The Learning Curve for the Anterior Approach: Early, Middle, and How It Continues

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Introduction

The field of orthopedic surgery has experienced a rapid increase in innovation in an attempt at improving patient care and outcomes. Innovation has been introduced in terms of technology, surgical techniques, implants, and instrumentation. Although hip replacement has been termed the "operation of the century," this has not quenched the thirst for improvement [1]. Although the anterior approach to total hip arthroplasty is not novel, it has recently gained popularity for its superior early functional outcomes, improved component positioning, and lower dislocations rates [2–5]. Nakata et al. published their results comparing the anterior approach to the posterior approach and showed faster recovery, improved gait mechanics, and component positioning with the anterior approach [5]. Matta et al. followed with their consecutive series of patients using a specialized table and fluoroscopy showing accurate component position and low dislocation rates [4]. These early reports, in addition to the growing research, have fueled the enthusiasm for the anterior approach.

The posterior and lateral approaches have been the most popular approaches to hip arthroplasty in the United States and the more commonly taught in residency programs [6]. The adoption of the anterior approach has increased consistently over the last two decades. Sheth et al. reported a 4% anterior approach prevalence on the Kaiser Permanente data from 2001 through 2011 [7]. Subsequently, Maratt et al. showed a 14% on the Blue Cross Blue Shield data in Michigan in 2012 through 2014 [8]. More recently, a survey of the American Association of Hip and Knee Surgeons showed 56.2% usage among the responders [9]. These studies confirm the increased adoption of the approach in the United States.

The recent adoption of the approach along with the educational gaps at teaching institutions has led surgeons to learn the approach outside their formal surgical training. As with any learning process, the introduction of a new surgical technique or approach comes with a learning curve. The same AAHKS survey showed that fear of the learning curve was the main reason for not adopting the technique in 23.6% of the surgeons [9]. The learning curve presents an ethical dilemma where the surgeon must balance the risk of patients with the need to learn innovation aimed at improving patient care.

Surgical Learning Curve

The surgical learning curve is the association between a surgeon's proficiency in a procedure and the times he/she has performed the proce-

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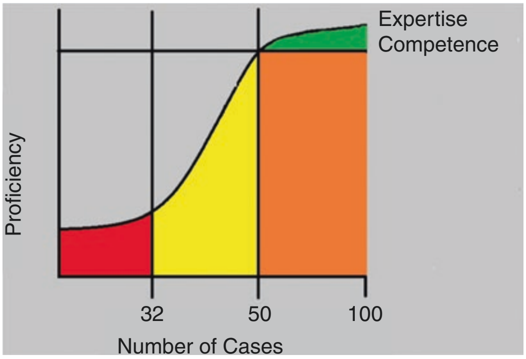

Fig. 5.1 Surgical learning curve example graph. From 0 cases to 32, the area under the curve is the highest risk area for patients and represents the early LC. This flat curve represents a slow gain in proficiency as per case basis and is where initial skills are developed. Bear in mind some skills are already present; that is why the curve inherently starts with some built-in proficiency as a measure of surgeons' training. The steepest part of the curve, between 32 and 50 cases, represents the optimization zone where there is an exponential gain in proficiency per case. There is a rapid progression in the intended measured variables such as blood loss or surgical time. The area under the curve between 50 and 100 cases illustrates the achievement of defined surgical competence and beyond. Once the competence level is achieved, further repetition leads to expertise that is slower to achieve, represented by flattening of the curve

dure. It tries to determine at what point the surgeon has become competent in the procedure. The standard curve has the proficiency outcome on the y axis and the number of cases on the x axis (Fig. 5.1). A steep learning curve has been perceived as negative when its intention is to define the curve by the amount of effort required to overcome it. In fact, a steep learning curve is advantageous since it means that the surgeon reached the proficiency level with a smaller number of cases. As explained in Gofton et al., a steep curve is ideal because only a small number of patients are being exposed to the increased risk of complications that are associated with the early stages of learning (1). The variables used to measure proficiency are numerous and include surgical time, blood loss, complication rate, and patient-reported outcomes. Although incomplete, surgical time has been shown to be an adequate indicator of surgical proficiency within a learning curve [10]. More comprehensive statistics such as a cumulative sum analysis can determine when competency is reached based on specific surgical performances [11]. Inconsistency remains the most effective method of measuring and monitoring an individual surgical learning curve.

The concern of a surgical learning curve was highlighted by the experience of laparoscopic cholecystectomy in which a spike in complications was observed after its early adoption [12]. This experience underlined the importance of proper training and education when implementing a new surgical technique. Other surgical fields such as spine and abdominal robotic surgery have also described this phenomenon. Curiously, 40 cases seem to be a consistent number of procedures required to reach a minimum surgical proficiency in these reports [13].

The literature describing surgical learning curves in the anterior approach is heterogeneous, making interpretation difficult. Study methodology, patient selection, specific technique, implants used, surgeon training, and experience vary significantly. Furthermore, there are single surgeon series, multiple surgeon series, and registry data. Proper interpretation of the data requires understanding of the strengths and weaknesses of each one. Single surgeon series are often the experience of highly skilled surgeons with vast experience and dedicated teams. Furthermore, not infrequently these surgeons are promoting a technique, approach, or implant. These series are often described as "what is accomplishable." Registry data may offer more information that is generalizable to surgeons as long as the data collected is ubiquitous and includes surgical volume and experience so that it can provide comparable benchmarks to individual surgeons.

Let us review the available data looking at various measures of surgical proficiency in the anterior approach to total hip arthroplasty.

Surgical Time

Surgical time is the most common parameter used when reporting learning curves in the literature [14–28]. In general, the surgical time decreases as the number of cases increases along the learning curve, but the number of cases needed to achieve a meaningful reduction varies. Zawadasky et al. reported an initial surgical time of 102.7 min that dropped to 82.4 min after 50 cases [14]. Similar time improvement was reported by Kong et al., where the initial 50 cases took 113.4 min and then dropped to 86.6 min [11]. Masonis and Van den Eeden et al. found that 100 cases were required prior to observing a significant drop in the surgical time [22, 23]. In general, using surgical time as the proxy for surgical proficiency in the anterior approach has shown a wide range of required cases from 20 to 100 [14–24, 26]. Some series have failed to demonstrate decreased surgical time, with a number of cases hinting at the inability to overcome the learning curve with the cases reported. Melman et al. and Woolson et al. reported no significant improvement in time throughout their series [29, 30]. However, when isolating studies that demonstrate robust training prior to the start of the learning curve, we can observe either no significant difference compared to the prior approach or a lower number of cases (32–50 cases) needed to overcome the learning curve in relation to surgical time [17, 21, 25]. Table 5.1 summarizes studies that have used surgical time for measurement of surgical proficiency in the anterior approach.

Table 5.1 Procedure time and number of cases needed to reach steady state

Study	LC surgical time (Min.)	Surgical time past LC (Min.)	No. of cases to reach steady state
Pogliacomi	111	85	30
Berend	99	69	37
Goytia	124	98.1	40
Spaans	84	77	46
Alexandrov	229.5	139	43
Zawadsky	102.7	82.4	50
Kong	113.44	86.66	50
Stone	108.98	88.98	50
Pirrucio	60.45	47.45	100
Masonis	132.8	109.9	100
Van Den Eeden	115	70	100

LC, learning curve

Blood Loss

Various studies have used blood loss as a measurement of surgical proficiency in the learning curve [14–28]. Some studies report it as a per case improvement in surgical blood loss, while others compare the blood loss to their previous approach. In this way, we can evaluate improvement in blood loss either as an absolute decrease or relative to the expected blood loss a particular surgeon has on his traditional approach. Goytia et al. divided his 81-case series into three groups (two groups of 20 and one 21) and showed a decrease in blood loss from 596 ml to 347 ml after the second group [18]. Similarly, but with a smaller number of cases, Alexandrov et al. reported a mean blood loss of 2180 ml (range 600–2600 ml) in the initial 10 cases that decreased to 500 ml (range 250–900 ml) in the following 10 cases [19]. Seng et al. showed an increased blood loss and transfusion requirements in the learning curve of the anterior approach in the initial 37 cases or 6 months since the start of the curve [17]. Other studies have shown a similar trend in blood loss decreasing with progression through the learning curve [17–19, 23]. On the contrary, other authors failed to show an improvement in their blood loss throughout the adoption of the anterior approach. Melman et al. did not find a decrease in blood loss after 120 cases, neither did Spaans et al. after 46 cases [25, 29]. Not surprisingly, studies describing meticulous training prior to the learning showed comparable blood loss to the previous approach even in the learning curve [21, 31]. Other studies have not been consistent in their findings [15, 21, 29].

Complications

The complication rate has also been used as a proxy of surgical proficiency. Reported overall complication rates in the early experience vary from 2% to 44% [11, 32]. Melman et al. reported no change in time or blood loss in their learning curve series but did report a decrease in complications from 11.5% to 2% after the initial 120 cases [29]. Van den Eeden et al. reported 12%

complication rate for the first 100 cases of DA and then 6% for the second 100 cases [23]. Kong et al. reported a 44% complication rate in the initial 50 cases that dropped to 16% in the second 50. Their data was analyzed using CUSUM analysis showing a steady state in complication rate as well as in surgical time after 85 cases [11]. Their study discusses the inconsistency in complication reporting. Their study is more liberal in the definition of complications, and when using the criteria used by Woolson et al. for complications, their overall complication rate was only 6% [30]. Similarly, Seng et al. report an overall complication rate of 5.4%, but only 2.2% clinically relevant complications [17]. The reader is cautioned when interpreting the results of these studies as the inclusion of clinically insignificant complications such as transient lateral thigh numbness, mild heterotopic ossification, or greater trochanteric small avulsion fractures overestimates the true complication rate. Nevertheless, the literature is consistent, demonstrating a higher complication rate in the early learning curve. Table 5.2 summarizes some of these articles reporting on complication rates in the learning curve of the anterior approach.

The majority of intraoperative complications in the anterior hip approach involved proximal femur fractures. Alexandrov et al. reported a 30% complication rate, and more than half were femur fractures [19]. As stated by Horne et al., proximal femur fracture rates using the direct anterior approach are inversely related to experience, and potentially 200 cases are required to decrease the fracture rate [33]. This has been proven in multiple case series like in Yi et al. where they had 8.2% of intraoperative femur fractures that occurred in the first 32 cases and none during the last 29 cases [28]. Masonis et al. reported that femur fractures occurred in the initial 62 cases [22]. Jewett et al. reported that 12/16 proximal femur fractures occurred in the first 200 cases [34]. Others reported a high proximal femur fracture rate that continued throughout their series [25, 30]. In general, there appears to be lessening of the femoral complications with increased experience after 20 to 200 cases [11, 17, 20, 22–24, 25–37, 29–35, 33, 36]. Again, isolating a series of experienced surgeons with healthy volume and rigorous training demonstrates either no increase in early complications or a reduced number of cases to achieve a steady state between 32 and 100 cases [17, 21, 22, 28, 35].

Table 5.2 Complications rates and number of cases needed to reach steady state

Study	LC complication rate	Steady-state complication rate	No. of cases to reach steady state
Muller	10%	2%	20
D'Arrigo	13.30%	6.70%	20
Yi	31.25%	0	32
Alexandrov	40%	30%	43
Kong	44%	16%	50
Van Den Eeden	12%	6%	100
Rathod	6.25%	1.40%	100
Hartford	5%	2%	100
Melman	11.50%	2%	120
Jewett	10%	0.83%	200

LC, learning curve

Revision Rates

The revision rate has also been used as a proxy for the learning curve. Both single surgeon series and registry data provide good insight. De Steiger et al. reported data from the Australian Orthopaedic Association National Joint Replacement Registry. They used a specific implant combination to identify patients undergoing the anterior approach. The cumulative percent revision at 4 years was 6% for surgeons with less than 15 cases and 2% for those with greater than 100 cases. They estimated that at least 50 cases were required in order to achieve the same risk of revision as of those with at least 100 cases [32]. Interestingly, the implant combination analyzed was flagged as a revision outlier in the first 2 years in the registry, most likely due to an anterior approach learning curve. Single surgeon series also corroborates these findings. Müller et al. reported a 5-year survivorship of 78.9% in their initial 20 cases compared to 96.8% for subsequent cases [36]. Hartford et al., with a clinical series of 500 cases, had a mean revision rate of 1.6%. He demonstrated a significant decrease in revision rate from the first 100 cases group to the last 100 cases group from 2% revision risk to 1%. The majority of revisions were due to proximal femoral fractures, 55.5% [37].

Component Positioning Accuracy

Another metric used to describe the learning curve for the anterior approach is the accuracy of component positioning, especially the acetabular component. Hamilton et al. and Rathod et al. demonstrated improved acetabular component positioning with less variance than their previous approach even in the learning curve with greater than 90% mean cup positioning within the safe zone [24, 2]. De Geest et al. and Van den Eeden et al. reported that the majority of their cup outliers occurred within the first 100 cases although their overall accuracy even in the learning curve was above 85% [23, 38]. These studies have shown an initial tendency of increased cup inclination and anteversion during the early experience. Yausa et al. showed a 5.9° increase in anteversion and 2.8° abduction when changing from posterior to anterior approach [35]. These series demonstrate that fluoroscopy helps both with accuracy and consistency in component positioning compared to other approaches even within an early learning curve.

Similarly, restoration of leg length and avoidance of over lengthening have been evaluated. The evaluation of leg length in a specialized table with reliance on fluoroscopic techniques could be more challenging in the early adoption. The utilization of the inferior ischial line has been shown to be inconsistent and affected by distortion and parallax [39]. Measuring leg length on a standard table with contralateral comparison may be less challenging in the early adoption. Van den Eeden reported greater than 1 cm leg length discrepancy in 13% of his initial 100 cases [23]. Hartford reported 7% perceived leg length discrepancy in the initial 100 cases followed by 2% [37]. The use of fluoroscopy appears to mitigate this issue even in the learning curve. Masonis et al. reported 3.5 mm LLD in the initial 100 cases and 1.1 mm after 200 cases [22]. Kong et al. reported greater than 94% within 10 mm with improvement over time, and Goytia et al. reported 87% within 5 mm of the contralateral side even in the learning curve [11, 18]. Newer technologies like standard computer navigation, fluoroscopic navigation, and robotics may improve in our ability to hit our targets.

We can appreciate the influence of fluoroscopy improving the restoration of leg length and reducing cup position outliers. However, proper interpretation of fluoroscopy is required and may present a learning curve of its own. Masonis et al. reported a 32.1 s mean of fluoroscopy time for the initial 100 cases, and then it decreased to a mean of 14.5 s for cases 101–300 [22]. Slotkin et al. evaluated cup positioning for 780 consecutive hips performed by two fellowship-trained surgeons including their learning curve. Primary endpoint was the number of cups that were within the targeted “safe zone” defined by Lewinnek et al. for anteversion and cup inclination [40]. The authors demonstrated high accuracy with a low variance that continued to improve throughout the first 3 years and peaked at 97.4% in the last year [3]. The reader must recognize the challenges of proper imaging interpretation due to the dynamic nature of the pelvic position that affects the appreciated cup anteversion and inclination angles. The authors recommend consistency in the intended pelvic position used to target cup positioning [3, 41–43].

Lessons Learned

Despite the heterogeneity of the literature, consistent findings and learning points can be identified. The literature has been consistent in the fact that early intraoperative complications occur on the femoral side [22, 25, 34, 30]. Intraoperative complications include femoral perforations, calcar fractures, and greater trochanter fractures. Patient-related factors such as bone quality (DORR C), diagnosis (hip dysplasia), gender (female), and BMI contribute to these complications. These findings suggest that the most challenging aspect of learning the anterior approach is adequate femoral exposure. Small incisions, inadequate releases, and compromised femoral exposure can all be contributing factors to these findings. Matta et al. describe their technique that dislocates the hip first, followed by reduction and femoral neck cut. This maneuver is intended at enhancing femoral exposure by traumatically releasing structures that help femoral exposure like the pubofemoral ligament, which is typically under released [4]. After the initial learning curve, the rate of intraoperative femoral fractures appears to be comparable to other approaches [22]. Technical keys for effective releases and femoral exposure should be prioritized in the training of surgeons adopting the anterior approach. Figure 5.2 illustrates the contrast between poor and adequate femoral exposure that would allow for safe and reproducible femoral stem preparation.

Increased blood loss and transfusion requirements can be anticipated in the learning curve as highlighted in the review of the literature [17]. The authors believe that this is a result of the immature understanding of the vascular anatomy through the anterior approach and increased length of surgery. Once the surgeon becomes proficient, blood loss can be equivalent or less than other approaches [17]. Nevertheless, adequate preoperative planning for the learning curve can help mitigate this issue in the beginning. Technology such as bipolar sealers and cell saver should be considered as options along with standard preoperative anemia optimization. The utilization of perioperative tranexamic acid for operative hemostasis, aspirin for VTE prophylaxis, and modification of transfusion thresholds has led to a significant reduction in transfusions across joint arthroplasty including anterior approach THA and should help ease this problem [44, 45].

Patient selection has been shown to influence success in the learning curve. Body habitus as well as radiographic signs can help identify the level of difficulty. Careful evaluation of these features can anticipate the difficulty of femoral exposure that is a critical component in the learning curve. Patients with short varus femoral necks as well as protrusion are more difficult since the periarticular structures such as the capsule and short external rotators are contracted and require more releases to mobilize the femur laterally (Fig. 5.3). A large tensor muscle can also make femoral exposure challenging. On the contrary, long valgus femoral necks with narrow pelvis provide easy mobilization and uninterrupted access to the femur with fewer releases. Typically, females tend to be more lax and easier in the learning curve.

Other factors such as BMI and bone type can influence the difficulty of the learning curve. Lower BMI has been associated with less surgical difficulty and improved component positioning [46]. Bone quality and bone type are also

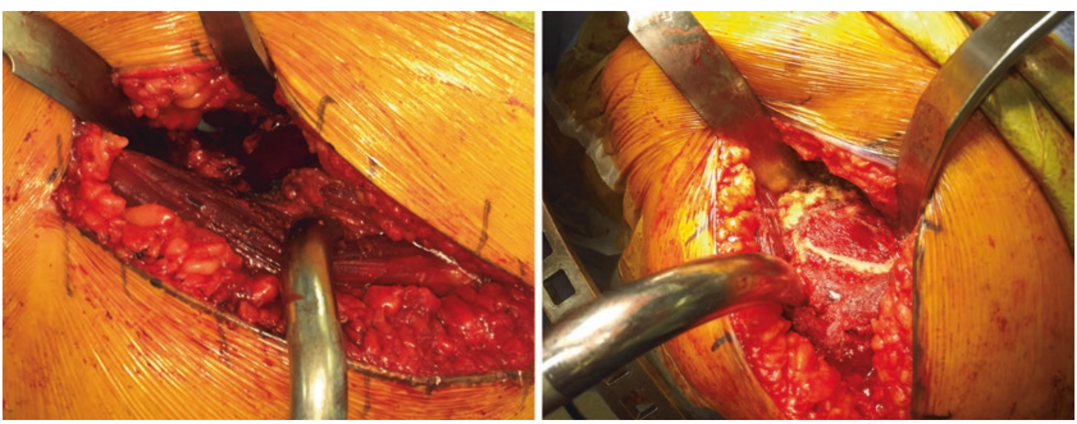

Fig. 5.2 Intraoperative photograph illustrating poor femur exposure (left) compared to generous femoral exposure with easy access to intramedullary canal

important. DORR type B bone provides the ideal balance of bone quality and morphology to prevent femoral complications [18, 27]. Osteoporosis leads to an increased risk of fractures in any approach and should be avoided during the learning curve. DORR type C bone presents challenges not only during bone preparation but also in the process of retractor placement and retraction. Cementation of the femoral stem could be more appropriate in these cases. DORR A with its metaphyseal/diaphyseal mismatch presents unique challenges. This type of bone may dictate the type of stems used including straight stems that require reaming and broaching. This would require more generous femoral exposure to enable safe femoral preparation that can be more challenging in the early learning process [15, 29]. Figure 5.4 shows the three types of bone as described by DORR et al. [27].

Fig. 5.3 Showing pelvis AP x-ray with right hip protrusio, which makes femoral exposure difficult due to capsule and short external muscle contractures

Although few studies have evaluated the benefits of the anterior approach for arthroplasty treatment of femoral neck fractures, none have analyzed its effect on the learning curve [47]. The

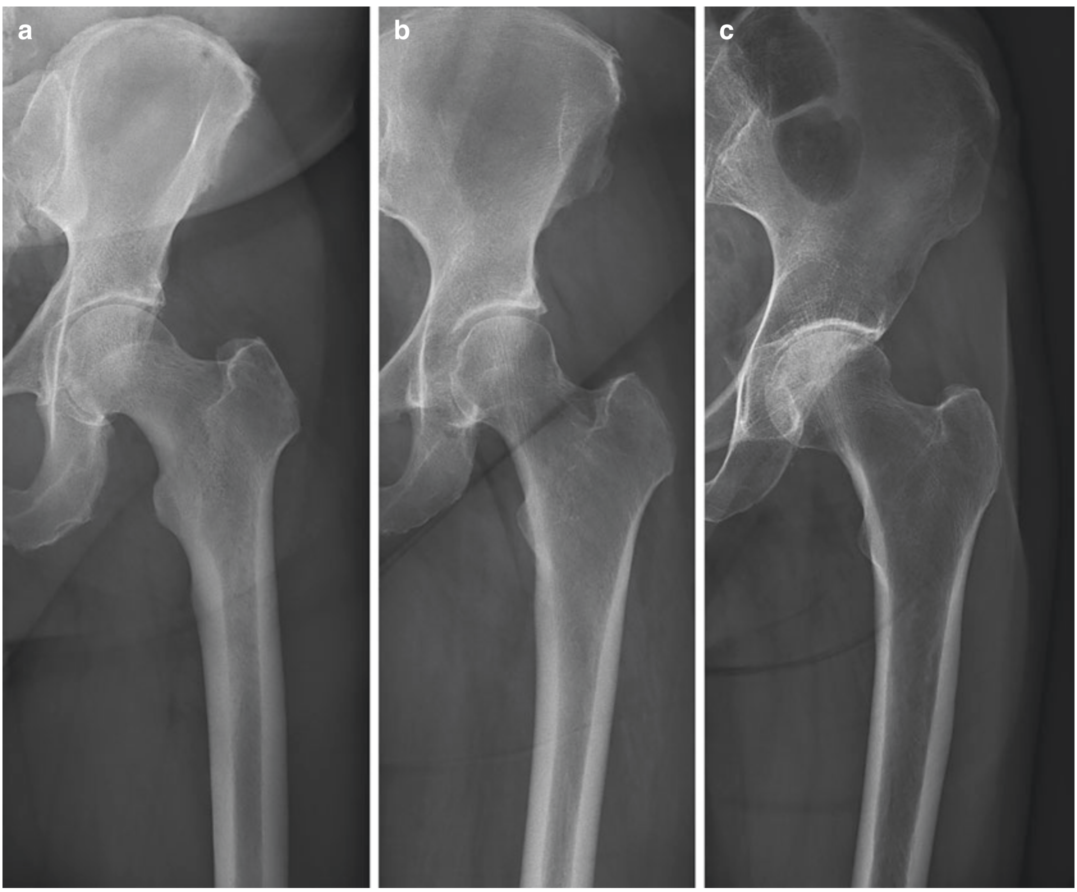

Fig. 5.4 Proximal femur morphology DORR type A, B, and C

authors caution against selecting femoral neck fractures in the learning curve as these patients have demonstrated compromised bone quality and are at high risk of fracture. Clear understanding of generous releases that facilitate femoral exposure is required to avoid femoral complications. Furthermore, the use of the anterior approach for hemiarthroplasty presents unique challenges. Hip reduction with large femoral heads used in hemiarthroplasties can be difficult as the rectus femoris muscle and/or capsule may hinder the ease of the maneuver. Forceful attempts at reduction may lead to femoral fractures. Techniques to mitigate these issues include aggressive femoral releases, anterior capsulectomy, and release of the indirect head of the rectus femoris. Figure 5.5 shows the anatomical location of the indirect head of the rectus femoris; generous release can improve visualization and ease of large head reductions.

There are inherent complications to the anterior approach, which both surgeons and patients need to be aware of. Lateral femoral cutaneous nerve neuropraxia has been commonly reported in the learning curve of the anterior approach [18]. The anatomical location of the LFCN makes it vulnerable to injury as it exits the pelvic region and typically runs over the sartorius muscle. Medialization of the incision or vigorous subcutaneous dissection can place the nerve at risk. Furthermore, the anatomical location of the nerve

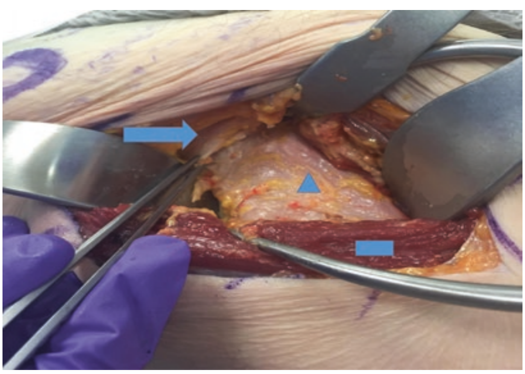

Fig. 5.5 Anterior hip exposure illustrating the hip capsule demarked by a triangle, tensor fasciae latae identified with a rectangle, and indirect head of rectus femoris identified with an arrow

and the pattern of ramification are variable, making it difficult to avoid consistently [48, 47]. Although true injury to the LFCN with meralgia paresthetica is low, mild peri incisional or lateral thigh numbness is not uncommon and typically resolves over time [18, 48]. Patients should be counseled regarding this possibility of LFCN injury that has been reported with a wide range of incidence from 0.1% to 81% in different clinical case series, but as reported by Goytia et al., the majority of cases resolved in their series where 10 of 12 cases resolved completely [18, 48]. Hartford et al., on their clinical series of 500 cases, reported an overall LFCN deficit of 5.4%, but interestingly the incidence was higher for the first 100 cases with a 7% incidence compared to 2% for the last 100 cases of the clinical series [37].

Component positioning is important for the stability and durability of a total hip arthroplasty. Although the anterior approach provides adequate acetabular visualization, there is a tendency of placing cups with high inclination and anteversion angles in the learning curve [23, 24]. The use of intraoperative fluoroscopy helps mitigate component malalignment. In fact, the use of fluoroscopy, even in the learning curve, has shown improved component positioning when compared to other exposures [2]. Proper fluoroscopy interpretation may pose an additional learning curve and should be part of a robust training process [3].

Surgical volume and experience influence the learning curve process as expected. Series from high volume, highly skilled surgeons provide insight of what is accomplishable in the adoption of the anterior approach with a steep learning curve and low complications [21]. In contrast, series from low-volume surgeons show a more challenging route [30]. Registry data is more generalizable and does show a higher early revision rate with lower volume and less experienced surgeons [32]. It is important for surgeons embarking in a surgical learning curve to anticipate the challenges experienced by comparable peers.

A common mistake when adopting the anterior approach is to change more than just the approach to total hip arthroplasty. The anterior approach enthusiasm led to the development of specialized tables, instrumentation, implants, and technology in order to facilitate the procedure. Unfortunately, adoption of other variables may have a learning curve of its own. Broach handle designs highlight this concept. Traditionally, surgeons have been accustomed to using straight broach handles that provide a direct force vector with minimal force dissipation. Offset handles have been designed in order to facilitate femoral preparation with limited exposure through an anterior approach (Fig. 5.6). Single and double offset handles have been popularized [16]. Vertical force transmission decreases as broach handle offset increases, and in double offset handles, there is a 20–60% deflection of the vertical load into the horizontal plane, thus increasing proximal femur stress; even more, if the impaction is inefficient, it can increase up to an 86.9% of deflection [16]. This force transmission can lead to inconsistent femoral bone envelope preparation, potentially resulting in fractures or femoral stem under-sizing, subsidence, and mechanical failures. Fleischman et al. reported a higher incidence of femoral-sided mechanical failures in the anterior approach compared to the posterior or anterolateral approach [42]. Experience with these handles is recommended prior to implementation into a new approach in order to avoid inconsistent femur broaching and compromising the bone envelope. In a similar way, implants and technology such as fluoroscopy may pose an additional learning curve that can lessen with judicious incorporation.

Useful training is paramount when adopting the anterior approach. Proper training may include didactic sessions, cadaveric courses, live surgical demonstrations, and expert surgeon visitations. The industry has taken a leading role in training surgeons and providing valuable cadaveric courses and surgeon visitation opportunities. The effectiveness of limited educational experiences prior to adoption of the anterior approach has shown poor success [30]. However, constant engagement with the educational experience that continues after the commencement of the learning curve is advantageous [21]. The most successful reports describe multiple cadaver sessions, surgeon visitation, and video evaluations prior to starting the learning curve, followed by further cadaver training and surgeon visitations after multiple cases have been performed. The recognition of surgical proficiency gaps and the ability to change behavior accordingly are only possible through repetition and exposure to training opportunities that alert the learner to those gaps. In this manner, the initial part of the curve can be steepened by making the learner aware of the surgical deficiencies in the anterior approach that will effect change and progression through the curve. The senior author did not learn

Fig. 5.6 Double offset handles are identified with black arrows. The other two handles are single offset handles

the anterior approach in residency or fellowship. However, he attended multiple cadaver courses, one-on-one cadaver sessions, and expert surgeon visitation prior to starting the anterior approach. The initial 20 cases were done with a peer who was also learning the anterior approach. Further courses and cadaver sessions were attended to work on the gaps and technical challenges identified in the early learning curve. We continue our learning process and challenge ourselves with increased complexity and revision surgery through the anterior approach.

It is our expectation that the anterior approach will continue to grow and infiltrate teaching institutions. Formal training can identify necessary milestones for successful surgical proficiency. This will provide much-needed structured training in the approach to residents and fellows and minimize their learning curve once removed from their training programs. Furthermore, exciting technology such as virtual reality may play a larger role in the future for surgical training. Lastly, the American Joint Replacement Registry will report broad information about the anterior approach, implants utilized, and their survivorships providing useful information to surgeons.

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