How much is enough? Finding the minimum annual surgical volume threshold for total knee replacement

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There is compelling evidence that the outcome of total knee replacement (TKR) depends on the annual caseload of the surgeon and the institution.1-3 The fact that high-volume centres have better outcomes is so well known that patients themselves increasingly seek treatment at high-volume institutions.4

But how do we determine the surgical volume threshold that constitutes an acceptable risk?

In the recent article by Okoro et al, data from nearly 170,000 TKR recipient in Ontario, Canada, were analysed using a state of the art restricted cubic spline (RCS) analysis.5 The authors identified an inflection point for increased probability for early revision or infection at 70 annual cases, after which the risk of complications plateaued. However, risk reduction continued even beyond an annual caseload of 70, highlighting the value of treatment by high-volume surgeons.

This method of identifying the surgical volume threshold differs from previous studies conducted in the last 10 years (table 1). While some papers fail to mention their methods for defining the volume groups, others have largely split the data by quartiles. This results in more or less arbitrary thresholds that are more dependent on local healthcare structure and population size than providing clinical meaningful volume categories. Due to varying methods for defining the volume groups, the lowest volume category in one study6 would have been defined as the highest volume category in another.7 Clearly, if the goal is to identify the annual caseload that reduces complications and produce meaningful thresholds that surgeons and institutions can aim to achieve, the volume categories should not be defined a priori. This methodological flaw is corrected by the RCS analysis, which uses the dataset to identify the actual caseload threshold where the risk of complications is reduced.

However, it is unlikely that the threshold of 70 annual cases to reduce risk of complications is universal. Like any surgery, TKR surgery is composed of teamwork and environmental factors, such as healthcare structure and population demographics, which influence the outcome. Okoro et al suggest that all communities with available real-world data perform similar RCS analysis to identify the caseload threshold relevant to their population. It should therefore be mentioned that Yu et al published a similar RCS analysis from Taiwan in 2019.8 They found the inflection point to be somewhat lower in their population, at 50 cases per year, proving the point that the caseload threshold varies between populations. Differences in specialty training practices and best practices across nations affect volume threshold estimates. We predict that future research will produce new and different surgical volume thresholds to reduce complications, and it is unlikely that a definite answer will be possible to find. It is more likely that the true annual caseload threshold varies over time, as surgical training, implant design and population characteristics change.

Another challenge in determining acceptable caseload thresholds is that different complications will have different volume thresholds. Existing literature on the effect of surgical volume has used a spectrum of different outcomes, including 30-day readmission, revision rate, radiological implant alignment,9 surgical site infection and length of hospital stay (table 1). Different complications will have different etiologies, not all related to the experience of the surgeon. Hospital environment, population characteristics, postoperative care and rehabilitation facilities all play a part in securing a good outcome after arthroplasty surgery. For example, length of stay is dependent on...
Table 1  A literature review of publications in English from 2011 to 2021, with a minimum of 20 000 patients included, evaluating the effect of surgeon and/or hospital volume on total knee replacement outcome

### Surgeon–volume relationship

| Study          | N       | Setting                                           | Volume thresholds | Definition of threshold | Outcome | Result                  | OR (95% CI)          | P value |
|----------------|---------|---------------------------------------------------|-------------------|-------------------------|---------|-------------------------|----------------------|---------|
| Namba et al. (2013a) | 64017   | Total Joint Replacement Registry, USA             | 1–9, 10–49, ≥50   | Not explained           | Aseptic revision | No difference           | 1.11 (0.66 to 1.23) | 0.690   |
| Namba (2013b)   | 56216   | Total Joint Replacement Registry, USA             | <20, 20–49, ≥50   | Not explained           | Surgical site infection | No difference         | 1.30 (0.90 to 1.98) | 0.160   |
| Wilson et al. (2016) | 28976  | Statewide Planning and Research Cooperative System (SPARCS), New York, USA | 0–12, 13–59, 60–145, ≥146 | SSLR | CR and revision | Higher risk for low volume | 1.85 (1.75 to 1.97) | NR      |
| Yu et al. (2019) | 30828   | Taiwan National Health Insurance Research Database, Taiwan | 1–49, ≥50         | RCSR | Readmission       | Higher risk for low volume | 1.44 (1.22 to 1.69) | <0.001  |
| de la Torre et al. (2019) | 36316  | Catalan Arthroplasty Registry, Spain             | <125, >125        | Previous studies        | Revision | Higher risk for low volume | 1.29 (1.16 to 1.44) | NR      |
| Badawy et al. (2013) | 26698  | Norwegian Arthroplasty Register, Norway          | <25, 25–49, 50–99, 100–149, ≥150 | Previous studies | Revision | No difference           | 0.81† (0.68)      |         |
| D’apuzzo et al. (2017) | 377705 | Statewide Planning and Research Cooperative System (SPARCS), New York, USA | 1–89, 90–235, 236–644, ≥645 | SSLR | Readmission       | Higher risk for low volume | 1.32 (1.16 to 1.51) | <0.001  |
| Kurtz (2016)    | 952593  | Medicare 100% claims, USA                         | 150–299, 300–499, 450–599, ≥600 | Not explained | Readmission       | Higher readmissions for low volume | 51.2%†            |         |
| Meyer et al. (2011) | 43180  | Krankenhaus-Infektions-Surveillance System, Germany | 1–50, 51–99, >100 | Previous studies        | Surgical site infection | Higher risk for low volume | 2.04              |         |
| Namba et al. (2013a) | 64017  | Total Joint Replacement Registry, USA             | <100, 100–199, ≥200 | Not explained           | Aseptic revision | No difference           | 0.93 (0.59 to 1.44) | 0.769   |
| Namba (2013b)   | 56216   | Total Joint Replacement Registry, USA             | <100, 100–199, ≥200 | Not explained           | Surgical site infection | Lower risk for low volume | 0.33 (0.12 to 0.90) | 0.030   |
| Pamilo et al. (2015) | 59696  | Perfect Knee Replacement database, Finland        | 1–99, 100–249, 250–449, ≥450 | chosen arbitrarily | LOS, Readmission, MUA, revision | Higher readmission risk for low volume, no difference for revision | Readmission: 1.11 (1.03 to 1.19) | NR |

### Hospital–volume relationship

| Study          | N       | Setting                                           | Volume thresholds | Definition of threshold | Outcome | Result                  | OR (95% CI)          | P value |
|----------------|---------|---------------------------------------------------|-------------------|-------------------------|---------|-------------------------|----------------------|---------|
| Namba et al. (2013a) | 64017   | Total Joint Replacement Registry, USA             | <100, 100–199, ≥200 | Not explained           | Aseptic revision | No difference           | 1.11 (0.66 to 1.22) | 0.690   |
| Namba et al. (2013b) | 56216   | Total Joint Replacement Registry, USA             | <100, 100–199, ≥200 | Not explained           | Surgical site infection | No difference           | 1.30 (0.90 to 1.98) | 0.160   |
| Wilson et al. (2016) | 28976   | Statewide Planning and Research Cooperative System (SPARCS), New York, USA | 0–12, 13–59, 60–145, ≥146 | SSLR | CR and revision | Higher risk for low volume | 1.85 (1.75 to 1.97) | NR      |
| Yu et al. (2019) | 30828   | Taiwan National Health Insurance Research Database, Taiwan | 1–49, ≥50         | RCSR | Readmission       | Higher risk for low volume | 1.44 (1.22 to 1.69) | <0.001  |
| de la Torre et al. (2019) | 36316   | Catalan Arthroplasty Registry, Spain             | <125, >125        | Previous studies        | Revision | Higher risk for low volume | 1.29 (1.16 to 1.44) | NR      |
| Badawy et al. (2013) | 26698  | Norwegian Arthroplasty Register, Norway          | <25, 25–49, 50–99, 100–149, ≥150 | Previous studies | Revision | No difference           | 0.81† (0.68)      |         |
| D’apuzzo et al. (2017) | 377705 | Statewide Planning and Research Cooperative System (SPARCS), New York, USA | 1–89, 90–235, 236–644, ≥645 | SSLR | Readmission       | Higher risk for low volume | 1.32 (1.16 to 1.51) | <0.001  |
| Kurtz (2016)    | 952593  | Medicare 100% claims, USA                         | 150–299, 300–499, 450–599, ≥600 | Not explained | Readmission       | Higher readmissions for low volume | 51.2%†            |         |
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| Namba et al. (2013b) | 56216  | Total Joint Replacement Registry, USA             | <100, 100–199, ≥200 | Not explained           | Surgical site infection | Lower risk for low volume | 0.33 (0.12 to 0.90) | 0.030   |
| Pamilo et al. (2015) | 59696  | Perfect Knee Replacement database, Finland        | 1–99, 100–249, 250–449, ≥450 | chosen arbitrarily | LOS, Readmission, MUA, revision | Higher readmission risk for low volume, no difference for revision | Readmission: 1.11 (1.03 to 1.19) | NR |

Continued
| Study          | N     | Setting                          | Volume thresholds | Definition of threshold | Outcome          | Result          | OR (95% CI)       | P value |
|---------------|-------|----------------------------------|-------------------|-------------------------|------------------|----------------|------------------|---------|
|               |       |                                  |                   |                         |                  |                |                  |         |
| Author year   |       |                                  |                   |                         |                  |                |                  |         |
| Singh et al   | 2011  | Pennsylvania Healthcare Cost    | 1–25              | Low                     | Not explained    | CR and MR      | Higher risk for  | 1.1     |
|               |       | Containment Council database,   | 26–100            | Medium low              |                  |                | low volume       | (0.8 to 1.6) |         |
|               |       | USA                              | 101–200           | Medium high             |                  |                | NR               |         |
| Wilson        | 2016  | Statewide Planning and Research  | 0–89              | Low                     | SSLR CR and      | Higher risk for | 1.37              | 1.32     |
|               |       | Cooperative System (SPARCS), New | 90–235            | Medium low              | revision         | low volume      | (1.32 to 1.42)   | NR      |
|               |       | York, USA                        | 236–644           | Medium high             |                  |                |                  |         |
|               |       |                                  | >645              | Very High               |                  |                | NR               |         |
| Yu            | 2019  | Taiwan National Health Insurance | 1–74              | Low                     | RCSR Readmission | No association  | 1.07              | 0.90     |
|               |       | Research Data base, Taiwan       | >75               | Medium high             |                  |                | (1.28 to 1.45)   | 0.435   |

Search performed in Medline 9 April 2021 yielded 72 papers for screening.

*Relative risk.
†Percentage difference.

CR, complication rate; LOS, length of stay; MR, mortality rate; MUA, manipulation under anaesthesia; NR, not reported; RCSR, Restricted Cubic Spline Regression; SSLR, Stratum-specific likelihood ratio.

SURGEON–VOLUME RELATIONSHIP

Definition of

Table 1 Continued

Surgeon–volume relationship

| Study          | N     | Setting                          | Volume thresholds | Definition of threshold | Outcome          | Result          | OR (95% CI)       | P value |
|---------------|-------|----------------------------------|-------------------|-------------------------|------------------|----------------|------------------|---------|
|               |       |                                  |                   |                         |                  |                |                  |         |
| Author year   |       |                                  |                   |                         |                  |                |                  |         |

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†Percentage difference.

CR, complication rate; LOS, length of stay; MR, mortality rate; MUA, manipulation under anaesthesia; NR, not reported; RCSR, Restricted Cubic Spline Regression; SSLR, Stratum-specific likelihood ratio.
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