What is the learning curve associated with a hip resurfacing?

Pablo Slullitel[1,2], George Grammatopoulos[1], Alessandro Calistri[3], Catherine Van Der Straeten[4]

[1]Division of Orthopaedic Surgery, The Ottawa Hospital, Ottawa, Ontario, Canada; [2]Institute of Orthopaedics 'Carlos E. Ottolenghi', Italian Hospital of Buenos Aires, Buenos Aires, Argentina; [3]Department of Anatomical, Histological, Forensic Medicine and Orthopaedics Sciences, Sapienza University of Rome, Rome, Italy; [4]Health Innovation and Research Institute, Ghent University Hospital, Ghent, Belgium

Contributions: (I) Conception and design: All authors; (II) Administrative support: All authors; (III) Provision of study materials or patients: All authors; (IV) Collection and assembly of data: All authors; (V) Data analysis and interpretation: All authors; (VI) Manuscript writing: All authors; (VII) Final approval of manuscript: All authors.

Correspondence to: George Grammatopoulos, MBBS, BSc, FRCS (Tr. & Ortho), DPhil (Oxon). Division of Orthopaedic Surgery, The Ottawa Hospital – General Campus, 501 Smyth Road, CCW 1638, Ottawa, ON K1H 8L6, Canada. Email: ggrammatopoulos@toh.ca.

Abstract: There is a paucity of literature on the minimum number of cases necessary to become an expert surgeon in hip resurfacing arthroplasty (HRA). Thus, we aimed to describe (I) the learning curve of a primary hip replacement; (II) the learning curve of HRA using different end-points (complications, joint survival, component alignment and patient-reported outcome measures); and (III) what the minimum number of cases performed per year should be to maintain competency. A comprehensive literature search was performed reviewing joint arthroplasty registries, case-controlled studies, and case-series that have reported on the above. The reported learning curve necessary to decrease the overall complication rate in primary total hip arthroplasty (THA) is 90 cases. Additionally, the literature suggests that at least 35 primary THA cases per year is the recommended number above which complications reduce significantly. There is no doubt that only surgeons trained in primary hip replacement should perform HRA of the hip. On average, a learning curve of 50 cases has been described. Following this threshold, less complications, better radiographic assessment and superior patient reported outcomes have been described. It is the authors' opinion that at least 25 cases should be performed annually, which is in line with other highly specialized surgical procedures.

Keywords: Learning curve; hip resurfacing; complications; total hip replacement

Received: 03 September 2019; Accepted: 23 September 2019; Published: 12 October 2019.

doi: 10.21037/aoj.2019.09.08

View this article at: http://dx.doi.org/10.21037/aoj.2019.09.08

Introduction

Modern hip resurfacing prosthetic systems have been in practice since the early 2000s (1). The indications of the appropriate patients have significantly evolved over the past decade (2). When compared to conventional total hip arthroplasty (THA), numerous benefits of hip resurfacing arthroplasty (HRA) have been portrayed, making it more suitable for the young and active patient: bone preservation at the femoral neck; maintenance of leg length; higher activity level; and great inherent stability provided by a large femoral head (3,4).

HRA has shown excellent clinical and radiographic outcomes at mid- to long-term follow-up (5,6). However, the outcomes of HRA have not been reproducible worldwide, and some registries have displayed substantially higher revision rates when compared to conventional primary hip replacement (7,8). Data from the Australian Orthopaedic Association National Joint Replacement Registry (AOANJRR) suggested that risk factors for revision of HRA were older patients, female gender, small femoral head sizes (less than 50 mm), patients with hip dysplasia, and certain implant designs (9).

Nonetheless, it is critical to recognize that registries may analyze implant survival in diverse phases of their implementation. As Corten and MacDonald suggested, registries may be biased since new implants and technologies are undoubtedly associated with a learning curve (7). Understanding the presence and implication of a learning curve can help place the findings of a study in a more pragmatic, clinical context (10). In this scenario, if clinical trials are to include surgeons on their learning curve, they will be additionally assessing the learning curve of the procedure itself (11).

There is no doubt that highly specialized orthopaedic surgeries have a learning curve; periacetabular osteotomy (PAO) and hip arthroscopy constitute 2 non-arthroplasty examples for hip surgeons to understand expectations when beginning to perform these procedures, especially when they were priorly trained to perform only joint replacements. In the late 1990s, Davey and Santore compared the first 35 with second 35 PAOs performed by a single surgeon, observing a substantial reduction in the major complication rate (from 17% to 2.9%) (12). In line with these findings, Peters *et al.* found a significant decrease in complications (30% *vs.* 2%) when comparing the first 30 with the second 53 PAOs done by a single surgeon who had been trained by one of the fathers of the procedure and also had done 4 cadaveric surgeries (13). Regarding hip arthroscopy, Konan *et al.* compared the first 30 with the following 70 prospectively followed operations and found a marked decrease in complications as well as in operative time both for the central and peripheral compartment (14). Similarly, a systematic review of the literature also shows a learning curve of 30 cases necessary to reduce operative time and complication rates (15).

The number of resurfacing procedures has significantly reduced according to the UK's National Joint Registry (8% in 2011 to 0.6% in 2017) (16,17) and the AOANJRR (9% in 2005 to 6% in 2008) (9). The sharp reduction in number of resurfacing arthroplasties performed has a resultant detrimental effect on the number of surgeons being trained on the procedure.

A hip resurfacing procedure is typically undertaken by surgeons that have mastered the ability to perform a THA; as it is universally accepted as a more challenging hip arthroplasty procedure given that the bony surface to work with is more limited and preserved femoral neck and head partially obstructs the acetabulum similar to a revision. Thus, additional steps may be necessary to improve visibility that may affect vascularity (e.g., capsular/soft-tissue release) and/or pelvic position (i.e., cup orientation), which are intimately related to the choice of the surgical approach. Thus, surgical approach might be an independent, additional, critical factor when describing and establishing the different learning curves associated with any procedure and in particularly hip resurfacing (18). In this paper we aimed to provide an updated literature review on what the learning curve is in order to perform a surface arthroplasty of the hip. To do so, we aimed to describe (I) the learning curve of a primary hip replacement; (II) the learning curve of hip resurfacing using different end-points (complications, joint survival, component alignment and patient-reported outcome measures); and (III) what the minimum number of cases performed per year should be to maintain competency.

Learning curve of a conventional total hip replacement

A learning curve has been described for both cemented and cementless THA. After comparing the first 90 cases of cemented Charnley THA operated between 1969–1973 with a matched cohort of 90 cases operated between 1984–1989 with the same prosthesis, Salai *et al.* evidenced a marked decrease in duration of operation, blood loss, dislocation rate, deep infection, breakage of trochanteric wires and early loosening (19). Callaghan *et al.* analyzed the results of the first and second series of 50 porous-coated THAs (20). Together with a lower percentage of femoral fractures (4% *vs.* 0%), substantial improvement in achieving femoral canal filling and a more accurate acetabular cup angle were seen in the second 50 cases (20).

In order to maintain a low number of complications over time, the literature suggests that 35 cases per year of primary THAs is the optimal number above which complications significantly reduce (21,22).

However, in addition to the minimum number performed per year for each surgeon, a volume effect of the treating center has been illustrated. In the early 70s, Adams *et al.* introduced the relationship between volume and outcome to the healthcare field (23). After analyzing data on coronary arteriography outcomes from 173 institutions, the authors found significantly lower complication rates in high-volume hospitals (23).

Likewise, it has been shown that surgical volume is undeniably related to short-term morbidity and mortality in primary and revision total joint arthroplasty (24). After analyzing 19,925 primary and 2,536 revision arthroplasties of the hip and knee, Lavernia *et al.* found that surgeons with a low volume of primary cases (<10 cases/year) had a significantly higher mortality rate (24%), higher costs, and increased average length of hospital stay (9.3 days) when compared to medium-volume (between 10 and 100 cases/year and high-volume surgeons (>100 cases/year) (24). Since complications were coded upon the ICD-9 codes (including not only periprosthetic but also urinary tract infections, for instance), their relative impact on outcome were not addressed by the current coding system. In a similar study of approximately 70,000 Medicare patients who underwent THA, those treated at high-volume centers (with >100 surgeries done per year) evidenced a significantly lower risk of death than patients treated at low-volume hospitals (with ≤10/yearly surgeries), showing a mortality rate of 0.7% and 1.3%, respectively (adjusted OR, 0.58; 95% CI, 0.38–0.89) (25). Moreover, when analyzing only cases of primary THA, surgeons performing more than 50 cases/year had a considerably lower risk of dislocation (dislocation rate, 1.5%) than surgeons performing 5 or less yearly (dislocation rate 4.2%) (25). In line with these findings, Hedlundh *et al.* described that the dislocation rate remains relatively constant after undertaking approximately 30 operations (26).

Volume has also been associated with patient-reported functional status and satisfaction. After adjusting for confounders, Katz *et al.* showed that patients who underwent surgery in low-volume centers (<13 procedures per year) had worse functional status at 3 years following primary and revision THA compared to those performed at high-volume centers (>100 cases per year) (27). Also, patients who underwent primary hip replacement in low-volume institutions were more prone to be dissatisfied compared with patients whose surgeries were performed in high-volume hospitals (27).

Learning curve of a hip resurfacing

Complications

Nunley *et al.* evaluated the learning curve of HRA by comparing the number of early complications of the first 650 cases amongst 5 hip surgeons (28). All of the surgeons had prior experience in hip resurfacing surgery, having each done more than 100 Birmingham (Smith & Nephew, Memphis, Tennessee, USA) HRAs. The authors detected 13 major complications (2%) with 7 (1.1%) reoperations; the major complication rate was greater for the surgeons' first 25 cases compared to the second 25 ones (5.6% versus 1.6%, P<0.002) (28). These major complications consisted of 3 femoral neck fractures; 5 dislocations (of which 2 were converted to THA); 3 nerve injuries (of which only one remained unresolved) and 1 acetabular component early loosening revised to a THA (28).

Berend *et al.* reported the outcomes of 73 hip resurfacings (64 patients) performed between 2006 and 2009, which represented 6% of all of the primary hip arthroplasty procedures performed by the two primary surgeons (29). Both surgeons had prior surgeon-to-surgeon visits and cadaveric training; and all procedures were performed via the modified direct lateral, abductor-splitting (anterolateral) approach, using the first Food and Drug Administration (FDA)-approved HRA (30), consisting of a cemented femoral component and a cementless acetabular shell [Birmingham Hip Resurfacing (BHR); Smith and Nephew, Memphis, TN, USA]. The authors stated that only 79% of cases reported good or excellent outcomes, with an overall failure rate of 8% at a mean of 33 months, including 2 deep infections, 2 femoral neck fractures, 1 femoral aseptic loosening and 1 acetabular aseptic loosening (29). Even though the authors made it clear it was the institution's early experience with HRA, there was no comparison in the timeline between the initial cases and the last ones.

In a similar study, Marker *et al.* analyzed the complication rate of 550 prospectively-followed HRAs operated by a single surgeon (31). In order to determine the effect of a learning curve on the operative results, the outcomes were stratified into 11 consecutive cohorts of 50 patients each. The authors detected 14 (2.5%) femoral neck fractures, with the risk being 8 times higher in the first 69 cases, markedly decreasing to 0.4% after this point, implying the existence of a learning curve related to this specific complication (31). Shimmin *et al.* were unable to show that fractures and other intraoperative complications occurred more often at the beginning of the learning curve (32). After analyzing 3,497 BHRs (Smith and Nephew) operated by 89 surgeons via the posterior approach, the authors found only 50 (1.46%) femoral neck fractures at a mean of 15.4 weeks (32). However, after reviewing the first 100 hip resurfacings performed by two experienced surgeons, the same authors reported that there was a learning curve of 50 cases, since the first 50 ones showed significantly more notching of the femoral neck and mal-seating of both the femoral and acetabular components when compared to the second 50 ones (33).

There have been two studies reporting on early data from designer centers. Aulakh *et al.* performed a multi-center analysis of 5,000 HRAs operated by 139 surgeons from 37 different countries, using the BHR (34). Of the 139 surgeons, only 2 had been involved in the design and of the implant. Thus, the series was divided into

2 groups: developer surgeons (n=2,391) and non-developer surgeons (n=2,144, with all surgeons having done at least 40 procedures) (34). There were 50 failures in developer group (97% survival, 13 neck fractures) and 104 (94% survival, 38 neck fractures, P=0.0025) failures in the non-developer group (34). Amstutz *et al.* reported a 94.4% survival at 2- to 6-year follow-up (average, 3.5 years) of the first 400 hips (355 patients) implanted with the Conserve Plus device (Wright Medical, Arlington, Tennessee, USA) (35). Twelve hips (3%) were revised to a conventional THA due to loosening (7 cases), femoral neck fracture (3 cases), recurrent subluxations (1 case), and deep infection (1 case); 75% of their complications occurred in the first 100 HRAs, suggesting that experience plays a major role in decreasing femoral neck fractures and other complications (35).

Data on the learning curve of HRA in Canadian academic centers has also been analyzed (36). The first fifty HRA cases of five high volume arthroplasty surgeons (more than 100 primary THAs yearly) with no prior training on HRA were reviewed. It was found that the overall reoperation rate was low (3.6%), with femoral neck fracture being the most common cause (1.6%) (36).

Component alignment

Witjes *et al.* reported on the first 40 HRAs implanted by a single-surgeon and decided to analyze the radiographic 'learning curve' by comparing postoperative implant positioning to that obtained on preoperative digital templating, measuring 6 established radiographic parameters (femoral offset, body moment arm, abductor moment arm, cup angle, stem-shaft angle and equator angle between cup and femoral component—called cup head angle) in 4 chronological groups of 10 cases each (37). An optimal radiographic result was established only in the last cohort, with the first initial cohorts showing a relatively steep cup position and a stem position in the posterior 1/3 of the neck (37).

In Nunley *et al.*'s study, the capacity to avoid relative femoral component positioning in varus did not improve until reaching 100 cases (31% of varus alignment in the first 100 surgeries versus 14% in the second 50 cases; P<0.004) (28). Regarding acetabular component orientation, specifically inclination, surgeons' first 50 cases showed a trend towards more vertical components (i.e., inclination greater than 45 degrees) when compared their subsequent 50 cases (28).

Conversely, O'Neill *et al.*, after analyzing the first 50 HRA of 5 high-volume Canadian arthroplasty surgeons, found that there was no learning curve in order to obtain an appropriate radiological component alignment, consisting of 140°±5° for stem-shaft angle and an acetabular inclination of between 35° and 45° (36). The authors reported a mean neck-shaft angle of 139° (range, 122°–155°) and an average acetabular abduction angle of 46° (range, 34°–64°), without any differences with cases who suffered a femoral neck fracture (36).

After analyzing 100 cases, Benoit *et al.* specifically focused on the learning curve of HRA through the anterior approach by comparing the first 50 consecutive cases done via this approach (Hueter group) to the 50 last consecutive cases performed through the Ganz approach (Ganz group) (38), which was the standard approach in the early 2000s at the author's institution (39). With no cups surpassing an inclination angle of 55°, 19 cases in the Hueter group were positioned in the range of 45° to 55°, compared to only 8 cases in the Ganz group (P=0.013). These 19 'vertical' shells detected with the anterior approach were almost equally distributed along the timeline (with 10 vertical acetabular components in the first 25 cases and 9 in the second 25 cases; P>0.05). However, no significant differences in intraoperative and postoperative complications were found between both groups (39). Since the primary surgeon of this series already had experience with the anterior approach and hip resurfacing through other approaches, the true learning curve of anterior approach HRA might be under-reported, taking into account that learning curves are partly surgeon-dependent and greatly influenced by preceding surgical and educational experiences (40).

The impact of computer navigation on the accuracy of component orientation in HRA has also been studied. In a randomized controlled trial, Cobb *et al.* analyzed the radiological results of HRA in models with cam-type deformity treated with conventional instruments, imageless navigation, and computed tomography-based navigation (41). Thirty-two students of surgical technology, priorly instructed in HRA, were shown detailed plans of the desired operative outcome, considering that this surgery should be performed within ±10 degrees of the optimal angular orientation and ±6 mm of entry-point translation in 95% of hips (41). The authors concluded that, for novice surgeons, only computed tomography-based navigation was accurate at reproducing hip biomechanics when compared to conventional neck-based instrumentation and imageless navigation (41). Although speculative, this ascertainment may also be true for novice surgeons learning primary THA.

Similarly, Ganapathi *et al.* compared 51 consecutive HRAs performed using image-free computer navigation with 88 consecutive HRAs performed without navigation, finding no differences in the average native femoral neck-shaft angles and the planned stem-shaft angle (42). Surgeries were performed by 2 experiences surgeons who had performed more than 75 HRAs using the conventional technique before the publishing study and therefore it was presumed that they were over the learning curve for conventional HRA (42). However, there were 33 patients (38%) in the non-navigated group with a deviation greater than 5 degrees in contrast to none in the navigated group when comparing the difference between the postoperative stem-shaft angle and the planned stem-shaft angle (42). Considering that the current literature has significant limitations, there is no consistent evidence of the benefits of computer navigation on the learning curve of arthroplasty trainees (43). Furthermore, there is little data on the effect on navigation on cup orientation in HRA, which is arguably the most important aspect of component orientation.

Patient reported outcome measures

Su and Su retrospectively reviewed their first 820 consecutive HRAs performed between the years 2004 and 2009, with a minimum 2-year follow-up (44). Overall, the clinical outcomes significantly improved when comparing preoperative and postoperative values (Average Harris Hip Score improved from 61 to 96.5 postoperatively), reporting only 13 revisions (1.6%): 3 femoral neck fractures, 5 avascular osteonecrosis, 2 acetabular loosenings, and 3 advanced local tissue reactions (44). In this sense, no significant effect of a learning curve was noticed in this study, with a safe application of HRA.

Maintaining competency

The need to perform a minimum number of cases per year to maintain competency in executing a highly specialized procedure has been introduced in other surgical fields but not orthopedics. Using retrospective data from National Registries, it has been highlighted that the minimum number of gastrectomies an upper gastro-intestinal surgeon should perform per year is 8 to 14 (average: 10) (45,46). There is no such guideline in arthroplasty to-date. However, the question of what the optimal number of periprosthetic joint infection (PJI) revision cases a surgeon needs to perform per year in order to improve outcomes was recently addressed in the PJI consensus meeting. Even though evidence is limited, some data suggest that surgeons who more often treat PJI patients will have better results than lower volume arthroplasty surgeons (47); seemingly, the former ones work at institutions performing variable number of PJI revision cases (between 3 to 80 PJI cases) annually (48-50).

The minimum number of cases required for improved outcome in overall revision THA is also unknown. Data from the UK national joint registry showed that 80% of surgeons performing revision knee arthroplasty and 60% of surgeons performing revision THA undertook less than 10 cases per year (51). Additionally, it has been shown that not only volume, but also the degree to which a surgeon specializes in a specific surgery may be equally important in order to reduce postoperative morbidity and mortality (52).

Taking these ambiguous figures into consideration, the last International Consensus Meeting (ICM) on the prevention of total joint arthroplasty infections recommended minimum surgical volume of 25 cases per year for a surgeon to qualify as an expert in PJI (47).

Conclusions

Undoubtedly, there is a learning curve associated with HRA. The findings of this review is in line with the Sixth Advanced Hip Resurfacing Consensus Meeting Statement that it takes at least 50 hip resurfacing procedures to get past the learning curve (61% agreement) and, in order to qualify to start doing this surgery, 75.7% of the surgeons suggested a minimum number of 100 THAs per year (53). Data has shown that this procedure should preferably not be done in hospitals that perform less than 25 HRA cases per year (54), which is similar to what it has been suggested for other highly specialized Adult Reconstructive surgeries. Our review clearly identifies that the learning curve influences complication-rates, radiographic measures and outcome. There is little data on how modern training should take place with the current low number of cases performed annually. It is our opinion that surgeons interested in performing HRA of the hip, should spend at least 6-month training in a high-volume center and make the appropriate arrangements for a 'surgeon-mentor' to be present for the first few cases they perform in an independent setting. We also encourage novice surgeons to perform additional training with virtual and augmented reality since it has proven to improve the accuracy of component orientation (55).

Acknowledgments

Funding: None

Footnote

Provenance and Peer Review: This article was commissioned by the editorial office, *Annals of Joint for* the series "Hip Resurfacing for the Young Arthritic Hip". The article has undergone external peer review.

Conflict of Interest: All authors have completed the ICMJE uniform disclosure form (available at http://dx.doi.org/10.21037/aoj.2019.09.08). The series "Hip Resurfacing for the Young Arthritic Hip" was commissioned by the editorial office without any funding or sponsorship. GG served as the unpaid Guest Editor of the series and serves as an unpaid editorial board member of *Annals of Joint* from May 2019 to Apr 2021. The authors have no other conflicts of interest to declare.

Ethical Statement: The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

References

1. Matharu GS, Pandit HG, Murray DW, et al. The future role of metal-on-metal hip resurfacing. Int Orthop 2015;39:2031-6.
2. Su EP. Design Considerations for the Next Generation Hip Resurfacing Implant: Commentary. HSS J 2017;13:50-3.
3. Amstutz HC, Ball ST, Le Duff MJ, et al. Resurfacing THA for patients younger than 50 year: results of 2- to 9-year followup. Clin Orthop Relat Res 2007;460:159-64.
4. Fisher NE, Killampalli VV, Kundra RK, et al. Sporting and physical activity following hip resurfacing. Int Orthop 2011;35:977-80.
5. Tice A, Kim P, Dinh L, et al. A randomised controlled trial of cemented and cementless femoral components for metal-on-metal hip resurfacing: A bone mineral density study. Bone Joint J 2015;97-B:1608-14.
6. Amstutz HC, Le Duff MJ, Bhaurla SK. Are There Long-term Benefits to Cementing the Metaphyseal Stem in Hip Resurfacing? Clin Orthop Relat Res 2015;473:3197-203.
7. Corten K, MacDonald SJ. Hip resurfacing data from national joint registries: What do they tell us? Clin Orthop Relat Res 2010;468:351-7.
8. Seppänen M, Karvonen M, Virolainen P, et al. Poor 10-year survivorship of hip resurfacing arthroplasty: 5,098 replacements from the Finnish Arthroplasty Register. Acta Orthop 2016;87:554-9.
9. Prosser GH, Yates PJ, Wood DJ, et al. Outcome of primary resurfacing hip replacement: Evaluation of risk factors for early revision: 12,093 replacements from the Australian Joint Registry. Acta Orthop 2010;81:66-71.
10. Cook JA, Ramsay CR, Fayers P. Statistical evaluation of learning curve effects in surgical trials. Clin Trials 2004;1:421-7.
11. Simpson AH, Howie CR, Norrie J. Surgical trial design - learning curve and surgeon volume: Determining whether inferior results are due to the procedure itself, or delivery of the procedure by the surgeon. Bone Joint Res 2017;6:194-5.
12. Davey JP, Santore RF. Complications of periacetabular osteotomy. Clin Orthop Relat Res 1999;(363):33-7.
13. Peters CL, Erickson JA, Hines JL. Early results of the Bernese periacetabular osteotomy: the learning curve at an academic medical center. J Bone Joint Surg Am 2006;88:1920-6.
14. Konan S, Rhee SJ, Haddad FS. Hip arthroscopy: analysis of a single surgeon's learning experience. J Bone Joint Surg Am 2011;93 Suppl 2:52-6.
15. Hoppe DJ, de Sa D, Simunovic N, et al. The Learning Curve for Hip Arthroscopy: A Systematic Review. Arthroscopy 2014;30:389-97.
16. Metcalfe D, Peterson N, Wilkinson JM, et al. Temporal trends and survivorship of total hip arthroplasty in very young patients: A study using the national joint registry data set. Bone Joint J 2018;100-B:1320-9.
17. Young E, Mccormack V, Swanson M. National Joint Registry for England, Wales, Northern Ireland and Isle of Man: 15th Annual Report 2018;1821:218.
18. Amanatullah DF, Cheung Y, Di Cesare PE. Hip

Resurfacing Arthroplasty: A Review of the Evidence for Surgical Technique, Outcome, and Complications. Orthop Clin North Am 2010;41:263-72.
19. Salai M, Mintz Y, Giveon U, et al. The learning curve of total hip arthroplasty. Arch Orthop Trauma Surg 1997;116:420-2.
20. Callaghan JJ, Heekin RD, Savory CG, et al. Evaluation of the learning curve associated with uncemented primary porous-coated anatomic total hip arthroplasty. Clin Orthop Relat Res 1992;(282):132-44.
21. Losina E, Barrett J, Mahomed NN, et al. Early failures of total hip replacement: effect of surgeon volume. Arthritis Rheum 2004;50:1338-43.
22. Ravi B, Jenkinson R, Austin PC, et al. Relation between surgeon volume and risk of complications after total hip arthroplasty: propensity score matched cohort study. BMJ 2014;348:g3284.
23. Adams DF, Fraser DB, Abrams HL. The complications of coronary arteriography. Circulation 1973;48:609-18.
24. Lavernia CJ, Guzman JF. Relationship of surgical volume to short-term mortality, morbidity, and hospital charges in arthroplasty. J Arthroplasty 1995;10:133-40.
25. Katz JN, Losina E, Barrett J, et al. Association between hospital and surgeon procedure volume and outcomes of total hip replacement in the United States medicare population. J Bone Joint Surg Am 2001;83:1622-9.
26. Hedlundh U, Ahnfelt L, Hybbinette CH, et al. Surgical experience related to dislocations after total hip arthroplasty. J Bone Joint Surg Br 1996;78:206-9.
27. Katz JN, Phillips CB, Baron JA, et al. Association of hospital and surgeon volume of total hip replacement with functional status and satisfaction three years following surgery. Arthritis Rheum 2003;48:560-8.
28. Nunley RM, Zhu J, Brooks PJ, et al. The learning curve for adopting hip resurfacing among hip specialists. Clin Orthop Relat Res 2010;468:382-91
29. Berend KR, Lombardi AV, Adams JB, et al. Unsatisfactory surgical learning curve with hip resurfacing. J Bone Joint Surg Am 2011;93:89-92.
30. Della Valle CJ, Nunley RM, Raterman SJ, et al. Initial American Experience with Hip Resurfacing Following FDA Approval. Clin Orthop Relat Res 2009;467:72-8.
31. Marker DR, Seyler TM, Jinnah RH, et al. Femoral Neck Fractures After Metal-on-Metal Total Hip Resurfacing. A Prospective Cohort Study. J Arthroplasty 2007;22:66-71.
32. Shimmin AJ, Back D. Femoral neck fractures following Birmingham hip resurfacing. J Bone Joint Surg Br 2005;87:463-4.
33. Shimmin AJ, Young D, Back DL. The learning curve associated with the hip resurfacing procedure. Orthopaedic Proceedings - International Hip Society (IHS) Closed Meeting, Gothenburg, Sweden, June 2018;87-B:e4.
34. Aulakh TS, Jayasekera N, Singh R, et al. Hip resurfacing arthroplasty: A new method to assess and quantify learning phase. Acta Orthop Belg 2014;80:397-402.
35. Amstutz HC, Beaulé PE, Dorey FJ, et al. Metal-on-Metal Hybrid Surface Arthroplasty: Two to Six-Year Follow-up Study. J Bone Joint Surg Am 2004;86:28-39.
36. O'Neill M, Beaulé PE, Nasser AB, et al. Canadian Academic Experience with Metal-on-Metal Hip Resurfacing. Bull NYU Hosp Jt Dis 2009;67:128-31.
37. Witjes S, Smolders JM, Beaulé PE, et al. Learning from the learning curve in total hip resurfacing: A radiographic analysis. Arch Orthop Trauma Surg 2009;129:1293-9.
38. Ganz R, Gill TJ, Gautier E, et al. Surgical dislocation of the adult hip a technique with full access to the femoral head and acetabulum without the risk of avascular necrosis. J Bone Joint Surg Br 2001;83:1119-24.
39. Benoit B, Gofton W, Beaulé PE. Hueter Anterior Approach for Hip Resurfacing: Assessment of the Learning Curve. Orthop Clin North Am 2009;40:357-63.
40. Valsamis EM, Chouari T, O'Dowd-Booth C, et al. Learning curves in surgery: variables, analysis and applications. Postgrad Med J 2018;94:525-30.
41. Cobb JP, Kannan V, Dandachli W, et al. Learning how to resurface cam-type femoral heads with acceptable accuracy and precision: the role of computed tomography-based navigation. J Bone Joint Surg Am 2008;90 Suppl 3:57-64.
42. Ganapathi M, Vendittoli PA, Lavigne M, et al. Femoral component positioning in hip resurfacing with and without navigation. Clin Orthop Relat Res 2009;467:1341-7.
43. Saithna A, Dekker AP. The influence of computer navigation on trainee learning in hip resurfacing arthroplasty. Comput Aided Surg 2009;14:117-22.
44. Su EP, Su SL. Adoption of Hip Resurfacing Arthroplasty at Hospital for Special Surgery: A Cohort Study. HSS J 2012;8:283-6.
45. Bachmann MO, Alderson D, Edwards D, et al. Cohort study in South and West England of the influence of specialization on the management and outcome of patients with oesophageal and gastric cancers. Br J Surg 2002;89:914-22.
46. Mamidanna R, Ni Z, Anderson O, et al. Surgeon volume and cancer esophagectomy, gastrectomy, and pancreatectomy: A populatio n-based study in England. Ann Surg 2016;263:727-32.

47. Abblitt WP, Ascione T, Bini S, et al. Hip and Knee Section, Outcomes: Proceedings of International Consensus on Orthopedic Infections. J Arthroplasty 2019;34:S487-95.
48. Grammatopoulos G, Kendrick B, McNally M, et al. Outcome Following Debridement, Antibiotics, and Implant Retention in Hip Periprosthetic Joint Infection-An 18-Year Experience. J Arthroplasty 2017;32:2248-55.
49. Berend KR, Lombardi AV, Morris MJ, et al. Two-stage treatment of hip periprosthetic joint infection is associated with a high rate of infection control but high mortality. Clin Orthop Relat Res 2013;471:510-8.
50. Zahar A, Kendoff DO, Klatte TO, et al. Can Good Infection Control Be Obtained in One-stage Exchange of the Infected TKA to a Rotating Hinge Design? 10-year Results. Clin Orthop Relat Res 2016;474:81-7.
51. Getting it right first time. London, England: British Orthopaedic Association; 2014. Available online: https://www.boa.ac.uk/standards-guidance/guidance-documents.html
52. Sahni NR, Dalton M, Cutler DM, et al. Surgeon specialization and operative mortality in United States: retrospective analysis. BMJ 2016;354:i3571.
53. Van Der Straeten C, De Smet KA. Current expert views on metal-on-metal hip resurfacing arthroplasty. Consensus of the 6th advanced hip resurfacing course, Ghent, Belgium, May 2014. HIP Int 2016;26:1-7.
54. Australian National Joint Replacement Registry (AOANJRR) 2018, Annual Report 2018.
55. Liu H, Auvinet E, Giles J, et al. Augmented Reality Based Navigation for Computer Assisted Hip Resurfacing: A Proof of Concept Study. Ann Biomed Eng 2018;46:1595-605.

doi: 10.21037/aoj.2019.09.08
Cite this article as: Slullitel P, Grammatopoulos G, Calistri A, Van Der Straeten C. What is the learning curve associated with a hip resurfacing? Ann Joint 2019;4:42.

