends, uncertainty at the country level remains. Second, our binary age split may hide utilization trends in granular age bands (e.g., 65–74 or ≥ 85 years). Future work should try to disaggregate knee-arthroplasty utilization to identify more granular inflection points. Third, ICD coding and sampling heterogeneity existed over the study period. Especially the transition from ICD-9 to ICD-10 (e.g., 81.54 ICD-9 code converted to > 20 procedure codes under ICD-10) and the redesign of the NIS sampling strategy may affect comparability across years that span these changes. Using contemporaneous obesity data may underestimate the lagged influence on utilization, calling for studies with longer data series. Moreover, system-level factors seem to mediate how risk factors translate into surgical volume, but are hard to model directly.

Future research on historic utilization rates can prioritize country-specific studies to better understand how national health nuances shape utilization rates. While some single-country analyses exist, many regions remain underexplored. Applying this framework to emerging economies will help determine if current trends extend beyond the OECD. Lastly, our findings inform the expectations of future knee arthroplasty burden based on historical trends, yet they do not include a formal projection. Future research can use our revised starting point to drive OECD and country-level projections.

Conclusions

Despite current utilization rate falling short of our earlier projection, knee arthroplasty has risen across OECD countries over the past decade, albeit at a slower pace than expected in 2015. Cross-country variation has narrowed with previously low utilization countries catching up in procedures. Obesity remains strongly associated with utilization rates, particularly in the ≥65 group, though its impact seems weaker in higher-income countries. Compared to our 2015 study, patients below 65 years now account for more than 50% of procedures, marking a milestone in the volume shift towards younger cohorts. Our findings suggest a revised, lower near-term burden than projected previously and highlight the continued importance of age-stratified monitoring to inform orthopedic planning.

CRediT authorship contribution statement

Author 1: Conceptualization, Methodology, Formal analysis, Data curation, Interpretation, Writing – original draft, Writing – review & editing, Visualization, Project administration. **Author 2:** Conceptualization, Interpretation, Writing – review & editing, Supervision. **Author 3:** Conceptualization, Interpretation, Writing – review & editing, Supervision. **Author 4:** Conceptualization, Project administration, Interpretation, Writing – review & editing, Supervision.

Funding

None.

Conflict of interest

None.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.joca.2026.03.002.

References

[1] M. Bhandari, J. Smith, L.E. Miller, J.E. Block, Clinical and economic burden of revision knee arthroplasty, Clin. Med. Insights Arthritis Musculoskelet. Disord. 5 (2012) 89–94, https://doi.org/10.4137/CMAMD.S10859
[2] J.Le Ren, J. Yang, W. Hu, The global burden of osteoarthritis knee: a secondary data analysis of a population-based study, Clin. Rheumatol. (2025), https://doi.org/10.1007/s10067-025-07347-6
[3] I. Shichman, M. Roof, N. Askew, et al., Projections and epidemiology of primary hip and knee arthroplasty in medicare patients to 2040–2060, JB JS Open Access 8 (2023), https://doi.org/10.2106/JBJS.OA.22.00112
[4] C. Pabinger, H. Lothaller, A. Geissler, Utilization rates of knee-arthroplasty in OECD countries, Osteoarthr. Cartil. 23 (2015) 1664–1673, https://doi.org/10.1016/j.joca.2015.05.008
[5] S. Kurtz, F. Mowat, K. Ong, N. Chan, E. Lau, M. Halpern, Prevalence of primary and revision total hip and knee arthroplasty in the United States from 1990 to 2002, J. Bone Jt. Surg. J. Bone Jt. Surg. Inc. 87 (2005) 1487–1497, https://doi.org/10.2106/JBJS.D.02441
[6] B. Kayani, S. Konan, A. Ayuob, E. Onochie, T. Al-Jabri, F.S. Haddad, Robotic technology in total knee arthroplasty: a systematic review, EFORT Open Rev. 4 (2019) 611–617, https://doi.org/10.1302/2058-5241.4.190022
[7] S.P. Ryan, J.B. Stambough, J.I. Huddleston, B.R. Levine, Highlights of the 2023 American joint replacement registry annual report, Arthroplast Today 26 (2024), https://doi.org/10.1016/j.artd.2024.101325
[8] F. Picard, A. Deakin, N. Balasubramanian, A. Gregori, Minimally invasive total knee replacement: techniques and results, Eur. J. Orthopaed. Surg. Traumatol. 28 (2018) 781–791, https://doi.org/10.1007/s00590-018-2164-4
[9] W.M. Mihalko, H. Haider, S. Kurtz, M. Marcolongo, K. Urish, New materials for hip and knee joint replacement: what's hip and what's in kneed? J. Orthopaed. Res. 38 (2020) 1436–1444, https://doi.org/10.1002/jor.24750
[10] A. Aprato, S. Risitano, L. Sabatini, M. Giachino, G. Agati, A. Massè, Cementless total knee arthroplasty, Ann. Transl. Med. 4 (2016), https://doi.org/10.21037/atm.2016.01.34
[11] OECD, OECD Health Statistics, 2025. ⟨https://www.oecd.org/en/data/datasets/oecd-health-statistics.html⟩.
[12] World Bank, World Bank Open Data, 2025. ⟨https://data.worldbank.org/indicator/NY.GDP.PCAP.CD⟩.
[13] M. Le Stum, M. Le Goff-Pronost, E. Stindel, G. Dardenne, Incidence rate of total knee arthroplasties in eleven European countries: do they reach a plateau? PLoS One 20 (2025) e0312701, https://doi.org/10.1371/journal.pone.0312701
[14] A. Wengler, U. Nimptsch, T. Mansky, Hip and knee replacement in Germany and the USA, Dtsch. Arztebl. Int. 111 (2014) 407–416, https://doi.org/10.3238/arztebl.2014.0407
[15] H.M. Kremers, D.R. Larson, C.S. Crowson, et al., Prevalence of total hip and knee replacement in the United States, J. Bone Jt. Surg. Am. Vol. 97 (2014) 1386–1397, https://doi.org/10.2106/JBJS.N.01141
[16] R. Otten, P.M. van Roermund, H.S.J. Picavet, Trends in the number of knee and hip arthroplasties: considerably more knee and hip prostheses due to osteoarthritis in 2030, Ned. Tijdschr. Geneeskd. 154 (2010).
[17] M. Le Stum, T. Gicquel, G. Dardenne, M. Le Goff-Pronost, E. Stindel, A. Clavé, Total knee arthroplasty in France: male-driven rise in procedures in 2009–2019 and projections for 2050, Orthop. Traumatol. Surg. Res. 109 (2023), https://doi.org/10.1016/j.otsr.2022.103463
[18] S. Nemes, O. Rolfson, A. W-Dahl, et al., Historical view and future demand for knee arthroplasty in Sweden, Acta Orthop. 86 (2015) 426–431, https://doi.org/10.3109/17453674.2015.1034608
[19] J. Backes, C. Pabinger, H. Lothaller, A. Geissler, Utilization rates of hip arthroplasty in OECD countries revised, Osteoarthr. Cartil. (2025), https://doi.org/10.1016/J.JOCA.2025.09.012 (Published online September).
[20] P.J. Rullán, A.K. Emara, G. Zhou, et al., National inpatient datasets may no longer be appropriate for overall total hip and knee arthroplasties projections after removal from inpatient-only lists, J. Knee Surg. 37 (2022) 214–219, https://doi.org/10.1055/a-2037-6323
[21] D.P. Doane, L.E. Seward, Measuring skewness: a forgotten statistic? J. Stat. Educ. 19 (2011), https://doi.org/10.1080/10691898.2011.11889611
[22] S.M. Kurtz, E. Lau, K. Ong, K. Zhao, M. Kelly, K.J. Bozic, Future young patient demand for primary and revision joint replacement: national projections from 2010 to 2030, Clin. Orthopaed. Relat. Res. 467 (2009) 2606–2612, https://doi.org/10.1007/s11999-009-0834-6 k.
[23] W.H. Dietz, Obesity and excessive weight gain in young adults – new targets for prevention, JAMA - J. Am. Med. Assoc. Am. Med. Assoc. 318 (2017) 241–242, https://doi.org/10.1001/jama.2017.6119
[24] B. Snoeker, A. Turkiewicz, K. Magnusson, et al., Risk of knee osteoarthritis after different types of knee injuries in young adults: a population-based cohort study, Br. J. Sports Med. 54 (2020) 725–730, https://doi.org/10.1136/bjsports-2019-100959
[25] E. Losina, T.S. Thornhill, B.N. Rome, J. Wright, J.N. Katz, The dramatic increase in total knee replacement utilization rates in the United States cannot be fully explained by growth in population size and the obesity epidemic, J. Bone Jt. Surg. 94 (3) (2012) 201–207, https://doi.org/10.2106/JBJS.J.01958
[26] T. Kontio, M. Heliövaara, E. Viikari-Juntura, S. Solovieva, To what extent is severe osteoarthritis preventable? Occupational and non-occupational risk factors for knee and hip osteoarthritis, Rheumatology 59 (2020) 3869–3877, https://doi.org/10.1093/rheumatology/keaa238
[27] A.J. Price, A. Alvand, A. Troelsen, et al., Knee replacement, Lancet 392 (2018) 1672–1682, https://doi.org/10.1016/S0140-6736(18)32344-4
[28] R. Cook, P. Davidson, R. Martin, More than 80% of total knee replacements can last for 25 years, BMJ 367 (2019), https://doi.org/10.1136/bmj.l5680
[29] W.J. Long, C.D. Bryce, C.S. Hollenbeak, R.W. Benner, W. Scott, Total knee replacement in young, active patients: long-term follow-up and functional outcome: a concise follow-up of a previous report, J. Bone Jt. Surg. Am. Vol. 96 (1) (2014) e159, https://doi.org/10.2106/JBJS.M.01259
[30] J. Sniderman, A. Khoshbin, J. Wolfstadt, The influence of the COVID-19 pandemic on total hip and knee arthroplasty in Ontario: a population-level analysis, Can. J. Surg. 66 (2023) E485–E490, https://doi.org/10.1503/cjs.016122
[31] E. Gómez-Barrena, I. Rubio-Saez, N.G. Padilla-Eguiluz, P. Hernandez-Esteban, Both younger and elderly patients in pain are willing to undergo knee replacement despite the COVID-19 pandemic: a study on surgical waiting lists, Knee Surg. Sports Traumatol. Arthrosc. 30 (2022) 2723–2730, https://doi.org/10.1007/s00167-021-06611-x
[32] M. Uimonen, I. Kuitunen, V. Ponkilainen, V.M. Mattila, Prioritizing elective surgery during the COVID-19 pandemic has caused age-related inequality: a multicenter study, SN Compr. Clin. Med. 4 (2022), https://doi.org/10.1007/s42399-021-01080-2
[33] M. Thaler, N. Kort, L. Zagra, et al., Prioritising of hip and knee arthroplasty procedures during the COVID-19 pandemic: the European Hip Society and the European Knee Associates Survey of Members, Knee Surg. Sports Traumatol. Arthrosc. 29 (2021) 3159–3163, https://doi.org/10.1007/s00167-020-06379-6
[34] T.S. Brown, N.A. Bedard, E.O. Rojas, et al., The effect of the COVID-19 pandemic on hip and knee arthroplasty patients in the United States: a multicenter update to the previous survey, Arthroplast Today 7 (2021) 268–272, https://doi.org/10.1016/j.artd.2020.11.025
[35] R. Shumnalieva, G. Kotov, P. Ermencheva, S. Monov, Pathogenic mechanisms and therapeutic approaches in obesity-related knee osteoarthritis, Biomedicines 12 (2023), https://doi.org/10.3390/biomedicines12010009
[36] D.M. Saudek, J. Kay, Advanced glycation endproducts and osteoarthritis, Curr. Rheumatol. Rep. 5 (2003) 33–40, https://doi.org/10.1007/s11926-003-0081-x
[37] K.M. Leyland, A. Judge, M.K. Javaid, et al., Obesity and the relative risk of knee replacement surgery in patients with knee osteoarthritis: a prospective cohort study, Arthritis Rheumatol. 68 (2016) 817–825, https://doi.org/10.1002/art.39486
[38] S.M. Hussain, I.N. Ackerman, Y. Wang, et al., Trajectories of body mass index from early adulthood to late midlife and incidence of total knee arthroplasty for osteoarthritis: findings from a prospective cohort study, Osteoarthr. Cartil. 31 (2023) 397–405, https://doi.org/10.1016/j.joca.2022.11.013
[39] NHS England, The NHS Digital Weight Management Programme, 2025. ⟨https://www.england.nhs.uk/digital-weight-management/⟩.
[40] M. Semyonov, N. Lewin-Epstein, D. Maskileyson, Where wealth matters more for health: the wealth-health gradient in 16 countries, Soc. Sci. Med. 81 (2013) 10–17, https://doi.org/10.1016/j.socscimed.2013.01.010

[41] N. Gandhi, A.S. Qadeer, A. Meher, et al., Costs and models used in the economic analysis of total knee replacement (TKR): a systematic review, PLoS One 18 (2023), https://doi.org/10.1371/journal.pone.0280371
[42] C.A. Waimann, R.J. Fernandez-Mazarambroz, S.B. Cantor, et al., Cost-effectiveness of total knee replacement: a prospective cohort study, Arthritis Care Res. 66 (2014) 592–599, https://doi.org/10.1002/acr.22186
[43] D. Rodríguez-Reyes, R. Vargas-Figueroa, A.S. Vázquez-Lloret, H.E.L. Martinez, G. Gonzalez-Diaz, R.S. Ortiz, Nonoperative management recommendations for knee osteoarthritis: a review of clinical guidelines and treatment alternatives, Cureus 17 (10) (2025) e95540, https://doi.org/10.7759/CUREUS.95540
[44] R.H. Brophy, Y.A. Fillingham, AAOS clinical practice guideline summary: management of osteoarthritis of the knee (nonarthroplasty), third edition, J. Am. Acad. Orthop. Surg. 30 (9) (2022) e721–e729, https://doi.org/10.5435/JAAOS-D-21-01233
[45] S. Bierma-Zeinstra, M. van Middelkoop, J. Runhaar, D. Schiphof, Nonpharmacological and nonsurgical approaches in OA, Best Pract. Res. Clin. Rheumatol. 34 (2) (2020) 101564, https://doi.org/10.1016/J.BERH.2020.101564
[46] S.T. Skou, E.M. Roos, Good life with osteoArthritis in Denmark (GLA:D™): evidence-based education and supervised neuromuscular exercise delivered by certified physiotherapists nationwide, BMC Musculoskelet. Disord. 18 (1) (2017) 1–13, https://doi.org/10.1186/S12891-017-1439-Y
[47] I. Holm, A.H. Pripp, M.A. Risberg, The active with OsteoArthritis (AktivA) physiotherapy implementation model: a patient education, supervised exercise and self-management program for patients with mild to moderate osteoarthritis of the knee or hip joint. A national register study with a …, J. Clin. Med. 9 (10) (2020) 1–14, https://doi.org/10.3390/JCM9103112
[48] T. Kamp, S. Brouwer, G.H. Seeber, et al., Return to work policies and practices after total hip or knee arthroplasty in Denmark, Germany, and the Netherlands: an exploratory study, Disabil. Rehabil. 46 (22) (2024) 5313–5322, https://doi.org/10.1080/09638288.2024.2304084
[49] European Union, Regulation (EU) 2021/2282 of the European Parliament and of the Council of 15 December 2021 on health technology assessment and amending Directive 2011/24/EU (Text with EEA relevance), 2021. Accessed 1 August 2025. ⟨https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX%3A32021R2282⟩.
[50] I. Shichman, M. Roof, N. Askew, et al., Projections and epidemiology of primary hip and knee arthroplasty in medicare patients to 2040–2060, JB JS Open Access 8 (2023), https://doi.org/10.2106/JBJS.OA.22.00112